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IMPROVING PLANTING STOCK QUALITY—THE HUMBOLDT EXPERIENCE

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State of the Science



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Abstract: A seedling testing program was developed to improve the survival and growth potential of planting stock produced in the USDA Forest Service Humboldt Nursery, situated on the Pacific Coast in northern California. Coastal and inland seed sources of Douglas-fir and eight other conifers in the Pacific Slope forests of western Oregon and northern California were assessed in both nursery and field studies. Seedling top and root growth capacities were evaluated just after lifting and after cold storage, and stored seedlings were tested for survival and growth on cleared planting sites in the seed zones of origin. Safe lifting and cold storage schedules were defined, and seedling cultural regimes were formulated to produce successful 1-0, 1-1, and 2-0 stock types. Testing demonstrated the critical elements of reforestation and proved that rapid establishment is attainable on diverse sites. Accomplishments of the Humboldt program recommend similar programs for other forest nurseries and their service regions.

Retrieval terms: artificial regeneration, nursery management, plantation establishment, reforestation, seedling culture, seedling root growth capacity, seedling survival; *Abies concolor*, *A. grandis*, *A. magnifica* var. *shastensis*, *A. procera*, *Libocedrus decurrens*, *Picea sitchensis*, *Pseudotsuga menziesii* var. *menziesii*, *Thuja plicata*, *Tsuga heterophylla*

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Cover: Shown in Humboldt Nursery are (top pair) 2-0 and 1-1 Douglas-fir, (middle pair) 2-0 western hemlock and western redcedar, (bottom pair) 2-0 Sitka spruce, and 1-0 red alder and Jeffrey pine.

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*Douglas-fir of 70-inch dbh on Fox
Ridge, Gasquet Ranger District, Six
Rivers National Forest*

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Douglas-fir timberlands, Gasquet Ranger District: View of Fox Ridge from Muzzleloader Ridge, and below, view of recently logged Gordon Creek unit 2/4 from Jones Ridge unit 2, planted 18 years earlier



REFORESTATION AND THE NURSERY

Planting stock of high survival and growth potential is of paramount importance for reforestation on the Pacific Slope. In the Mediterranean ecosystems of California and western Oregon, planted seedlings must extend new roots rapidly to survive summer drought the first year and outgrow tough competitors in subsequent years. Managers of these major timberlands are dependent, to different degrees, on large-scale plantings to regenerate harvested stands and renew those destroyed by wildfire. In California alone, the Forest Service, U.S. Department of Agriculture, plants 30,000 acres (12,150 ha) annually and may plant 50,000 acres (20,240 ha). The scope and diversity of planting programs required for prompt reforestation place a manifold burden on the larger forest tree nurseries. Whether in very large or small quantities, planting stock of high survival and growth potential is needed for up to 20 different conifers, and for very long terms.

Any nursery that would efficiently produce high-quality planting stock must have effective and reliable seedling cultural regimes and safe lifting and cold storage schedules. When planting needs were few and nurseries were small, cultural regimes and lifting and cold storage schedules were developed empirically. To carry today's manifold burden, each nursery must develop an understanding of how its soil, climate, seed sources, cultural regimes, and lifting schedules affect field survival and growth. Each nursery has a unique combination of soil, climate, and seed sources, and the best regimes and schedules in one nursery will not prove optimum in others, if they work at all.

The Forest Service's Humboldt Nursery is a key supplier of bareroot planting stock for Federal timberlands in northern California and western Oregon. Situated at low elevation on the Pacific Coast in northernmost California, Humboldt has grown seedlings for planting programs on ten National Forests and four Districts of the Bureau of Land Management, U.S. Department of Interior, for 30 years. Yet until recently, optimum seedling cultural regimes and safe lifting and cold storage schedules for this nursery had not been defined. To learn what they are, determine how and why they work, and share findings with clientele, the Pacific Southwest Region, Forest and Range Experiment Station, and Humboldt Nursery in 1975 started a seedling testing program.

From the outset, planting stock quality was assessed by greenhouse tests of seedling top and root growth capacity and by field tests of survival and growth in tree seed zones of origin. These tests of growth capacity and field performance proved to be sure ways to assess and improve stock quality. Safe lifting and cold storage schedules were determined for seed sources typical of the regions served, and biologically sound cultural regimes were developed. The overall payoff was an integrated, proven system for producing 1-0, 2-0, and 1-1 Douglas-fir and 2-0 Shasta red fir, white fir, noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar stock of high survival and growth potentials.

This report compiles the results of 14 years of seedling testing and describes the management guides derived for Humboldt Nursery. Eleven program accomplishments, including lifting and cold storage schedules and seedling cultural regimes, are fully documented. Findings have already been assimilated by Humboldt and are extensively applied by nursery clientele on the Pacific Slope. Singly or together, the demonstrated payoffs advocate similar testing programs for other forest tree nurseries, and may guide anyone who researches, produces, or plants bareroot seedlings.

THE REFORESTATION PROCESS

Reforestation is a primary responsibility of forest stewardship. The task is complex, has high visibility both economically and esthetically, and exerts intense pressure on forest land managers. In Pacific Slope forests and other coniferous forests of western North America, reliance on natural regeneration to restock timberlands promptly after harvest or wildfire almost never accomplishes management objectives. To meet obligations of harvest and forest renewal quickly, consistently, and over large areas, new stands must be regenerated artificially.

To protect watersheds and sustain timber yields, the Forest Service and Bureau of Land Management normally plan to regenerate stands within 3 to 5 years of logging. Given western forest environments, this objective demands efficient reforestation systems and logically leads to planting on a large scale. Successful establishment of new stands starts with

seeds collected from or local to the harvest stands, requires that genetically adapted seedlings be properly planted on prepared sites, and depends on timely protection against competing plants and hungry mammals. Silvicultural systems and artificial regeneration guides have been developed for the widespread and commercially important western conifers, and are available (Burns 1983, Cleary and others 1978, Duryea and Landis 1984, Schubert and Adams 1971, Schopmeyer 1974, Tappeiner and others 1986).

Most of the Pacific Slope conifers harvested for timber are regenerated by planting bareroot seedlings. Of the 30 or more species grown in forest tree nurseries, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) is the most extensively planted. A highly valued tree, it thrives in diverse soils and climates in coastal and inland regions, and abounds in most of the major forest cover types of western British Columbia, Washington, Oregon, and northern California (Barbour and Major 1977, Eyre 1980, Fowells 1965, Franklin and Dyrness 1973, Griffin and Critchfield 1976).

Whatever species is planted, however, a well-planned and coordinated effort is essential to establish plantations quickly and consistently. The Federal programs for reforestation of Pacific Slope conifers use a wide variety of planting stock types to fit a wide range of site conditions. This stock is supplied primarily by a small number of large, well-equipped forest tree nurseries operated by the Forest Service. To the extent possible, the seedlings are raised from seeds collected in 20 or more stands situated in the same tree seed zone as the sites to be regenerated (Buck and others 1970, Kitzmiller 1976, USDA Forest Service 1969, 1973).

Spring planting programs on the Pacific Slope always confront the same difficult problems, whether the planting units were cleared by regeneration harvests or created by wildfire. In coastal and inland regions of western Oregon and northern California, summers are hot and dry, and soil water depletion normally curtails the growing season. To survive on the planting site, newly planted seedlings must be able to extend new roots in moist soil (Stone and Jenkinson 1970, 1971; Stone and others 1962, Stone and Schubert 1959a, 1959b). If the site is to be captured and a new stand established, the surviving seedlings must grow fast enough to overtop and suppress the resurgent competing vegetation. Sixty years of regeneration efforts have repeatedly demonstrated that high survival and rapid growth critically depend on effective site preparation, robust planting stock of local seed sources, proper planting times and methods, and timely seedling protection. In brief,

- Site preparation must clear plantable areas of logging slash or other woody debris, expose enough mineral soil for tree planters to find acceptably deep planting spots, and eradicate competing vegetation to conserve water for the growth and survival of planted seedlings. Effective preparation requires appropriate mechanical or chemical treatments, controlled burning, or combinations of these methods, depending on planting site environment and competing plant species (Stewart 1978).
- Planting stock must be genetically adapted to the site climate and growing season. For spring planting, dormant seedlings must be lifted without damage from the nursery beds, graded for size and top-root balance, root-pruned, and stored in polyethylene-lined bags at 0–1 ° C (32–34° F) until the planting sites open. At planting time, seedling roots must be suspended and sealed in moist mineral soil that is warm enough to permit immediate water uptake, and that will soon warm enough to start new root elongation (Jenkinson 1980). Elongating roots must reach enough soil water for the seedlings to expand shoots, form buds, survive summer drought, support photosynthesis, assimilate stored reserves, secure cold hardiness, and resist winter desiccation.
- Seedling protection is often needed the first 2 years to insure high survival and promote rapid growth on the planting site. Threatened plantations should be quickly cleared of invasive vegetation such as grasses, forbs, weeds, shrubs, or brush, and immediately protected against hungry mammals such as deer, elk, mountain beaver, gophers, rabbits, hares, and domestic livestock.

Paying diligent attention to these three critical elements practically assures successful plantation establishment in 2 to 3 years (Jenkinson 1980, 1984). Inattention to any one element risks or promotes partial or complete plantation failure. Most failures waste up to 5 years, even when immediate mortality has obviously precluded success. When seeds of the proper sources are available, the time needed to produce the replacement stock and again prepare the sites and plant should not exceed 3 years. The worst failures waste site resources for three or more decades. Sooner or later, maladapted trees show overwinter mortality, freeze damage, snow breakage, chronic slow growth, or worst of all, midrotation collapse (Campbell 1975, Conkle 1973, Silen 1978).

NURSERY PRACTICE AND STOCK QUALITY

Planting stock quality should never be in doubt. **The nursery mission is to produce—efficiently, in the amounts ordered, and on time—seedlings that can survive and grow in the field.** Nurseries are judged by successful plantation establishment, and establishment has ranged from spectacular in some years to outright failure in others. High survival and rapid growth are normally achieved when seedling growth and conditioning requirements are met in the nursery and site preparation, seedling planting, and protection are faultless in the field.

Seedling cultural regimes and lifting schedules for cold storage fix the growth capacity and survival potentials of planting stock. Net seedling response to the growing season, cultural regime, autumn-winter weather up to lifting time, and storage period markedly affects seedling dormancy, frost hardiness, drought resistance, and top and root growth capacity at planting time. Planting date fixes the immediate site climate, soil temperature, and moisture regimes, all of which affect the expression of growth capacity.

Optimum cultural regimes and safe lifting times depend on the nursery soil, climate, and seed sources sown. Consequently, each nursery, if it is to produce high-quality planting stock efficiently and consistently, needs to evaluate its cultural regimes and lifting schedules and determine what works best. Nursery culture time lines annually begin with soil preparation and seedbed formation, extend through the sowing, growing, and lifting seasons to soil erosion control, and challenge management planning. Management tools should include a system for monitoring seedling top and root growth in the beds, an integrated and flexible time line for scheduling the treatments used, and a seedling testing program.

A testing program is essential to assess the key effects of seed source, nursery climate, cultural practice, lifting date, and cold storage on planting stock quality. The biological knowledge gained enables informed and confident decisions on seedling cultural regimes and lifting schedules. In the long term, periodic assessments of seedling quality permit the nursery to improve practices, strengthen its technology, and keep abreast of continually rising standards.

Cultural regimes and lifting schedules should be assessed using a broad selection of seed sources, and preferably ones that are ordered often and in large quantity. Tests of seedling top and root growth capacity (TGC, RGC; Stone and Jenkinson 1970,

1971) and field survival and growth measure the net effects of nursery practice, and are the best means to assess and improve planting stock quality. Seedlings that are lifted and stored at the right time have high TGC and RGC at spring planting times, and should display high survival and rapid growth when planted on cleared sites in the seed zones of origin. Field performance tests provide the definitive criteria for judging cultural regimes and lifting schedules, and careful planting and timely protection guarantee the best test results in the least time.

SEEDLING TESTING AT HUMBOLDT NURSERY

The chance to develop and prove the worth of a comprehensive seedling testing program arose from clientele concerns about the survival potential of Humboldt Nursery's planting stock, and from Forest Service concerns about projected future needs for expanding seedling production. One of two major Forest Service nurseries in California, Humboldt is situated on the Pacific Coast north of McKinleyville, at latitude 41° N and 1 mile (1.6 km) northeast of Eureka-Arcata Airport (*figs. 1, 2*). Humboldt Nursery harvested its first crop of 2-0 Douglas-fir in 1964 (see Appendix A, Humboldt Origins). By 1975, many of Humboldt's clients had become openly skeptical of the physiological quality of the planting stock produced. Frequent questions, even chronic criticism, stemmed largely from random observations of failed plantations on inland sites, in the hotter, drier, and colder climates away from Humboldt's coastal location. Clients blamed poor stock quality for the failures. The nursery blamed poor site preparation, inept planting, and inadequate seedling protection.

Three points were abundantly clear. (1) The seeming incongruity of using a coastal site to grow seedlings for inland and high-elevation sites had cast serious doubt on whether Humboldt could ship stock of high survival and growth potentials. Until that doubt was dispelled, poor stock quality would be deemed the most likely cause of any plantation failure. (2) Faulting either the nursery or field without complete records of the seedling and planting site histories was a futile exercise. (3) Systematic action to gain an objective understanding of how nursery seedlings are successfully cultured and lifted for overwinter cold storage and spring planting was long overdue. The need was urgent. Regeneration cutting had increased, reforestation backlog areas from past fires and failed plantations were many and extensive, and



Figure 1—Aerial view of Humboldt Nursery, looking east. The nursery is situated on an ancient marine terrace on the Pacific Coast in northwest California. The area supported coastal mixed conifer forest until around the turn of the century, when most of it was cleared and variously used for log landings, permanent pastures, and rhododendron gardens. Here, the red fields contain seedlings, the black fields are moist, plowed soils, and the white fields are fumigated soils under polyethylene sheeting (U-2 infrared photography flown in summer, 1983).

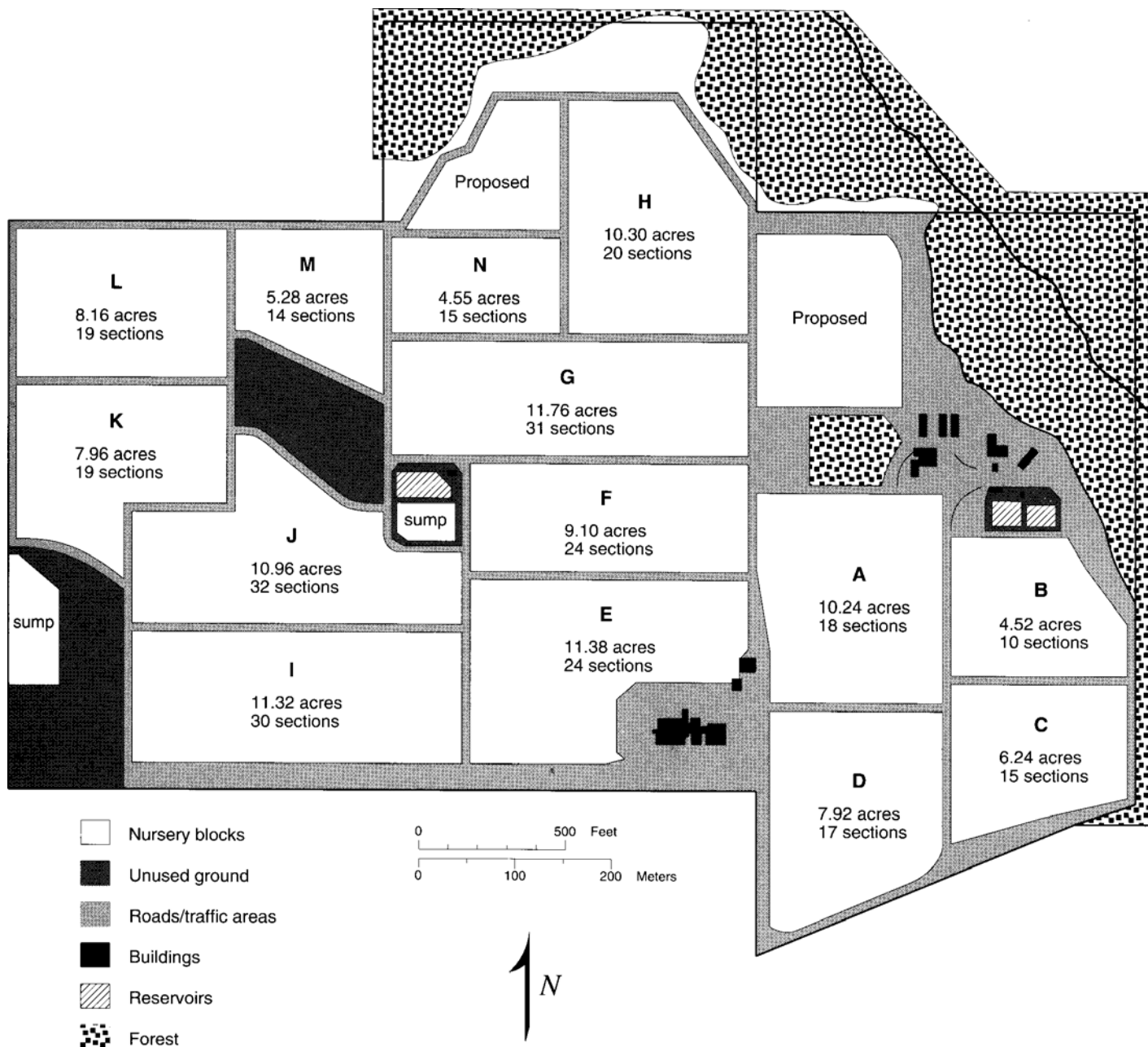


Figure 2—Ground plan of Humboldt Nursery, 1990. Humboldt could ship up to 24 million seedlings per year by cropping two-thirds and fallowing one-third of the 120 acres (49 ha) developed for seedbeds. The letters A to N denote the 14 nursery blocks, individually graded fields or soil management units. To facilitate sprinkler irrigation, each block is divided into multiple sections of six or seven seedbeds each. The seedbeds range from 240 ft (73.2 m) to 640 ft (195 m) in length and run north-south, except in A, D, and H Blocks where they run east-west.

orders for planting stock had soared. To resolve doubts about the nursery's supposed inability to supply seedlings that are physiologically tuned to climates on inland planting sites, Pacific Southwest Region, Pacific Southwest Research Station, and Humboldt Nursery began the seedling testing program to assess stock quality. Initial program

objectives were to evaluate and improve the traditional seedling cultural regime, determine safe lifting and cold storage schedules, and develop nursery management guides that could guarantee planting stock of high survival and growth potential. The ultimate goal was to insure successful plantation establishment.

Physiographic Regions Served

Humboldt Nursery commonly serves ten National Forests and four Resource Areas in northern California and western Oregon, and may occasionally serve the Bureau of Indian Affairs and National Park Service, U.S. Department of Interior. Clients manage Douglas-fir, mixed conifer, and true fir forests in six physiographic regions on the Pacific Slope (*fig. 3*). Client forests are situated in the North Coast and Oregon Coast Ranges, the Klamath Mountains, the western Oregon Cascades, the California Cascades, and the northern Sierra Nevada. These forests extend from near sea level to timberline, 7000 ft (2134 m) or higher, and span 30 or more tree seed zones (*fig. 4*) and their component 500-ft (152-m) elevational bands (Buck and others 1970; USDA Forest Service 1969, 1973). The zones and bands stratify environmental gradients associated with seed source latitude, altitude, and distance inland from the Pacific Ocean. Foresters identify cone and seed collections by the zone and band of parent stands, to secure planting stock of local seed origin and prevent use of maladapted stock.

Planting site environments vary widely, and within regions may be cool and wet or warm and dry, depending on slope, aspect, altitude, and distance from the Pacific Ocean. Summer drought prevails in coastal and inland regions, but inland planting sites at lower latitudes are normally warmer and drier than coastal sites at higher latitudes. Winter snowpacks and freezing weather are the rule for high elevation inland sites, and in some years, for high-elevation coastal sites as well.

By 1975, Humboldt's 2-0 Douglas-fir had been planted over a wide range of mesic to xeric sites in coastal and inland regions of northern California and western Oregon. Results indicated that this stock survived and grew well even on sites characterized by deep winter snowpacks and hot, dry summers. Fully stocked plantations of Humboldt trees

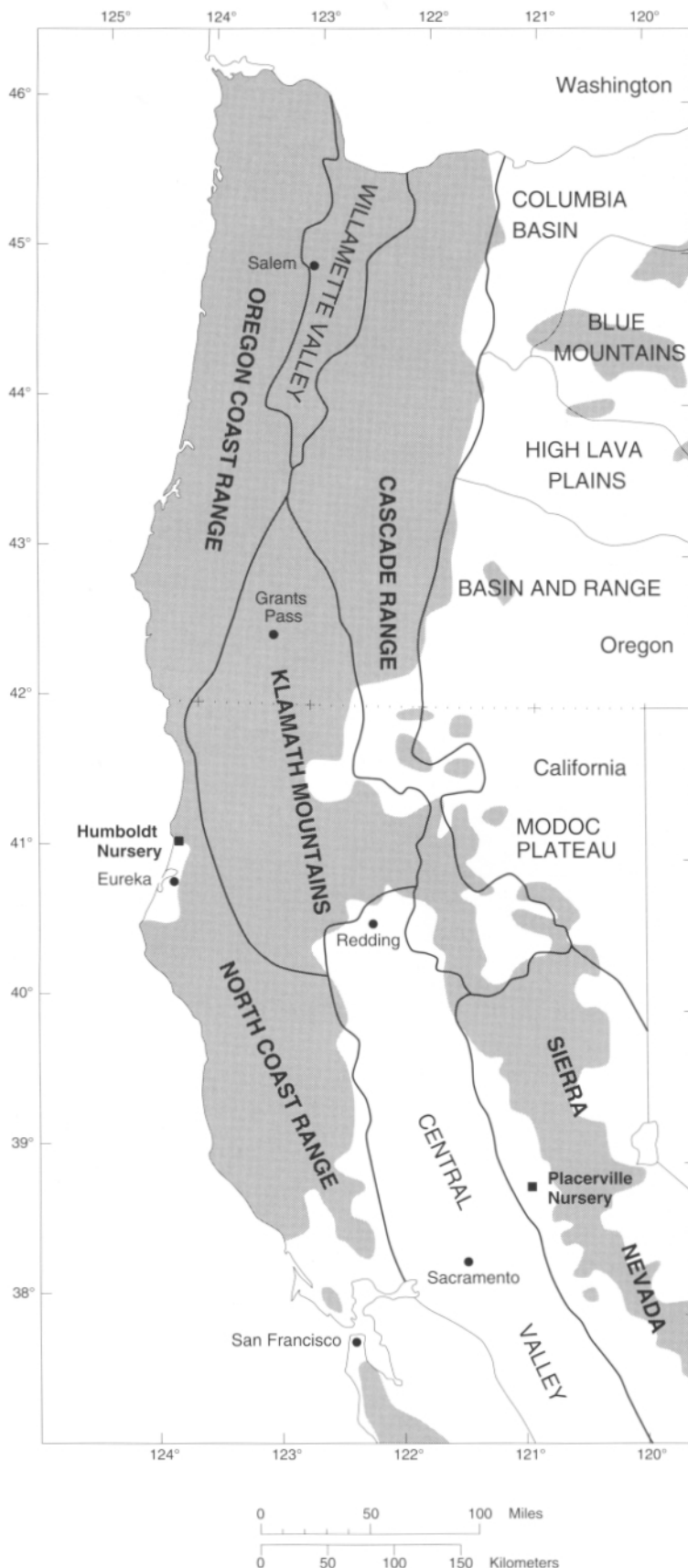
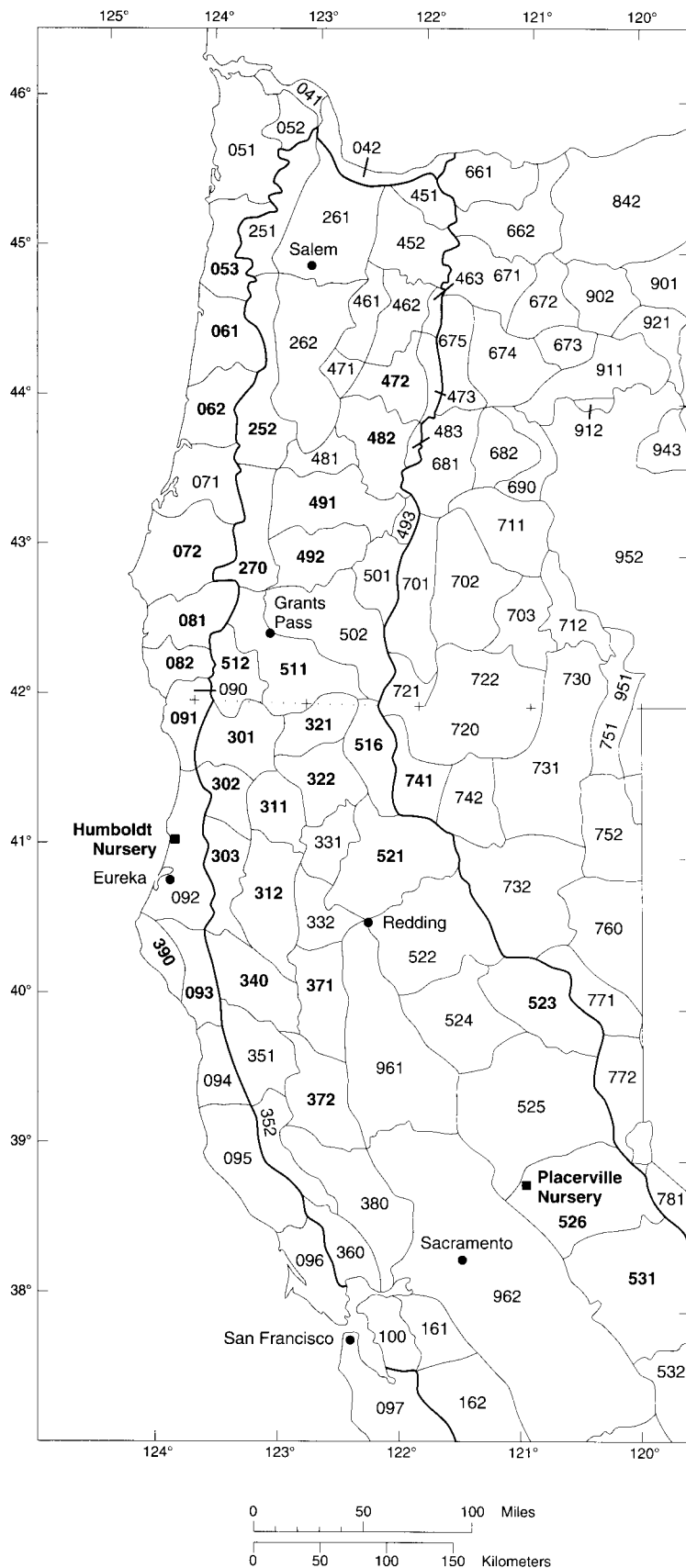


Figure 3—Physiographic regions and the natural range of Douglas-fir (shaded areas) in western Oregon and northern California (Bailey 1966, Franklin and Dyrness 1973, Griffin and Critchfield 1976, Little 1971). Humboldt Nursery produces planting stock for Federal timberlands in the Oregon Coast and North Coast Ranges, the Klamath Mountains, the western Oregon Cascades, the California Cascades, and the northern Sierra Nevada.



are growing well on the Six Rivers and Mendocino National Forests in the North Coast Range south to latitude 39° N, and on the Siskiyou and Siuslaw National Forests in the Oregon Coast Range north to 48° N on the Olympic National Forest in southwest Washington. Successful plantations of Humboldt trees are also growing inland, east through the Klamath Mountains to longitude 122° W on the Willamette National Forest in the Oregon Cascades and Shasta-Trinity National Forest in the California Cascades, and south to latitude 38° N on the Stanislaus National Forest in the western Sierra Nevada.

Most of the plantation failures noted earlier were reported by clients in the drier and warmer inland regions of the North Coast Range and Klamath Mountains. Nevertheless, early research had shown that Humboldt's standard 2-0 Douglas-fir survived and grew well when the seedlings were lifted and stored properly, planted carefully on well-prepared sites, and protected immediately against browsing deer and rabbits (Strothmann 1971, 1976). In test plantings at 2000 ft (610 m) of elevation on the south slope of a ridge in the Klamath Mountains, on a gravelly loam soil that had been cleared of knobcone pine (*Pinus attenuata* Lemm.), survival averaged 98, 97, and 95 percent after 1, 3, and 10 years, respectively. Growth was somewhat better in February than in March plantings, with 10-year height of all trees averaging 5.2 ft (1.6 m) against 4.2 ft (1.3 m), respectively, and height of dominants only, 12.9 ft (3.9 m) against 10.2 ft (3.1 m).

Planting Stock Produced

Humboldt Nursery continues to produce planting stock for the complete elevational range of mesic to xeric sites in coastal and inland regions of western Oregon and northern California. Annual sowings represent a total of 100 or more seed lots from up to 30 different tree seed zones (USDA Forest Service 1969,

Figure 4—Tree seed zones in western Oregon and northern California (USDA Forest Service 1969, 1973). Humboldt Nursery grows Douglas-fir and 17 other conifers for a range of elevations in 30 or more seed zones. Sowing requests for 100 or more seed sources are received yearly. Quality of the planting stock produced by Humboldt Nursery was assessed for sources in the zones shown in **bold.**

1973). Production capacity in terms of 2-0 planting stock is 24 million seedlings per year, enough to plant 55,000 acres (22,270 ha) with seedlings spaced 10 ft (3 m) apart.

Humboldt's output has consisted mostly of 2–0 Douglas-fir, 89.6 percent of the 205 million total seedlings shipped from 1964 to 1987. The other 10.4 percent has consisted of at least 18 additional conifers and one hardwood, as listed below. The symbol † marks species that were assessed in the testing program.

- † Douglas-fir
 Pseudotsuga menziesii [Mirb.] Franco
- † Sitka spruce
 Picea sitchensis [Bong.] Carr.
 Engelmann spruce
 P. engelmannii [Parry] Engelm.
 Brewer spruce
 P. breweriana S. Wats.
- † western hemlock
 Tsuga heterophylla [Raf.] Sarg.
- † western redcedar
 Thuja plicata Donn ex D. Don
 Port-Orford-cedar
 Chamaecyparis lawsoniana [A. Murr.] Parl.
- † incense-cedar
 Libocedrus decurrens Torr.
 coast redwood
 Sequoia sempervirens [D. Don] Endl.
 California red fir
 Abies magnifica A. Murr. var. *magnifica*
- † Shasta red fir
 A. m. var. *shastensis* Lemm.
- † white fir
 A. concolor var. *lowiana* [Gord. Lemm.]
- † noble fir
 A. procera Rehd.
- † grand fir
 A. grandis [Dougl. ex D. Don] Lindl.
 Jeffrey pine
 Pinus jeffreyi Grev. & Balf.
 ponderosa pine
 P. ponderosa Dougl. ex Laws. var. *ponderosa*
 sugar pine
 P. lambertiana Dougl.
 western white pine
 P. monticola Dougl. ex D. Don
 lodgepole pine
 P. contorta Dougl. ex Loud.
 red alder
 Alnus rubra Bong.

Sitka spruce, western hemlock, western redcedar, noble fir, grand fir, coast redwood, California red fir, Shasta red fir, white fir, Jeffrey pine, ponderosa pine, sugar pine, and red alder are ordered annually or frequently. Incense-cedar, western white pine, lodgepole pine, Engelmann spruce, Brewer spruce, and Port-Orford-cedar are ordered infrequently or rarely.

The Nursery Environment

Situated 1 mile (1.6 km) inland from the Pacific Ocean and 250 ft (76 m) above the surfline (*fig. 1*), Humboldt Nursery has both a superior climate and excellent soils for growing conifer seedlings. The soils are classified as Arcata loam, fine sandy loam, and fine loam taxadjunct, and exceed 10 ft (3 m) in depth. They overlie marine terrace deposits of poorly to moderately consolidated silts, sands, and gravels (Hookton Formation, Quaternary Period) and form flat benches on wave-cut Franciscan Formation (Granfield 1990).

Overall, the nursery site slopes gently toward the west. About 120 of its 210 acres (49 of 85 ha) have been developed for seedbeds. The seedbed areas are divided into 14 fields, soil management units designated as Blocks A to N (*fig. 2*). The fields range in size from 4.5 to 11.8 acres (1.8 to 4.8 ha), and most have slopes of 3 percent or less. The seedbeds range from 240 to 640 ft (73 to 195 m) in length, and depending on field, are oriented north-south or east-west to cross the prevailing slope.

The nursery climate is maritime in both annual and daily temperature cycles (*fig. 5*). In most years, the growing season begins in March and ends in November, judging by the period of time that seedlings show new white root tips in the nursery beds. Summers are mild and dry, but coastal fogs are common. Winters are normally cool and wet, and in some years heavy rains frequently interrupt lifting operations. Winter lows have hit 20° F (–6° C), but soil in the seedling beds rarely freezes deeper than the surface inch. The potential lifting season extends from late November to the middle of March.

The coastal mixed conifer forest that once covered the nursery area was cleared for pasture and agriculture. Douglas-fir, Sitka spruce, coast redwood, western hemlock, western redcedar, grand fir, Pacific madrone, and red alder are found in the residual bordering stands. Cutover units adjoin the nursery to the north and east, and a small grove of Sitka spruce, western hemlock, and grand fir still grows just north of Block A. Bullwinkle Creek flows in the deep canyon cutting the northeast corner of the property, Patrick's Creek once traversed the western part of the nursery area, and Strawberry Creek meanders between the nursery and Dow's Prairie, a natural grassland to the south. Eastward, rolling, dissected uplands rise to 1000 ft (305 m) or 1500 ft (457 m) of elevation and merge with higher coastal ridges of the North Coast Range.

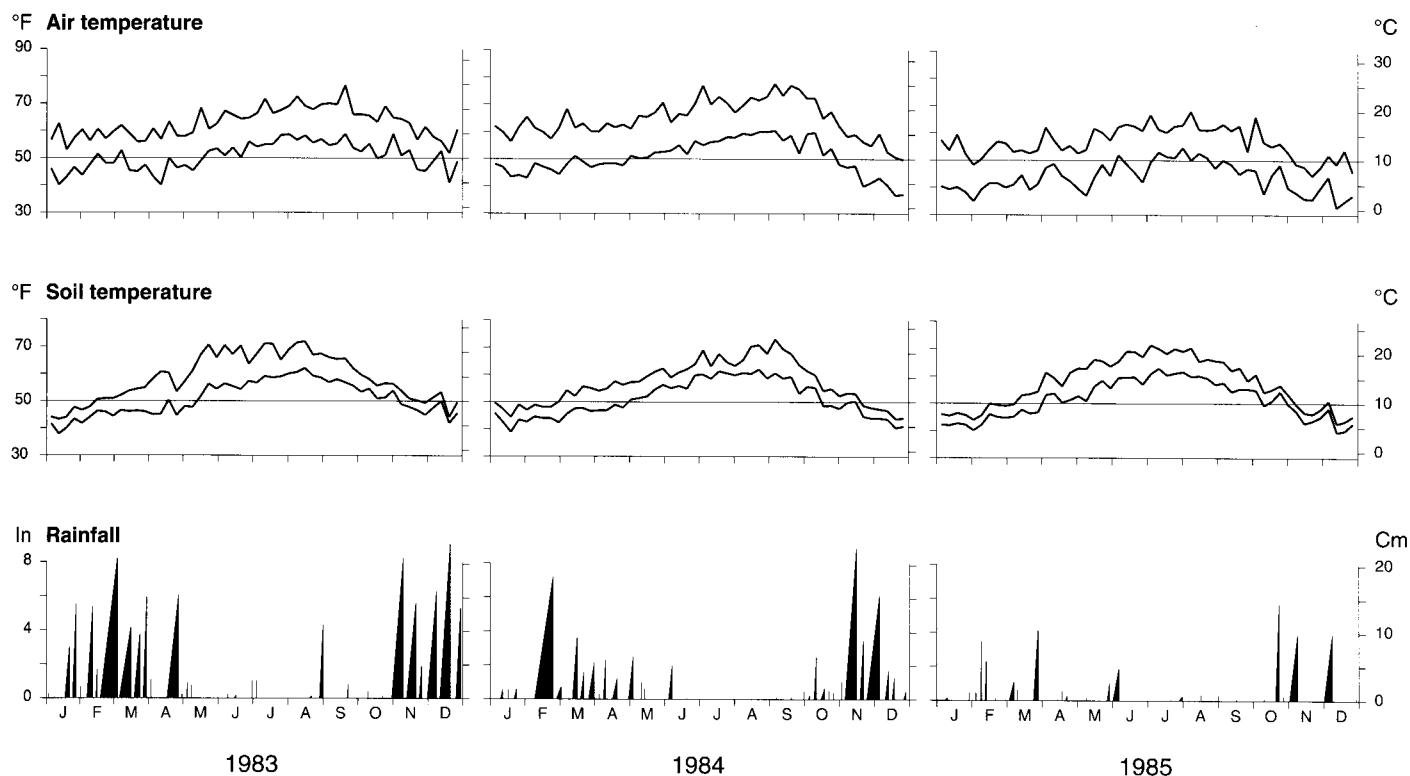


Figure 5—Climate in Humboldt Nursery. The climate is maritime, with cool, wet winters and foggy summers. Growing seasons begin in March and end in November, as judged by the times Douglas-fir seedlings start and stop root elongation in the nursery beds. Mean daily maximum and minimum temperatures were recorded for air at 5 ft (1.52 m) above ground and soil at a depth of 3 inches (8 cm). The seasonal patterns of temperature and rainfall in 1983 to 1985 show the range of variation in 14 years of records from the seedling testing program.

Standard Cultural Practices

When we began the testing program, Humboldt Nursery was producing planting stock by adhering to an empirically determined seedling cultural regime and midwinter lifting schedule worked out by the first superintendent (*fig. 6*). Most of the seedlings lifted in the winter of 1975–76 were of acceptable morphological grade for that time, indicating that the fertilization, irrigation, and undercutting practices in use were basically satisfactory. The crop consisted entirely of 2–0 planting stock, except for a small amount of 3–0 Douglas-fir.

Seedlings were cultured for 2 years, the time needed to produce planting stock of acceptable sizes (*figs. 6, 7*). Seedbeds were prepared and shaped in May. The production cycle was initiated during the preceding summer, when fallow soil was irrigated, cultivated, and fumigated. A standard mixture of methylbromide (67 percent) and chloropicrin (33 percent) was injected beneath a thin, continuous sheet of polyethylene. Then as now, fumigation was essential to kill weed seeds and control the common

soil-borne pathogens, damping-off and *Fusarium* root disease (Smith 1975). After the spring rains had passed, the fumigated areas were chisel-plowed to improve soil aeration and drainage, power-harrowed, and shaped into seedbeds across the prevailing slope. The seedbeds were set 16 inches (40 cm) apart to provide access for tractors and people, and measured 4 ft (1.2 m) wide and 4 inches (10 cm) high after settling.

Seeds were usually stratified 1 month at 36–38° F (2–3° C), coated with thiram to repel rodents and migrating birds, and sown sometime in late May or early June. The seeds were drilled about 0.125 inch (3 mm) deep in rows spaced 6 inches (15 cm) apart. Sowing rates were calculated to produce 100 to 120 seedlings per lineal foot (330 to 395 per m) or 25 to 30 per square foot (270 to 325 per m²). Most seedlings were stunted after the first growing season. During the rainy season, which normally extends from late autumn to late spring, chlorothalonil was sprayed biweekly to control *Phoma*, a foliar pathogen that had destroyed seedlings by the millions (pers. commun., Richard S. Smith, 1976).

Traditional Cultural Regime for 2-0 Douglas-fir

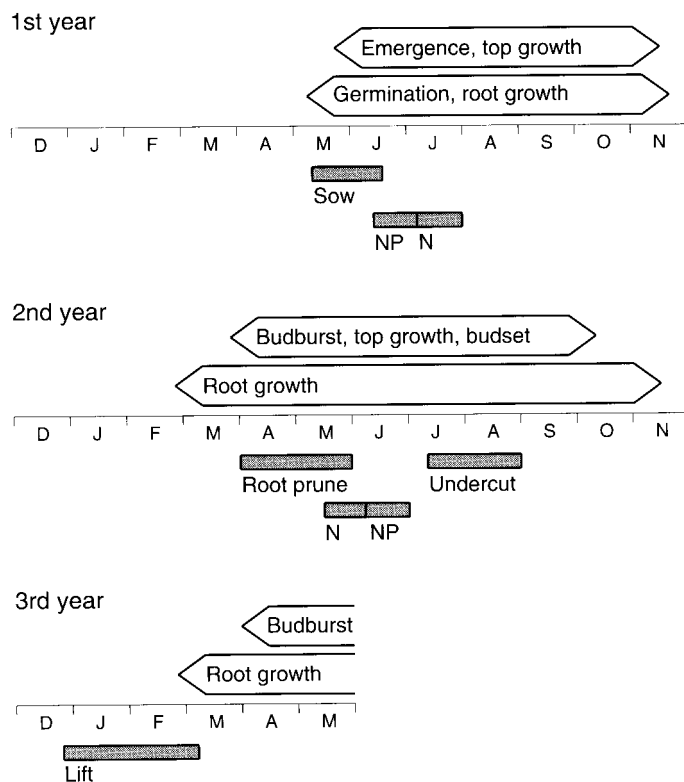


Figure 6—Traditional seedling cultural regime for producing 2-0 Douglas-fir planting stock at Humboldt Nursery. Seeds were stratified 30 days at 2° C (36° F) and sown in May–June, after the spring rains had passed. Ammonium nitrate (N) and diammonium phosphate (NP) fertilizers were applied through the sprinkler irrigation system in June and July the first year and in May and June the second year (Strothmann and Doll 1968), at rates to supply the crop with a total of 154 lb N and 53 lb P per acre (173 kg N and 60 kg P per ha).

Seedlings were either very small or stunted the first year, but grew vigorously the second year. To control top height, increase root mass, induce dormancy, and facilitate lifting, root systems of second-year seedlings were vertically pruned to a depth of 4 inches (10 cm) between rows in May and undercut once at a depth of 8 inches (20 cm) in July or August.

The 2-0 seedlings were lifted in late December to March, graded to a stem diameter of 0.16 inch (4 mm), root-pruned at 10 inches (25 cm) below the ground line, and stored at 1° C (34° F) for spring planting in the seed zones of origin (see *fig. 7*).

In late spring of the second year, seedling roots crossing between the seedling rows were vertically pruned to a depth of 4 to 6 inches (10 to 15 cm). This procedure forced new root growth near the taproot, effectively separated the seedling rows, and facilitated winter lifting and sorting with minimal root damage. In late summer, seedlings were undercut at a depth of 8 inches (20 cm) below the bed surface. This single undercut was sufficient to control top height, induce budset, and increase root mass above lifting depth (Zaerr and others 1981).

Most of the crop was lifted in January and February. A mechanical lifter mounted behind a tractor was used to undercut the beds at 10 inches (25 cm). Then as now, the undercut seedlings were pulled by hand. Lifting procedures at that time differed from the current standard in that today much greater care is taken to lift and pull seedlings when the soil and weather conditions permit safe lifting, that is, minimize root breakage and seedling water stress. Pulled seedlings were shaken free of soil, placed in plastic boxes, covered with wet burlap, and hauled to the packing shed.

At the packing belts, seedlings were graded to a stem diameter of 0.16 inch (4 mm), culled to remove the damaged or malformed ones, root-pruned at 10 inches (25 cm) below ground line, taped in bundles of 50, and packed with wet shingletow in double-walled paper bags lined with polyethylene. The bags of packed stock were folded shut and either taped and tied to hold them closed or strapped with a banding machine. Packed bags were placed on pallets and held in cold storage until spring planting time. The cooler temperatures were maintained at 34–36° F (1–2° C), significantly warmer than the current standard of 32–34° F (0–1° C) for seedlings in the center of the bag.

The Testing Program

Humboldt's testing program was configured to investigate all aspects of planting stock production and plantation establishment, at least to the extent compatible with an ongoing obligation to supply 18 million seedlings per year. Studies were designed to assess effects of seed source and lifting date on seedling growth capacity and field performance. Testing progressed along several lines and at different rates, with the choices of seed sources depending on what seedlots had been requested. Advantage was taken of every opportunity to explore effects of traditional and potential cultural practices on seedling development. Once Humboldt's pioneer group of field cooperators had witnessed results on their own turf, they quickly spread the word. Confidence in the program grew rapidly thereafter, and the scope and depth of testing increased fourfold.

Tests centered on the field performance of stock planted on cleared sites in the seed zones of origin, with special attention paid to elevations of greatest reforestation activity. Seed sources were chosen to sample forest environments typical of Douglas-fir in the North Coast and Oregon Coast Ranges, the Klamath Mountains, the Cascades of western Oregon and northern California, and the northern Sierra Nevada (*figs. 3, 4*). The seed sources and planting sites were arrayed from latitude 38° N in central California to 46° N in northwest Oregon. Douglas-fir was sampled in a total of 30 tree seed zones on 12 National Forests, 32 Ranger Districts, and 3 Resource Areas (see *table 1* in Appendix B, Reference Tables). See Seed Source Assessments—Douglas-fir, *fig. 10*, for a map showing the locations of field performance tests installed from 1975 to 1990, during the first 14 years of the testing program.

Field performance tests were used to determine safe lifting and cold storage schedules, identify successful planting times, and improve seedling cultural regimes. The nature of their designs permitted most field tests to serve at least two and sometimes all three uses. The need to safeguard newly planted stock was repeatedly demonstrated. Field survival and growth were spectacular with immediate seedling protection against aggressive vegetative competition and animal damage, and were frequently catastrophic without it.

Seedling testing confirmed much of Humboldt's traditional, empirically determined practice, defined benefits of some proposed practices, and developed new and improved seedling cultural regimes. Returns for Humboldt and its service regions were marked and sustained improvements in planting stock quality and quantity. Production of planting stock is efficient and consistent, and stock is confidently shipped with high growth capacity and survival potential. Success of the new cultural regimes and the extended lifting and cold storage schedules developed for Humboldt validate and justify the testing program approach.

PRODUCING 2-0 PLANTING STOCK AT HUMBOLDT NURSERY

Soil Preparation

A Fumigate fallow soil



B Chisel-plow soil



C Chisel-plow



D Apply fertilizers



Figure 7—Steps in the production of 2-0 planting stock at Humboldt Nursery. Stock quality depends on the timing and execution of proven cultural and harvest practices.

Soil preparation methods insure rapid drainage and aeration, and control weeds and soilborne pathogens. In summer, fallow soil, readied for fumigation using the

equipment shown here (B, C, E-G), is injected with a mixture of methylbromide and chloropicrin under a continuous sheet of polyethylene (A).

Fumigated soil is plowed to a depth of 20 inches (50 cm) using a gang of curved chisels mounted in two offset rows (B, C). Triple superphosphate and potassium sulphate fertilizers are applied using a standard spreader (D).

E Disk and roll soil



F Harrow soil



Figure 7 (continued)—Fertilizers are incorporated using a two-gang disc and ring roller (E). A power harrow and coupled herringbone roller complete the preparation process (F, G).

Prepared soil is shaped to form seedbeds 4 ft (1.2 m) wide and 4 inches (10 cm) high (H). Next, chilled seeds are surface-dried and drilled in rows spaced 6 inches (15 cm) apart, at rates to produce 25 to 30 seedlings per square foot (273 to 328 per m²) of bed (I).

G Power harrow and roller



Seed Sowing

H Shape nursery beds



I Sow seeds



Seedling Culture

J Control pathogens



K Root prune seedlings



L Undercut seedlings



M Change undercut blade



Figure 7 (continued)—First-year seedlings are sprayed with chlorothalonil fungicide biweekly from late autumn to spring to control *Phoma*, a pathogen that has killed millions of Douglas-fir and true fir seedlings at Humboldt (J).

As seedlings develop in their second year, steps are taken to achieve balanced growth. In spring, before crown closure occurs, roots between the seedling rows are vertically pruned to a depth of 4 inches (10 cm), using a gang of sharpened colters mounted beneath a tractor (K).

Seedlings approaching target height are undercut at a depth of 7 to 8 inches (18 to 20 cm) to halt height growth, stimulate root growth, and induce budset (L). The undercutting blade is made of machine-steel, is 0.8 inch (2 cm) thick by 4 inches (10 cm) wide by 5 ft (1.52 m) long, and is changed frequently for resharpening (M).

Seedling Harvest—Field

N Lift seedlings in nursery



O Seedling lifter



P Hand-pull seedlings



Q Shake soil and box seedlings



Figure 7 (continued)—In winter, seedlings are lifted by undercutting the beds at a depth of 10 inches (25 cm), using a sharpened machine-steel blade and coupled variable-speed shaker mounted behind a tractor (N, O).

Lifted seedlings are immediately hand-pulled in large bundles, shaken free of soil, placed in plastic totes, and covered with wet burlap (P, Q).

Seedling Harvest—Packing Shed

R Haul seedlings to packing shed



S Move seedlings to precooler



T Hold seedlings in precooler



U Monitor seedlings



Figure 7 (continued)—Boxed seedlings are loaded on trailers, hauled to the packing shed, and transferred by forklift into a precooler, where they are held for grading and packing (R-T).

To monitor seedling condition and insure proper handling, pressure bombs (PMS Instruments, Corvallis, OR) are used to measure plant moisture stress (PMS) before and during lifting, in the precooler, during packing, and in cold storage (U).

V Grade, prune, and bundle seedlings



X Pack seedlings



Y Store seedlings in cooler



Figure 7 (continued)—Precooled seedlings are separated, graded, and counted at stations along conveyor belts (V).

Graded seedlings are bundled, root-pruned, and packed in double-walled, polyethylene-lined paper bags at the end of the belt (W, X).

The packed bags are folded and banded shut, placed in framed pallets, and stored in drive-in coolers until spring planting time (Y). The cooler thermostats are set to maintain the in-bag temperatures at 1° C (34° F).

FOCUS OF THIS REPORT

Specific information in this report is limited to Humboldt Nursery and seed sources in the forests of western Oregon and northern California. The overall findings have broad application, however, and should interest anyone concerned with improving planting stock quality and reforestation success. Whether real or supposed, problems of seedling production and stock quality confront all forest tree nurseries and their clientele, wherever they are located. With that focus in mind, we compiled the 14 years of results from Humboldt's testing program. Herein we describe the related series of nursery studies and field performance tests that were used to develop Humboldt's current operating guides and seedling cultural regimes, point out the repeatedly demonstrated payoffs in improved field survival and growth, and duly emphasize implications of the program's success for other forest nurseries and their service regions.

The special value of the Humboldt program is its comprehensive design. Every study incorporated a deliberate effort to evaluate seedling growth capacity just after lifting and after cold storage, determine field survival and growth for a minimum of 2 years on prepared planting sites, and assess the key importance of seed source in determining results. The guides derived for improved seedling production and stock quality thus took full account of seed source differences in seedling response to nursery climate, cultural regimes, and time of lifting for cold storage to spring planting time.

Much of the information contained herein is already known. Results and implications of the work have been communicated directly to nursery clients by Humboldt's Administrative Studies Unit and its host of cooperators on Forest Service Ranger Districts and Bureau of Land Management Resource Areas. Findings in written format have been made available through accomplishment reports to Pacific Southwest and Pacific Northwest Regions (Jenkinson 1976, 1978, 1979; Jenkinson and Nelson 1985a, 1985b; Jenkinson and others 1985, Knight and others 1980, Nelson and Jenkinson 1985, 1992; Turpin and others 1985) and in a series of published papers (Jenkinson 1984, 1988, 1989; Jenkinson and Nelson 1978, 1983, 1985, 1986). This report provides a definitive overview of the testing program, presents results of unpublished work, collates the operating guides derived for nursery management, demonstrates the principles of successful plantation establishment, and makes the entire work easily accessible.

In our view, Humboldt's experience is a strong recommendation for establishing seedling testing programs in other forest nurseries and regions. Specific accomplishments of the testing program are itemized in the next chapter (see Assessing Planting Stock Quality, Program Accomplishments).

FIGURES AND TABLES

The figures and tables illustrate the important take-home lessons, and by design are the heart of this report. They consolidate all data gathered in the period from 1975 to 1992, and for easy reference are listed here, by chapter:

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MOVING INTO THE'90'S

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Table 6—Top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir from April sowings tested just after lifting and after cold storage at Humboldt Nursery

Table 7—Significance of seed source, sowing date, and lifting date effects on top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery

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Regeneration cuts in Douglas-fir forest: View of recently logged Flat Cant units 17/23 and 15, with Ship Mountain in distance, and below, closer view of unit 17/23, with Fox Ridge to the left and Table Mountain in distance



ASSESSING PLANTING STOCK QUALITY

Comprehensive assessments of planting stock quality are essential for building an efficient seedling production program. Assessments are needed to clarify seedling requirements in the nursery's operational environment, that is, climate, soils, cultural regimes, and lifting schedules for cold storage, and to evaluate effects of traditional and proposed nursery cultural practices on field survival and growth. Field performance tests of seedlings of known seed sources are the most direct way to evaluate planting stock quality and nursery practice. Field tests provide proof of the nursery's ability to deliver planting stock that can survive and grow well, and show unequivocally whether a particular practice is beneficial or harmful, and for which seed sources. Planting stock should be tested on an array of cleared sites in the seed zones of origin, in the physiographic regions that the nursery serves.

Workloads and funding limitations generally prohibit nurseries from doing independent extensive field testing. The strength of any seedling testing program, therefore, largely depends on the nursery's ability to enlist the help of clientele. Field foresters are willing to provide test sites and plant, protect, and measure seedlings of local seed origin because they recognize the direct benefits. Field testing directly supports their tree planting programs, and experience has shown that it is easier and cheaper to insure planting stock of high quality than to explain and rectify plantation failures.

Besides a dedicated nursery cadre, some modest but reliable funding, and enough field cooperators to sample the physiographic regions served, a complete testing program needs a controlled-environment facility. Such a facility is highly desirable even if not absolutely essential. A small greenhouse equipped with basic air conditioning, simple water baths, light banks, and an overhead shade screen serves the purpose and is easily maintained. Field tests provide proof of planting stock quality. Growth capacity tests supply the underlying physiological explanations for success or failure and improve our understanding of seedling requirements. Knowing the **why** of success is the key to achieving and sustaining reliable outputs of high-quality planting stock.

Humboldt's experience shows that an ongoing testing program can build a factual and relevant data base, nail down real nursery problems, indicate studies that are needed to assess and improve cultural practices, permit informed biological decisions, and facilitate nursery management. Nurseries in need of or contemplating such a program should not be deterred by what might appear to be a massive and complex undertaking. The Humboldt program was aggressively managed, but was never unwieldy. To make workloads manageable and guarantee good data, nursery and field tests were deliberately limited in size, design, and number. Cooperators were easily enlisted to carry out the field tests, and the manifest results built confidence in Humboldt's ability to supply high-quality stock for Pacific Slope forests.

THE PROGRAM DESIGN

Planting stock quality was assessed by using standard tests of seedling growth capacity and field performance (*fig. 8*). Beginning with the testing program's initial winter lifting season in 1975-76, studies were designed to assess effects of seed source and cultural practice on

- Seedling top and root growth capacity (TGC, RGC; Stone and Jenkinson 1970, 1971) just after lifting and after cold storage to spring planting time
- Field survival and growth of outplanted seedlings after 1 and 2 years on cleared planting sites in the seed zones of origin

Following a standard sampling scheme, seed sources were selected in the nursery, and seedlings were lifted monthly from autumn to spring, starting in late October or early November and ending in late March. Lifted seedlings were graded, root-pruned, packed in polyethylene bags, and stored at 1° C (34° F). The graded seedlings were subsampled for growth capacity tests just after lifting and after cold storage, and for field performance tests at spring planting time. This approach allowed us to evaluate

Testing Planting Stock Quality

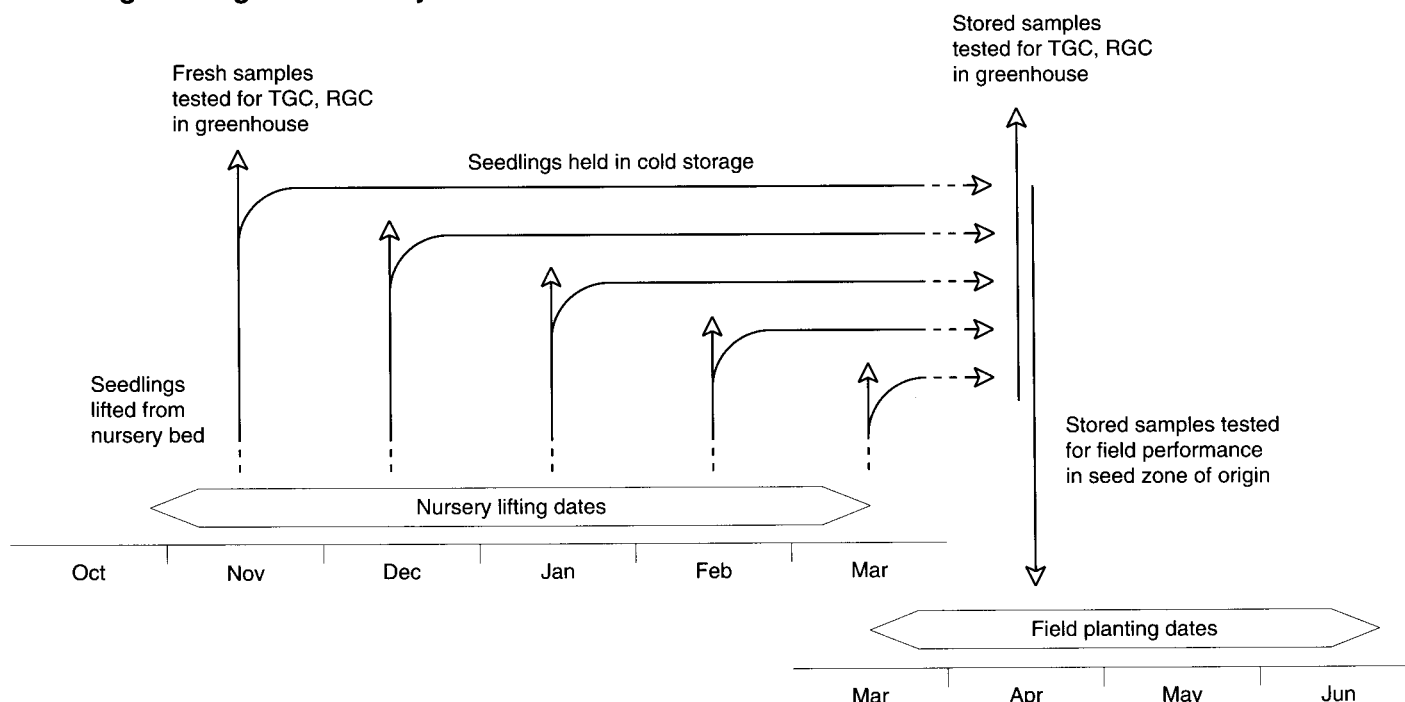


Figure 8—Sequence of standard tests of planting stock quality at Humboldt Nursery. Seedlings in the beds were sampled monthly in autumn to spring, graded, root-pruned, and held in cold storage at 1° C (34° F). Seedling top and root growth capacities (TGC, RGC; Stone and Jenkinson 1970, 1971) were evaluated in greenhouse tests just after lifting and after cold storage, at spring planting time (see fig. 9). Survival and growth were evaluated in field performance tests on cleared planting sites in the seed zones of origin.

- Seasonal patterns of seedling TGC and RGC in the nursery, through the winter lifting season
- Combined effects of lifting date and cold storage on seedling TGC and RGC at spring planting time
- Combined effects of lifting date and cold storage on survival and growth of outplanted seedlings
- Relation of first-year field survival to seedling RGC after cold storage, at spring planting time
- Critical seedling RGC for first-year survivals, to estimate severity of planting site environments

First-year field survivals indicate the percentages of seedlings that had RGC higher than critical, that is, RGC higher than the lowest RGC associated with survival on the planting site. Where seedlings are properly planted and immediately protected, first-year survival depends on the soil type, topographic position, and weather from planting time in spring to onset of winter. Under these conditions, the critical RGC is typically low. Where seedlings are poorly planted or not protected, however, mortality is often excessive, and the critical RGC may be greatly inflated.

PROGRAM ACCOMPLISHMENTS

As accomplishments of the seedling testing program accrued, Humboldt Nursery's cultural regimes and lifting and cold storage schedules were reshaped. By adhering to our new and proven management guides, Humboldt has consistently produced large 1-0, 2-0, and 1-1 Douglas-fir, achieved dramatic gains in seedling yield and planting stock quality, and greatly improved cost efficiency. Annual tests of seedling top and root growth capacity (TGC, RGC) after cold storage, at planting time, have indicated high survival and growth potentials for seedlings of every seed source and stock type.

Results of specific studies led directly to major changes away from Humboldt's traditional practices. Lifting and cold storage schedules were expanded to include November to late March, encompassing the entire winter season. The seedling cultural regime

for 1-0 planting stock was developed by combining extended seed chilling and sowings in midwinter to early spring with heavy fertilization just after seedling emergence was complete. The traditional cultural regime for 2-0 planting stock was replaced with one that coupled the 1-0 cultural regime to double undercutting in spring of the second growing season. Improvements in soil management, seed treatment, and seedling fertilization, irrigation, lifting, handling, and cold storage, together with a system for monitoring soil and seedling conditions during harvest, all stemmed directly from the testing program. In brief, the program

- **Determined seasonal patterns of TGC and RGC of Douglas-fir** from coastal and inland regions in western Oregon and northern California, **Shasta red fir, white fir, and incense-cedar** from the Klamath Region, and **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** from the Oregon Coast Range. The TGC patterns, except those of incense-cedar and western redcedar, which show high TGC in autumn and winter, are sigmoidal and show that winter chilling promotes budburst and shoot extension. The RGC patterns are of three distinct types, showing either a single peak, two separate peaks, or a high plateau, and typify the genetic diversity found in seedling response to nursery climate.
- **Determined cold storage effects on TGC and RGC of Douglas-fir** from coastal and inland regions in western Oregon and northern California, of **Shasta red fir, white fir, and incense-cedar** from the Klamath Region, and of **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** from the Oregon Coast Range. Cold storage at 1° C (34° F) completes the chilling needed for rapid budburst and shoot extension, and either increases or decreases RGC, depending on seed source and lifting date.
- **Determined seed source lifting windows**, that is, the safe calendar periods to lift seedlings for cold storage and spring planting, for **Douglas-fir** in 74 field tests in coastal and inland regions of western Oregon and northern California, for **Shasta red fir and white fir** in 6 tests in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** in 20 tests in the Oregon Coast Range. Lifting windows are reliably defined by first-year survivals on cleared sites in the seed zones of origin, and are used to schedule lifting of tested and untested seed sources.
- **Evaluated 2-year survival and growth of Douglas-fir** in 68 field tests in coastal and inland regions of western Oregon and northern California, of **Shasta red fir and white fir** in 4 tests in the Klamath Region, and of **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** in 19 tests in the Oregon Coast Range. Survival and growth are uniformly high within the seed source lifting windows; outside these windows, survival is lower and growth is often slower.
- **Determined relation of first-year field survival to RGC at planting time** for **Douglas-fir** on 35 sites in western Oregon and northern California, for **Shasta red fir and white fir** on 5 sites in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** on 15 sites in the Oregon Coast Range. In tests in coastal and inland regions, RGC after seedling cold storage explained 90 to 99 percent of the variation in first-year survival.
- **Estimated critical RGC**, that is, the lowest RGC associated with first-year survival, for **Douglas-fir** on 35 sites in western Oregon and northern California, for **Shasta red fir and white fir** on 5 sites in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** on 15 sites in the Oregon Coast Range. Critical RGCs for known sites can be used to predict first-year survivals of planting stock destined for similar sites in the same or adjacent seed zones.
- **Developed 1-0 Douglas-fir** for coastal and inland regions of western Oregon and northern California. Large 1-0 planting stock with high survival and growth potentials is produced by using the management guides that were developed for soil preparation, extended seed chilling, sowing in midwinter to early spring (January-March), and heavy fertilization after seedling emergence.
- **Developed spring undercutting regimes to carry 1-0 Douglas-fir over for 2-0 stock.** Undercutting second-year seedlings at 15 cm (6 in) in March and again at 20 cm (8 in) in May can control top height, increase root mass, and consistently result in balanced planting stock.

- **Red-flagged mycorrhizal inoculation, root wrenching, and freeze storage**, practices that had been proposed to improve the field performance of traditional **2-0 Douglas-fir**. Inoculating May sowings reduced the survival and growth of coastal seedlings and the survival of inland seedlings. Wrenching reduced the survival of coastal seedlings, but improved that of inland seedlings. Freeze storage at -1° C (30° F) reduced the survival of inland seedlings and the growth of coastal seedlings.
- **Determined safe precooler storage of Douglas-fir** destined for coastal and inland regions of northern California. Seedlings waiting to be graded and packed can be held 15 days at 1° C (34° F) under wet burlap in plastic totes in the precooler, with no loss in field survival and growth potentials.
- **Defined site planting windows for Douglas-fir** at middle elevations in the coastal regions of northwest California and southwest Oregon. Sites dominated by Pacific Ocean air can be safely planted from October to May by using newly lifted seedlings in autumn, either newly lifted or stored seedlings in winter, and stored seedlings only in spring, after root elongation resumes in the nursery.

Field performance tests vividly illustrated the most important results and persuasively communicated implications for reforestation. Cooperators that installed and measured field tests observed take-home lessons right on the planting sites. These tests invariably demonstrated safe times to lift and store seedlings for spring planting, and more often than not, warned clients of possible shortfalls in their planting programs. Improved site preparation and immediate protection of planted seedlings against competing vegetation and browsing mammals proved to be widespread needs.



Douglas-fir seedlings in their second growing season in Humboldt Nursery, looking south in G Block

STANDARD TESTING PROCEDURES

Standard tests and testing procedures save time, avoid confusion, yield reliable data, facilitate the conduct of related studies, provide continuity of results, and permit direct comparisons within and between years. Tests of seedling top and root growth capacity (TGC, RGC) at lifting and after cold storage were run in a controlled-environment greenhouse built at the nursery. Field performance tests were installed in spring on cleared planting sites in the seed zones of origin, with rare exceptions. Data from these standard tests were used to relate first-year field survival to RGC after seedling cold storage, and to estimate values of critical RGC for the planting sites. Detailed instructions were prepared for those who wish to evaluate the growth and survival potentials of delivered planting stock (see Appendix C, Growth Capacity Test Instructions).

Seed Source Selection

The seed sources chosen for testing are of major importance to the scientific credibility of results and the scope and practical application of results. Seed sources typical of forests in the physiographic regions served by the nursery should be assessed in every major study, to insure results that are comprehensive. At Humboldt Nursery, that has always meant testing seedlings destined for coastal and inland regions of western Oregon and northern California.

To the extent possible, seed sources were chosen to sample the genetic variation associated with environmental gradients on the Pacific Slope, on coast-inland transects from the Pacific Ocean to the Cascade Range-Sierra Nevada and along latitudinal transects in the coastal and inland regions of western Oregon and northern California. In every region, practical choices were made to include seed zones that covered extensive areas of current and projected future reforestation efforts.

Choices available in most years were dictated by the seedlots sown, that is, by whatever seed sources the clientele had ordered. Possible best sources for testing were first located in the nursery inventory and then inspected in the seedbeds. Pacific Northwest and Southwest Region seed bank records were used to identify large seedlots of broad genetic base, and

to avoid small seedlots or older seedlots of uncertain origin. Selections of sources in the nursery were made in October, to be sure that seedlings of good morphological grade were available in quantity.

For studies designed to explore alternative nursery practices and new seedling cultural regimes, large seedlots of broad genetic base and high seed quality were selected from the seed bank inventories of both Regions. Again, seed sources were chosen in seed zones and elevations typical of coastal and inland regions in western Oregon and northern California.

Monitoring Nursery Climate

Nursery soil and air temperatures and rainfall occurrence and amounts were recorded to describe environmental conditions during seed germination and seedling emergence, early growth, and dormancy, and to address questions about influences of maritime climate on seedling physiological condition. In most years, monitoring extended from September to April, to cover the autumn onset and spring release of seedling dormancy and span the winter lifting season.

Soil temperatures were recorded at depths of 8 cm (3 in) and 13 cm (5 in). Thermograph probes were inserted horizontally into the soil profile in plots that were kept free of weeds but not cultivated. Temperature traces at 8 cm reflect diurnal changes in air temperature and show fluctuations typical of the upper root zone. Traces at 13 cm reflect the more stable environment of the lower root zone, and are paired with traces at 8 cm to evaluate daily and seasonal temperature gradients in the soil-root profile.

Air temperatures were recorded by a calibrated hygrothermograph and min-max thermometers housed 1.5 m (5 ft) above ground in a weather shelter. Rainfall was measured by a precipitation gauge positioned near the weather shelter, and was recorded at 8 A.M. on workdays during and after each storm.

Natural cold exposure or chilling of seedlings in the nursery was estimated from the diurnal traces of air temperature graphed in late autumn and winter. Seedling chilling from October 1 to any particular lifting date was expressed as the sum of hours that air in the nursery was cooler than 10° C (50° F). The use of any lower threshold temperature practically precluded meaningful estimates of chilling rates in Humboldt's maritime climate.

Seedling Sampling and Handling

Douglas-fir seedlings that were sampled in the first 4 years of the testing program (see Seed Source Assessments-Douglas-fir), and all of the seedlings that were sampled for other conifers (see Seed Source Assessments-Other Conifers), were grown under Humboldt's traditional cultural regime (see Reforestation and the Nursery, Standard Cultural Practices). In 1979, the program was necessarily expanded to include the development of two new cultural regimes, one to produce 1-0 Douglas-fir and the other to carry holdover 1-0 seedlings for 2-0 planting stock (see Assessing Nursery Culture Alternatives).

Sampling in most years was done through the calendar period in which seedlings conceivably might be lifted. Seedlings of selected seed sources were sampled monthly, beginning in November and ending in March. Seedlings of a few sources were also sampled in October, to test the belief that lifting for overwinter cold storage before root growth had ceased in the nursery would result in planting stock that had zero growth capacity and no survival potential at spring planting time.

Intervals of 1 month between lifts were sufficient to reveal changes in seedling growth capacity and to provide the time needed for growth capacity tests. Actual calendar dates for sampling and testing were mapped out in October, to skirt weekends and holidays and schedule the work needed to end the preceding test, lift the next set of seedlings, and install the new test. Each sampling schedule included a series of short time cushions to allow for the anticipated, unavoidable delays caused by inclement weather or wet soil conditions.

Sampling plots in the nursery were flagged in October. All sampling was done in beds containing average and larger seedlings at stockings of 25 to 35 stems per square foot (270 to 380 stems per m²). Seed source plots measured 10 ft (3 m) long, were mapped by field (block), section, bed, and distance in from the ends of the bed, and were recorded in the study plan and sampling schedule. The source

plot areas were staked with colored plastic flags to mark them for the sampling crew and prevent accidental lifting by the harvest crew. Locations where sampling plots would unduly interfere with harvest operations were avoided.

About 200 seedlings were sampled for each seed source and lifting date, or for each combination of source, date, and cultural treatment. Seedlings were dug with round-point shovels with sharpened blades that measured 5 inches (13 cm) wide and 12 inches (30 cm) long. Monthly sampling spanned the width of the bed and proceeded in sequence from one end of the plot. This strategy sampled all eight rows and standardized cutting of the lateral roots of residual seedlings. Machine lifting causes less root damage and is much easier, but is too costly and wasteful an option for the periodic taking of small samples.

Lifted seedlings were labeled with plastic tags to show seed source and cultural treatment, wrapped in wet burlap in plastic totes or polyethylene bags, and brought to the greenhouse. Following standard practice for 2-0 planting stock, seedlings were graded to a stem diameter of 4 mm (0.16 in), root-pruned 25 cm (10 in) below the cotyledon node, and culled for damage, deformity, or excessive size. Graded seedlings were randomly sorted into 16 sets of 10 each, and each set was labeled to show seed source, lifting date, and treatment.

Seedlings of three randomly drawn sets were tested for top and root growth capacity (TGC, RGC) just after lifting ($n = 30$). The remaining 13 sets were held in cold storage until spring planting time, when three more sets were drawn and used to test seedling TGC and RGC ($n = 30$) and 10 sets were used to test field performance ($n = 100$).

Stored seedlings were sealed in new polyethylene bags or double-walled, polyethylene-lined paper packing bags and maintained in coolers that were operated to hold seedling temperatures at 0-1° C (32-34° F), not to exceed 1.5° C (35° F) in the bag. The seedling tops were dipped in a suspension of captan fungicide (0.4 percent) to prevent molds, and the roots were packed in moist shingle tow to absorb any free water in the bag.

Growth Capacity Tests

Seedling top and root growth capacities (TGC, RGC) were determined by planting seedlings in a controlled-environment greenhouse and measuring their new shoots and roots after 28 days (*fig. 9*). Groups of five to seven seed sources were tested concurrently just after lifting. Groups of two to three sources that had been sampled on the same lifting dates were tested together after cold storage, at spring planting time. Series of tests were started at weekly intervals in order to have enough time to install each new test and evaluate that just completed. Three sets of 10 seedlings each were tested for each combination of seed source, lifting date, and cultural treatment ($n = 30$).

Each seedling set was planted in a stainless steel container, or tray. Each tray was 7.5 by 37.5 by 30 cm (3 by 15 by 12 in) deep, and held 8 liters (2 gal) of a moist soil mix of shredded redwood, perlite, river sand, and Humboldt Nursery's Arcata sandy loam (1:1:1:1). After planting, trays were irrigated until water flowed freely from the drain ports, drained overnight, weighed to the nearest 0.1 kg (0.25 lb), and sealed with rubber stoppers.

The watertight trays were immersed to within 1 cm (0.4 in) of their rims in stainless steel water baths. The trays were randomized to place seedlings of each seed source in three separate baths. The baths, arranged in rows of four each, held six trays apiece and were individually controlled to maintain the soil and seedling roots at temperatures of $20^{\circ} \pm 0.5^{\circ} \text{C}$ ($68^{\circ} \pm 1^{\circ} \text{F}$). Water was circulated constantly through an external tube-bundle heat exchanger, to extract the excess heat generated by a submersible water pump positioned on the bath floor.

Greenhouse air was circulated by a ducted fan, and was warmed or cooled as needed to hold air temperatures above 17°C (63°F) at night and below 25°C (78°F) in sunlight. Photoperiod was extended to 16 hours. Self-ballasted mercury-phosphor lights, centered 1 m (3.28 ft) above the baths, were set to operate from 6 to 8 A.M. and 4 to 10 P.M., and produced 30 W/m^2 at seedling level. In October and in March-June, a polypropylene screen (53

percent shade) was installed over the greenhouse to reduce incident sunlight and permit effective air conditioning.

Water lost by transpiration and evaporation was replaced weekly. Trays were removed from the baths, unstoppered to permit even percolation, placed on a scale, watered to the initial recorded weights, stoppered, and returned to the baths. Bath water levels and thermistor readings were checked morning and evening to insure uniform soil-root temperatures.

After 28 days, the trays were removed from the baths, unstoppered, flooded from below in a tank of water, and gently emptied onto a sloped drain table. Seedlings were washed free of soil by using the dispersing stream of a waterbreak, wrapped in wet paper towels, stored in polyethylene bags at 1°C (34°F), and measured within 3 days in order to avoid browning of the new roots. New root elongation is white and is easily seen and measured (Stone and Schubert 1959a, Stone and others 1962).

Seedling top and root growth capacities (TGC, RGC) were expressed as follows:

TGC

- Budburst, the percent of seedlings with new shoots extended $>2.5 \text{ mm}$
- Shoot extension, the length of the longest new shoot $>1 \text{ cm}$, per seedling

RGC

- Root elongation, the new length of roots elongated $\geq 1.5 \text{ cm}$, per seedling
- Roots elongated, including the number $\geq 1.5 \text{ cm}$ and the number $>2 \text{ mm}$ but $<1.5 \text{ cm}$, per seedling

New root length is a direct measure of a planted seedling's ability to reach available soil water, and is the preferred measure of RGC. Counting the longer new roots is a satisfactory alternative, however, and is less tedious and faster than evaluating length. Tallying new roots in both the long and short categories estimates the number of active root tips, and is a useful way to measure RGC when root elongation is especially slow.

TESTING SEEDLING TOP AND ROOT GROWTH CAPACITY

A Overview of test environment



B Plant seedlings in watertight trays



C Irrigate seedlings, drain overnight



D Hold trays in water baths 28 days



Figure 9—Procedure for testing seedling top and root growth capacities (TGC, RGC) at Humboldt Nursery. Test seedlings were held in a standard controlled environment and evaluated for budburst or shoot extension and new root elongation after 28 days.

The tests were run under a 16-hour photoperiod in an airconditioned greenhouse (A). The seedlings were planted in a moist soil mix in watertight trays (B, C). The trays were irrigated, drained overnight, sealed with rubber stoppers, and immersed to the rims in constant-temperature water baths (C, D). The bath thermostats were set to maintain the seedling roots at 20° C (68° F).

To lift seedlings for evaluation, stoppers were removed and the trays were flooded from below in a plastic tote filled with water (E). The soil mass was eased onto a sloped drain table, and the roots were washed clean with the dispersing stream of a waterbreak (F).

E Flood trays from below



F Wash soil from roots



Field Performance Tests

Survival and growth of outplanted seedlings were determined on cleared planting sites in the seed zones of origin. Ten sets of 10 seedlings each were tested for each combination of seed source, lifting date, and cultural treatment ($n = 100$).

Outplanting arrangements were made well in advance of spring planting. The program manager (J. Nelson) lined up field test cooperators in autumn, as soon as seed lots were screened and selected in the nursery beds. Copies of the completed study plan were mailed soon thereafter. Cooperators were asked to install their tests in the planting units that had been prepared for the stock ordered. By this means, tests were installed on an array of planting sites that covered the spectrum of climatic and edaphic conditions found in clearcuts and after wildfire on the Pacific Slope (see Appendix D Planting Site Descriptions).

Graded seedlings for each field test, labeled in 10 replications of 10 per lifting date and cultural treatment, were held in cold storage at Humboldt Nursery. When cooperators were ready to install their tests, the appropriate seedlings were packed in an insulated ice chest and delivered by the program manager. This procedure allowed him to inspect the clients' cold storage facilities, answer cooperators' last-minute questions about purposes, installation, and maintenance of tests, and guarantee the proper handling of test seedlings right up to planting time. Additional copies of the study plan, planting design, and report form to be used were delivered with the seedlings.

Most cooperators installed their field tests after their own planting programs were completed for the year. This practical approach prolonged seedling cold storage and enhanced the credibility of test results. Almost every test was planted within the site planting window, that is, after soil was daily warming above 5°C (41°F) at a depth of 8 cm (3 in) and before the last spring rain (Jenkinson 1980).

The test layout consisted of 10 replications of a randomized complete block of lifting date plots. Where the lifting date plots were simple in design, each plot contained a single row of 10 seedlings. Where they were split for cultural treatment, each of the treatment plots contained a single row of 10 seedlings. Test blocks were oriented so that the plot rows ran up the prevailing slope. The blocks were clustered or separated as needed to avoid rock outcrops, tree stumps, and logging slash.

Planting holes were supposed to be made with a powered soil auger, and seedlings were to be spaced 2 ft (0.6 m) apart. Most cooperators, however, used the traditional planting hoes, that is, hoedags or

used shovels (Greaves and Hermann 1978). A few cooperators opted to use a spacing of 3 ft (0.9 m) or 4 ft (1.2 m), but wider spacings were discouraged because they greatly increase the work needed to install, maintain, and evaluate tests.

Every study plan contained a planting design and a standard report form for the specific test layout. Two types of forms were devised, one for tests using a simple plot design and the other for those using a split-plot design. The forms were used to map seedlings in each plot and block, and to monitor site conditions, score seedling vigor, top activity, and damage, and record survival and growth (see Appendix E, Field Test Data Forms).

First-year survival was recorded in autumn. In most tests, survival was recorded monthly through the first summer, and in some it was recorded again in the following spring. During the monthly checks, live seedlings were individually scored for budburst, shoot extension, and general appearance, and for any damage caused by deer, elk, mountain beaver, gophers, rabbits, or cattle. Invading vegetation was noted as it developed, and was removed at the discretion of cooperators.

Seedlings were measured for height, leader length, and basal stem diameter in autumn of the second year. If a seedling was missing its leader, the length of its longest new shoot was measured instead. Because they wanted additional information, dedicated cooperators measured a few tests the first year and a host of tests for 3, 4, and more years.

All tests were supposed to be protected against plant competition and animal damage (Greaves and others 1978). In reality, protection ranged from prompt and highly effective to none. Browsing mammals destroyed some tests outright, ate the new leaders and laterals in many others, and repeatedly proved the high cost of inattention to seedling protection. Such losses did not cripple the testing program, but did create annoying gaps in our data base. The level of protection depended largely on the Ranger District or Resource Area, that is, on local practices for new plantations and the workloads and resources of individual cooperators.

All new tests were reviewed on the ground in autumn. Reviews in later years included most of the second-year tests and many highly successful older tests. The program manager arranged these trips to photograph the planting sites, test blocks, and typical surviving seedlings, and was accompanied by the Pacific Southwest Region's reforestation specialist (M. Knight) and the Pacific Southwest Station's cooperating plant physiologist (J. Jenkinson). Local cooperators always joined in, and usually included the forest silviculturist and other timber staff. The reviews were informal, and time spent on any one

site was short, but the perspectives and slide files gained proved invaluable for interpreting results, judging implications, and reporting findings. Perhaps as important, these reviews quickly became open forums for candid exchanges on all aspects of reforestation. They stimulated great interest in the testing program, developed strong support for it, and sustained the morale and efforts of people on the ground and in the nursery.

Variance Analyses

Variance analyses were run to assess seed source and lifting date effects on seedling top and root growth capacities (TGC, RGC) just after lifting and after cold storage, and to assess lifting date effects on survival and growth on cleared planting sites in the seed zones of origin.

Seedling TGC and RGC—Analyses of TGC and RGC just after lifting were run on groups of seed sources that were sampled on the same set of lifting dates. Seed source and lifting date effects were assessed using variance analysis program BMD P8V, with sources and dates fixed and replications random (Jennrich and Sampson 1985).

Because the field tests of stored seedlings were installed on dates ranging from March 10 to June 19, the analyses of TGC and RGC after cold storage were run on each seed source separately. The combined effects of lifting date and cold storage were assessed using variance analysis program BMD P2V, with dates fixed and replications random (Jennrich and others 1985).

Least significant differences (LSD, $p = 0.05$) between lifts were calculated by $LSD = q[ems/r]^{1/2}$, where ems is error mean square from program P2V run on individual seedling data for the seed source. In tests of five lifts of 30 seedlings each, for example, $r = 30$ and $q = 2.81$ for 116 degrees of freedom (Steel and Torrie 1960).

Field survival and growth—Analyses of survival and growth in field tests, like those of TGC and RGC after cold storage, were run for each seed source separately. Survival was analyzed using the number of live seedlings remaining in each plot. Growth traits, that is, height, leader length, and basal stem diameter, were analyzed using the mean of survivors in each plot. Lifting date and cultural treatment effects were assessed using variance analysis program BMD P8V, with dates and treatments fixed and blocks random (Jennrich and Sampson 1985).

Least significant differences (LSD, $p = 0.05$) between lifts were calculated by $LSD = q[ems/r]^{1/2}$, where ems is error mean square from program P8V. In tests of five lifts and 10 blocks, for example, $r = 10$ and $q = 2.87$ for 36 degrees of freedom (Steel and Torrie 1960).

Correlation Analyses

Correlation analyses were used to survey the effects of seedling cold storage on TGC and RGC, to evaluate the relation of first-year survival to RGC after cold storage, at spring planting time, and to estimate critical RGC for the planting site.

Surveying cold storage effects—Coefficients of determination, r^2 , were calculated for $Y = a + bX$, where Y is TGC or RGC after cold storage and X is TGC or RGC just after lifting. Seedling TGC is expressed as budburst, percent, and RGC, as new root length, cm ($n = 30$ seedlings per lift). Low values of r^2 indicate large changes in TGC and RGC during cold storage, and warn that survival should be related to TGC and RGC at spring planting time, after cold storage and not just after lifting.

Relating field survival to RGC—Coefficients of multiple determination, R^2 , were calculated for $Z = b \ln(Y + 1) + c[\ln(Y + 1)]^2$, where Z is first-year survival, percent ($n = 100$ seedlings per lift), and Y is RGC after cold storage, at spring planting time. Seedling RGC is expressed as new root length, cm, or number of roots elongated ($n = 30$ seedlings per lift). This equation reflects the fact that zero RGCs in greenhouse tests invariably signal near-zero survivals in field tests.

Estimating critical RGC for the site—Coefficients of determination, r^2 , were calculated for $Z = bY_1$, where Z is first-year survival, percent ($n = 100$ seedlings per lift), and Y, is the percent of seedlings ($n = 30$ per lift) having RGC greater than some minimum level after cold storage, at spring planting time. Critical RGC is estimated as the minimum new root length, cm, or number of roots elongated, that generates values of r^2 and line slope, b, closest to 1.00. The array of RGC values tried will normally include $\geq 5, 10, 20, \dots 100$ for both root length and roots elongated.

ASSESSING NURSERY CULTURE ALTERNATIVES

Seedling cultural practices in Humboldt Nursery came under continual review once the testing program was underway. Cooperators and our own observations forced us to consider a host of new and proposed practices before our efforts to evaluate seed source lifting windows for Douglas-fir and Shasta red fir were even 2 years old. As time and chance allowed, practices deemed worth testing were investigated in nursery and field studies of Douglas-fir from coastal and inland regions of western Oregon and northern California (*table 15*). Effects of the practices on planting stock quality were evaluated by the program's standard tests of growth capacity and field performance.

Extended seed chilling, sowing of fully chilled seeds in winter to early spring, heavy fertilization of newly emerged seedlings, spring undercutting of holdover 1-0 seedlings, and extended precooler storage of newly lifted seedlings proved to be highly advantageous practices, and were operationally adopted. Mycorrhizal inoculation of seedbeds just before spring sowing, root wrenching of seedlings in their second summer, and immediate freeze storage of graded seedlings had been proposed as possibly beneficial, but testing proved otherwise. Planting seedlings in fall and winter, a risky practice that foresters persistently try, proved highly successful on coastal sites in northwest California and southwest Oregon.

Efforts to assess nursery culture alternatives at Humboldt led to successful cultural regimes for 1-0 and 1-1 Douglas-fir, and to vastly improved regimes for plug-1 and 2-0 planting stock (see the next chapter, Moving into the '90's).

GROWING SEEDLINGS FOR 1-0 PLANTING STOCK

Humboldt first produced 1-0 planting stock in 1978, when Shasta-Trinity National Forest asked for help with several large lots of seeds that had been stratified for a container-seedling contract. These seeds, which already had 3 months of moist chilling, were surface-dried (Danielson and Tanaka 1978), held another month at 1° C (34° F), and sown in March, the earliest that Humboldt could shape the necessary seedbeds. The outcome was spectacular. Both the 1-0 Douglas-fir and Jeffrey pine that were produced were triple the size of first-year seedlings in the traditional May sowings.

The initial test of 1-0 Douglas-fir stemmed from this fortuitous sowing. In the following spring, 1-0 and 2-0 seedlings of seed source HA 312.25 were planted on a cleared site in the southern Klamath Mountains (*table 16*). The first-year survivals forever changed our perception of what works. The seed source lifting window was 4 months wide for either stock type and the 1-0 stock survived as well as the 2-0, averaging 90 against 94 percent within the window. On the down side, browsing deer severely damaged the 1-0 stock and warned of its greater need for protection (see Seed Source Assessments—Douglas-fir, *tables 3, 8*).

Subsequent testing proved that 1-0 Douglas-fir is an attractive option for reforestation in the Pacific Slope regions of Oregon and northern California. Advantages to foresters include shorter lead times and greater flexibility for stand regeneration after harvest or wildfire. Advantages to the nursery include more frequent opportunities to fallow, deep-rip, and chisel-plow the bed areas, to improve and maintain soil aeration and drainage. Furthermore, 1-0 seedlings cost less to grow, lift, grade, pack, store, ship, and plant. They take less water, fertilizer, weeding, and inventory effort, and unlike 2-0 seedlings, require neither undercutting nor vertical pruning in the nursery beds. They can be lifted and separated with less root damage, and root pruning after grading removes less of the root system. Up to five times more 1-0 than 2-0 can be packed in the

Table 15—*Cultural practices assessed for Douglas-fir in Humboldt Nursery, sowings and seed sources used, and lists of the tables and figures showing results obtained*

Cultural practice, nursery sowing, and seed source ¹			Tables	Figures	Cultural practice, nursery sowing, and seed source ¹			Tables	Figures
Seed chilling for March sowings					Carrying 1–0 for 2–0 stock				
1979	Oregon Coast Range, N				1985	N Coast Range, coastal			
	AL 252.15		17-18	30-31		GQ 091.25 86		32, 34	35-38
	Oregon Cascades, W					Klamath Mtns, central			
	MK 472.30		17-18	30-31		SA 311.40 86		32, 34	35-38
	N Coast Range, coastal				1987	N Coast Range, coastal			
	KI 390.20		17-18	30-31		GQ 091.25 88		33-35	38
	Klamath Mtns, E					Klamath Mtns, central			
	OK 321.30		17-18	30-31		SA 311.40 88		33-35	38
March sowings for 1–0 stock						Oregon Coast Range, N			
1978	Klamath Mtns, S					HE 053.10 88		33-35	38
	HA 312.25 79w		16	—		Oregon Cascades, W			
1979	Oregon Coast Range, N					MK 472.45 88		33-35	38
	AL 252.15 80w		19, 21-22	32-33	Undercutting for 2–0 stock				
	Oregon Cascades, W				1978	Klamath Mtns, S			
	MK 472.30 80w		19, 21-22	32-33		HA 312.50 80w		35, 41	—
	N Coast Range, coastal					HA 312.25 80w		35-37, 41	—
	KI 390.20 80w		19, 21-22	32-34	1979	Oregon Coast Range, N			
	Klamath Mtns, E					AL 252.10 81w		35, 38-42	—
	OK 321.30 80w		19, 21-22	32-33		Oregon Cascades, W			
April sowings for 1–0 stock						OA 482.30 81w		35, 38-42	—
1982	Oregon Coast Range, N					N Coast Range, coastal			
	HE 053.20 83w		20	—		GQ 091.20 81w		35, 38-42	—
	WA 061.20 83w		20	—		Klamath Mtns, E			
	AL 061.20 83w		20	—		OK 321.30 81w		35, 38-42	—
Topdressing early sowings					Mycorrhizal inoculation				
1983	Oregon Coast Range, S				1976	Klamath Mtns, N			
	CO 072.10 84w		23-25	—		IL 512.35 78w		43-45	—
	Klamath Mtns, N				1977	Oregon Coast Range, N			
	RO 270.20 84w		23-25	—		MA 062.10 79w		43-45	—
	N Coast Range, coastal				Root wrenching				
	KI 390.20 84w		23-24	—	1977	Oregon Coast Range, S			
Sowing windows for 1–0 stock						GO 081.20 79w		43-45	—
1985,	N Coast Range, coastal					Klamath Mtns, N			
1986	GQ 091.25 86		27-32, 34	35-38		IL 512.40 79w		43-45	—
	Klamath Mtns, central				Freeze storage				
	SA 311.40 86		27-32, 34	35-38	1981	Oregon Coast Range, N			
1987	N Coast Range, coastal					MA 062.10 83		46-49	—
	GQ 091.25 88		27-28,	38		Klamath Mtns, E			
	Klamath Mtns, central		30-31,			OK 321.40 83		46-49	—
	SA 311.40 88		33-34	38	Precooler storage				
	Oregon Coast Range, N				1983	Klamath Mtns, W			
	HE 053.10 88		27-28,	38		GQ 301.15 85		50	—
	Oregon Cascades, W		30-31,			Klamath Mtns, S			
	MK 472.45 88		33-34	38		HA 312.40 85		50	—
					Planting in October to March				
					1975,	Klamath Mtns, W			
					1976	GQ 301.30 77w, 78w		51	—
					1977	Oregon Coast Range, S			
						CH 082.25 79w		51-52	—

¹ See fig. 10, and Seed Source Assessments—Douglas-fir, table 3. The letter w indicates that the seed source lifting window was determined.

standard packing bag, multiplying the capacity of premium cold storage. Finally, planting is faster and easier, and proper root placement is more readily achieved with 1-0 than 2-0 stock, particularly in holes made with the ubiquitous planting hoe. On many sites, the use of 1-0 stock may enhance plantation establishment.

Biological justifications for producing 1-0 stock rest on a knowledge of the physiological ecology of conifer seeds and seedlings. In the wild, seeds of most conifers are shed in autumn, undergo moist overwinter chilling, and germinate in late winter-early spring, when conditions are cool and wet. Research on Douglas-fir, sugar pine, ponderosa pine, lodgepole pine, loblolly pine (*Pinus taeda* L.), Engelmann spruce (*Picea engelmannii* [Parry] Engelm.), and true firs (*Abies* species) has shown that extended seed chilling speeds germination, seedling emergence, and early growth in cool conditions (Adkins and others 1984, Allen 1960, Danielson and Tanaka 1978, Dunlap and Barnett 1982, Edwards 1982, Jenkinson and others 1982, McLemore 1969, Sorensen 1978, Tanaka and others 1986). Equally important, newly emerged seedlings appear to build resistance to pathogens while soils are still cool enough to inhibit damping-off and Fusarium disease (Bloomberg 1973, Filer and Peterson 1975, Jenkinson and others 1982, Johnson and others

1989, Smith 1975), yet warm enough to support root growth and promote mycorrhizae formation (Brown and Sinclair 1981, Parke and others 1983, Sinclair 1974, Sinclair and others 1982, Sylvia 1983).

Nursery and field experience with widespread pines in northern California encouraged our work on Douglas-fir. May sowings in the Institute of Forest Genetics nursery in the western Sierra Nevada consistently produced successful 1-0 ponderosa pine and Jeffrey pine (Jenkinson 1980), but not sugar pine. February-March sowings invariably produced large 1-0 sugar pine, whereas May sowings were susceptible to Fusarium disease and mostly yielded 1-0 seedlings that were too small to outplant (Jenkinson and others 1982). In Placerville Nursery, April sowing trials produced successful 1-0 sugar pine for the North Coast Range and Sierra Nevada (USDA Forest Service 1982). Like Humboldt, these nurseries are usually free of snow and hard freezes in winter-spring, but receive abundant rain with an average 42 inches (107 cm) and a record high of 68 inches (173 cm).

Before its surprise event with 1-0 Douglas-fir, Humboldt produced only 2-0 seedlings, sowing everything in May-June to avoid the rainy season (see *fig. 6*). The high survival of 1-0 seedlings from the first March sowing (*table 16*) triggered a series of field performance tests in the Oregon Coast Range

Table 16—Survival and growth in a field performance test to compare 1-0 and 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date) and planting stock type	Performance, by nursery lifting date ³					LSD ⁴
	Nov 20	Dec 18	Jan 15	Feb 12	Mar 12	
Klamath Mtns, S						
HA 312.25 79 (Apr 2)						
1-0 stock						
1-yr survival, <i>pct</i>	64	87	93	85	94	9.3
2-yr survival, <i>pct</i>	62	85	89	81	87	13.8
height, <i>cm</i>	14.5	15.4	15.7	14.3	15.5	2.33
diam, <i>mm</i>	4.9	5.6	5.6	5.5	5.4	.71
2-0 stock						
1-yr survival, <i>pct</i>	73	96	93	94	95	10.0
2-yr survival, <i>pct</i>	69	94	90	93	91	13.8
height, <i>cm</i>	28.2	28.7	31.5	30.8	30.5	2.33
diam, <i>mm</i>	8.0	8.8	8.8	8.9	9.1	.71

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ The 1-0 stock averaged 20 cm tall and the 2-0 stock, 30 cm. Deer browsed both stock types and reduced height of the 1-0 stock by 5 cm.

⁴ Least significant difference ($p = 0.05$).

and Cascades, the Klamath Mountains, the North Coast Range, and the California Cascades. By 1985, 1-0 seedlings of 11 different sources had been tested on cleared planting sites in the seed zones of origin. Survival and growth were superior. Within the source lifting windows, first-year survival averaged 81 to 99 percent, and protected seedlings doubled in height annually (Jenkinson 1984, Jenkinson and Nelson 1983, 1985; Turpin and others 1985).

By sowing early, most Pacific Slope nurseries could ship 1-0 Douglas-fir. There are reasons, of course, not to shift from the traditional sowing schedule (Owston and Stein 1974). At Humboldt, the prime deterrent was a fear of the torrential rains that might damage or destroy the seedbeds. Other concerns were that (1) soil preparation and seed treatment tasks might conflict with seedling harvest, (2) rains could obstruct any calendar for early sowing, and (3) work plans would have to be impossibly flexible to mesh lifting and sowing schedules efficiently. Those concerns were permanently put to rest. To encourage nursery acceptance of early sowing, proven ways to protect seedbeds and prevent soil erosion were built into the new cultural regimes and soil management guides. The ensuing rewards were great for both Humboldt and its clientele.

Tests of winter and spring sowings in Humboldt Nursery showed that any sowing in the period from early January to April could produce successful 1-0 Douglas-fir. Early sowings work when (1) soils are prepared to absorb heavy rains, (2) seeds have had extended chilling, and (3) seedbeds are safeguarded from rainsplash, soil puddling, and sheet erosion. With no other treatment, the 1-0 seedlings produced are big enough to outplant and are physiologically ready for winter lifting and cold storage to spring planting times.

The proven advantages of early sowings are the superior yields of uniformly large and healthy 1-0 seedlings per thousand seeds sown. The advantages are so great that Humboldt now produces 2-0 stock by holding what is essentially 1-0 stock in place for a second growing season. As explained later, judicious spring undercuts are used to control and balance the top and root growth of seedlings held in place (see Carrying 1-0 for 2-0 Planting Stock, and Undercutting Early Sowings for 2-0 Stock). Even more importantly, Humboldt now efficiently produces 1-1 stock by transplanting even the smallest of early-sow 1-0 seedlings (see the next chapter, Moving into the '90's).

Soil Preparation for Early Sowing

Soil preparation for early sowing followed the practices described earlier (see *fig. 7*). In brief, to promote subsurface drainage and aeration, summer-dry soil was deep-ripped in two directions with tines 3 ft (1 m) long and 2 ft (0.6 m) apart. Ripped soil was irrigated, cultivated, and fumigated to control weeds and soilborne pathogens. Before and after fumigation, the fields were chisel-plowed and power-harrowed to improve soil structure. To prevent plow pans, the fields were cultivated and seedbeds were shaped after soil water contents had decreased to field capacity at equipment depth.

Details of soil preparation evolved as experience was gained. Seedbeds for our first test of early sowing were shaped in March, 1979 (*table 15*). Monoammonium phosphate (NPK 11-48-0) and potassium sulfate (NPK 0-0-52) fertilizers were incorporated into the soil at rates of 200 lb and 50 lb material per acre, respectively, to supply 22 lb nitrogen (N), 96 lb phosphorus (P), and 26 lb potassium (K) per acre (100 lb per acre = 112 kg per ha). Seedbeds for our second and third tests of early sowing were shaped in early April, 1982 and 1983, and monoammonium phosphate and potassium sulfate were incorporated at rates of 350 lb and 50 lb material per acre to supply 38 lb N, 168 lb P, and 26 lb K per acre.

Seedbeds used in the 1985-87 tests to determine seed source sowing windows (*table 15*) were shaped in January, October, and November 1985-86, well in advance of sowing (see Determining Nursery Sowing Windows). Each test was installed in soil that had been amended with triple superphosphate (NPK 0-45-0) and potassium sulfate at rates of 450 lb and 200 lb material per acre, enough to supply 202 lb P and 104 lb K per acre, amounts recommended after critical technical review (USDA Forest Service 1983).

Before sowing, the target seedbeds were scarified to break any surface crust caused by winter or spring rains. Crusts formed in our 1979 test of early sowing were shattered by using garden rakes, and sowing was done with a Wind River seed drill. In later tests, crusts were shattered by using steel tines mounted under a wheeled tractor, and sowing was done with a Love-Oyjord seed drill. Seeds were sown to a depth of 0.1 inch (2 to 3 mm), in the standard eight rows and at rates to yield 30 seedlings per square foot (325 stems per m²).

Seed Treatment and Germination

The amount of seed chilling required for rapid, complete germination was determined under laboratory conditions at Humboldt Nursery. Seed sources typical of Douglas-fir forests in the coastal and inland regions of western Oregon and northern California were identified in the Pacific Northwest and Pacific Southwest Region seed bank inventories. From those, large seed lots of broad genetic base were chosen at middle elevations, specifically, source AL 252.15 in the northern Oregon Coast Range, source MK 472.30 in the western Oregon Cascades, source KI 390.20 in the coastal North Coast Range, and source OK 321.30 in the eastern Klamath Mountains.

Seeds were drawn from freeze storage, soaked 36 hours in aerated water at 22° C (72° F), and chilled 0, 20, 40, or 60 days at 1° C (34° F), times chosen to bracket Humboldt's traditional 30 days of chilling. Treated seeds were germinated concurrently in petri dishes in the laboratory at 22° C, ambient. The test layout consisted of four randomized complete blocks of split plots, with seed source split for chilling time. Each treatment plot was a petri dish that contained 100 seeds on a filter paper pad soaked with captan fungicide (0.4 percent). Tapwater was added as needed to keep the paper moist. New germinants, seeds with radicles extended 2 mm or more and showing geotropic response, were counted after 7, 14, and 21 days. Seed source and chilling period effects were assessed using variance analysis program BMD P2V (Jennrich and others 1985).

Seed source and chilling period significantly affected germination speed and amount (*table 17*). Each source germinated rapidly and completely after extended chilling, and poorly, if at all, without chilling (*fig. 30*). The 60-day chill achieved the highest rates and amounts for sources AL, MK, and

Table 17—Significance of seed source and chilling effects on germination of Douglas-fir from western Oregon and northern California¹

Source of variation	Degrees freedom	Variance (mean square) for germination (pct) after...		
		7 days	14 days	21 days
Seed source, S	3	1453.9 **	491.2 **	380.1 **
Seed chilling, T	3	19444.1 **	21978.9 **	15367.6 **
ST	9	529.8 **	433.3 **	469.4 **
Error	48	37.8	28.9	29.8

** Significant at p < 0.01.

¹ Seeds from coastal and inland sources were chilled 0, 20, 40, or 60 days at 1° C (34° F) and germinated at 22° C (72° F).

OK from the Oregon Coast Range, Oregon Cascades, and Klamath Mountains, respectively. By contrast, the 40-day chill achieved the highest rate and amount for source KI from the North Coast Range.

Seed Chilling and Seedling Emergence

California experience has consistently shown that germination at warm, constant temperatures in the laboratory does not predict seedling emergence at cool, fluctuating temperatures in the nursery. The ultimate practical measure of seed quality is seedling emergence in the bed. Accordingly, the seed sources assessed in our germination tests (*fig. 30*) were used to evaluate effects of extended seed chilling on rate and amount of seedling emergence in Humboldt Nursery.

Seedling emergence was evaluated in cool and warm soil conditions by sowing treated seeds in early spring and late spring. Seeds were soaked 40 hours in aerated water at 22° C (72° F), placed in unsealed polyethylene bags at 1° C (34° F), and chilled either 90 days or the traditional 30 days. Seeds of both treatments were sown March 14 and May 15, 1979. The test layout consisted of five randomized complete blocks of split plots, with March and May sowings assigned to adjacent seedbeds. Seed source plots were split across the beds for chilling period and between the beds for sowing date. The test extended the width of the field, with blocks 80 ft (24 m) long, source plots 20 ft (6 m), and treatment plots 10 ft (3 m). Impact sprinklers were used as needed to keep the bed surface moist until emergence was complete.

To track emergence, four sampling plots, each 1 ft (0.3 m) long and marked with parallin stakes, were randomly located in seed rows two to seven in the middle 5 ft (1.5 m) of each treatment plot. New germinants were counted when their hypocotyl crooks were clearly visible at the bed surface, and counts were made every other day until emergence slowed. Seed source and chilling effects were assessed for the March and May sowings separately, using variance analysis program BMD P8V and a split plot design with effects fixed and blocks random (Jennrich and Sampson 1985).

Seed source and chilling time significantly affected the rate and amount of seedling emergence, and did so in both the March and May sowings (*table 18*). Compared to the traditional 30-day chill, the 90-day chill resulted in greater amounts of emergence in cold soil, the March sowings, and faster rates of emergence in warm soil, the May sowings.

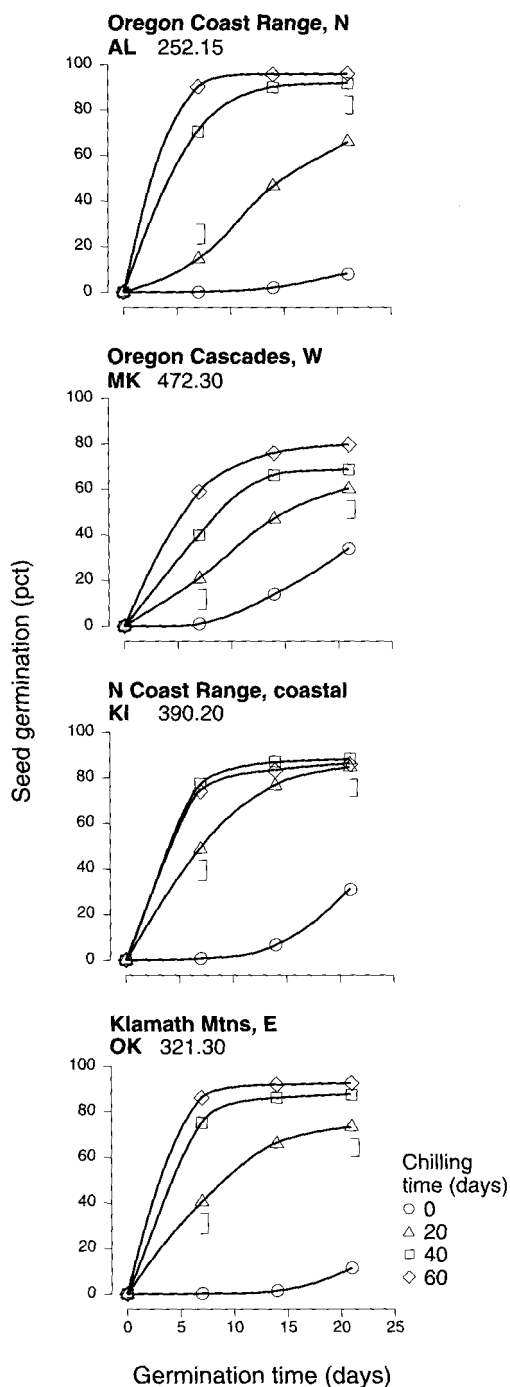


Figure 30—Seed source and seed chilling effects on germination of Douglas-fir in a laboratory. Seeds from coastal and inland sources in western Oregon and northern California were soaked in aerated water at 20° C (68° F), chilled at 1° C (34° F), and germinated at 22° C (72° F), mean ambient. The graphs show that germination is most rapid and complete after extended seed chilling. Brackets indicate least significant difference ($p = 0.05$).

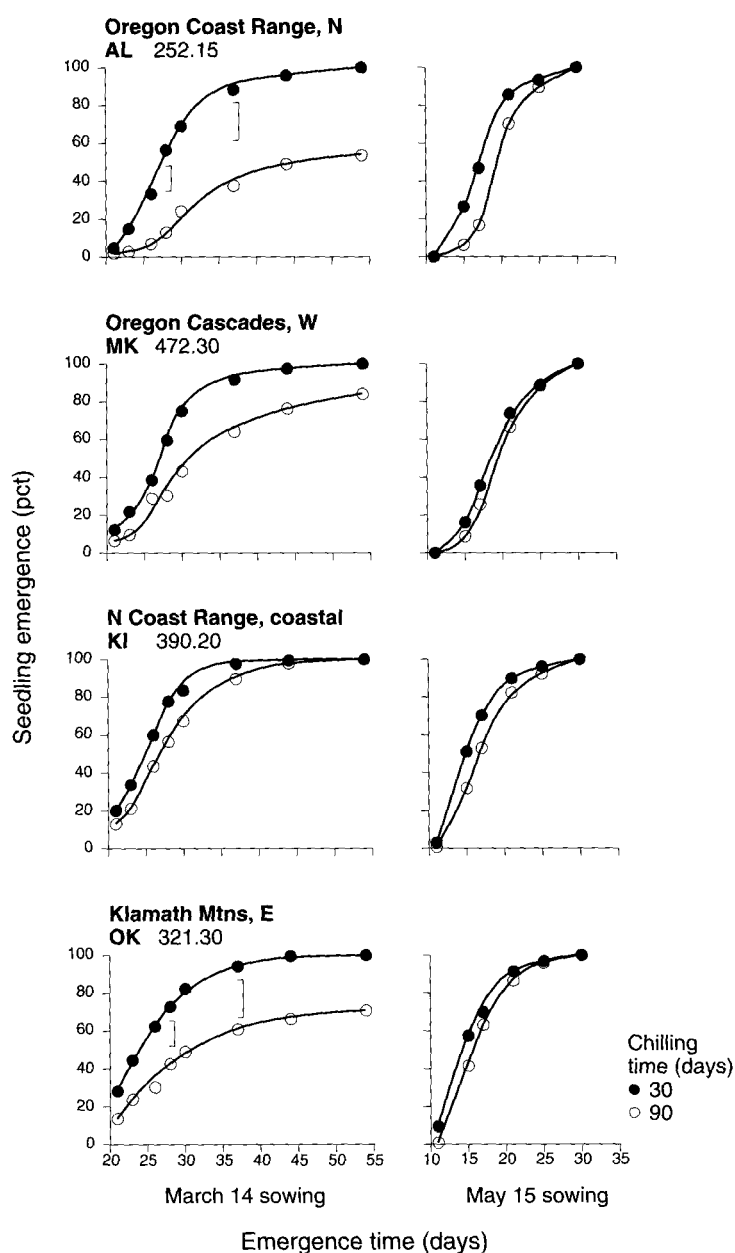


Figure 31—Seed source, chilling, and sowing date effects on emergence of Douglas-fir in Humboldt Nursery. Seeds from coastal and inland sources in western Oregon and northern California were soaked in aerated water at 20° C (68° F), chilled 90 days or the traditional 30 days at 1° C (34° F), and sown on March 14 and May 15. The graphs show that extended seed chilling permits rapid and complete emergence in early-spring sowings, when the soil is cool, and increases rate of emergence in late-spring sowings, when the soil is warm. Brackets indicate least significant difference ($p = 0.05$).

In March, when the soil was cold, emergence began 15 days after sowing, continued 40 days, and was much faster and greater for the 90-day chill than for the 30-day chill (*fig. 31*). After 28 days, total emergence of sources AL, MK, OK, and KI from the Oregon Coast Range, Oregon Cascades, Klamath Mountains, and North Coast Range, respectively, was 4.3, 2.0, 1.7, and 1.4 times greater for the 90-day chill. Compared to the 30-day chill, extended seed chilling increased total emergence of sources AL, MK, and OK by 46, 16, and 29 percent, but did not increase that of source KI.

In May, when the soil was warm, emergence began 10 days after sowing, continued 20 days, and again was faster for the 90-day chill. After 14 days, cumulative emergence of sources AL, MK, OK, and KI was 4.2, 1.8, 1.4, and 1.6 times greater for the 90-day chill than for the 30-day one. Extended seed chilling did not increase total emergence in warm soil, however, as it did in cold soil.

Superior emergence in the March sowings and other work cited earlier show that the full benefits of early sowing are achieved by seed treatments that substitute for overwintering in the wild. Douglas-fir from the Pacific Slope forests in Oregon and northern California emerges most rapidly and completely after extended seed chilling. Even source KI from the North Coast Range, which emerged completely with the 30-day chill, emerged faster with the 90-day chill.

Sowing fully chilled seeds early in Humboldt Nursery captures valuable weeks and months at the front end of the growing season, even though cold weather prevails and slows seedling emergence.

Cool soil conditions stretched emergence of the March sowings through April, whereas warm soil conditions enabled the May sowings to emerge completely by mid-June. Before seedlings in the May sowings were up, however, those in the March sowings had been elongating roots and expanding shoots for more than 6 weeks.

The lesson is clear. To obtain rapid and complete emergence in early sowings, seeds should be soaked in aerated warm water, drained until free of surface water, and chilled in polybags at 1° C (34° F) for at least 60 and preferably 90 days (see the next chapter, Moving into the '90's, *fig. 41*).

EVALUATING SIZE AND PERFORMANCE OF 1-0 STOCK

The first test of early sowing was designed to assess seed source and sowing date effects on the size of 1-0 Douglas-fir, and to supply the 1-0 stock needed for field performance tests. To enhance seedling growth, the beds were deep-irrigated twice weekly in summer-autumn, frequently enough to keep predawn xylem water potentials above -5 bars, or 0.5 mP (Zaerr and others 1981).

Field performances of 1-0 seedlings were evaluated for March sowings only (*table 19*), as most of the first-year seedlings in May sowings were too small to outplant. Results were generally excellent, particularly in the Oregon Coast Range, and cooperators on the Siuslaw National Forest promptly

Table 18—Significance of seed source and chilling effects on emergence of Douglas-fir in March and May sowings in Humboldt Nursery¹

Source of variation ²	Variance (mean square) for emergence (<i>pct</i>) in...					
	March 14 sowing, by			May 15 sowing, by		
	Apr 11	Apr 20	Apr 27	May 30	Jun 5	Jun 12
Seed source, S	250.8 **	142.5	102.3	1391.6 **	1867.8 **	1729.3 **
Seed chilling, T	1452.0 **	1404.2 *	113.0 *	1322.5 **	1081.6 **	483.0 *
Block, B	68.6	28.9	34.6	101.1	297.5	182.9
ST	58.1	156.2 *	158.3 *	118.5	126.5	230.6
BS	39.3	82.5	76.3	41.5	107.6	104.9
BT	54.7	124.9 *	138.2 *	29.6	9.0	39.2
BST	29.1	37.8	40.8	55.6	120.3	210.1

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seeds from coastal and inland sources in western Oregon and northern California were chilled 30 or 90 days at 1° C (34° F).

² Degrees freedom were 3, 1, 4, 3, 12, 4, and 12 for S, T, B, ST, BS, BT, and BST, respectively.

Table 19—Survival and growth in field performance tests of 1-0 Douglas-fir from March sowings in Humboldt Nursery¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov 26	Dec 26	Jan 21	Feb 19	Mar 17	
Oregon Coast Range, N						
AL 252.15 80 (Mar 31)						
1-yr survival, <i>pct</i>	72	99	99	99	99	9.8
height, <i>cm</i>	21.8	24.6	24.8	26.1	24.4	2.66
leader, <i>cm</i>	8.9	10.9	11.5	11.5	10.8	1.73
diam, <i>mm</i>	3.2	3.5	3.4	3.5	3.5	.22
2-yr survival, <i>pct</i>	69	92	98	97	96	11.2
height, <i>cm</i>	46.0	53.6	51.7	56.8	56.8	5.61
leader, <i>cm</i>	25.0	30.3	29.4	31.9	34.1	3.99
diam, <i>mm</i>	6.0	7.0	6.8	7.1	7.0	.83
3-yr survival, <i>pct</i>	67	92	95	97	96	11.7
height, <i>cm</i>	74.4	83.4	82.3	83.2	87.1	8.67
leader, <i>cm</i>	29.1	31.2	30.7	28.4	30.8	4.26
diam, <i>mm</i>	10.9	12.5	12.4	12.4	12.9	1.56
Oregon Cascades, W						
MK 472.30 80 (May 19)						
1-yr survival, <i>pct</i>	48	88	86	88	88	14.9
height, <i>cm</i>	18.6	23.3	21.5	24.2	23.9	1.69
diam, <i>mm</i>	4.5	5.0	5.2	5.1	5.5	.40
2-yr survival, <i>pct</i>	45	85	82	84	82	16.4
height, <i>cm</i>	22.2	28.5	26.5	29.1	29.8	3.43
leader, <i>cm</i>	7.8	9.4	8.9	9.0	9.9	1.52
diam, <i>mm</i>	5.7	6.7	6.4	6.7	7.0	.51
N Coast Range, coastal						
KI 390.20 80 (Apr 11)						
1-yr survival, <i>pct</i>	4	81	93	94	94	9.5
height, <i>cm</i>	—	25.0	24.9	25.3	24.7	.78
leader, <i>cm</i>	—	5.8	6.6	6.5	6.2	.33
2-yr survival, <i>pct</i>	4	68	74	77	80	17.6
height, <i>cm</i>	—	36.2	35.4	39.5	37.3	4.48
leader, <i>cm</i>	—	12.7	12.1	14.3	13.5	3.24
diam, <i>mm</i>	—	7.5	7.4	8.7	8.9	.88
3-yr survival, <i>pct</i>	4	67	74	77	80	17.4
height, <i>cm</i>	—	50.6	51.4	58.2	55.8	8.07
leader, <i>cm</i>	—	16.4	17.9	20.3	20.3	3.90
diam, <i>mm</i>	—	10.7	10.6	10.9	11.4	1.11
6-yr survival, <i>pct</i>	4	67	74	76	80	17.2
height, <i>cm</i>	—	129.4	130.3	142.9	142.5	19.2
leader, <i>cm</i>	—	27.3	27.0	28.7	30.3	5.05
diam, <i>mm</i>	—	20.0	20.3	22.2	23.6	2.87
Klamath Mtns, E						
OK 321.30 80 (Apr 3)						
1-yr survival, <i>pct</i>	58	73	88	84	79	13.9
height, <i>cm</i>	20.8	20.8	22.2	23.2	19.2	1.76
leader, <i>cm</i>	7.0	7.2	8.0	7.9	6.3	1.05
2-yr survival, <i>pct</i>	45	61	70	72	61	15.9
height, <i>cm</i>	28.8	30.9	32.2	33.0	29.3	3.70
leader, <i>cm</i>	10.4	11.8	12.6	12.2	11.6	2.53
diam, <i>mm</i>	8.2	8.9	8.6	9.4	8.1	1.20

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ Least significant difference ($p = 0.05$).

requested tests of additional seed sources. Seedlings used in the tests to confirm the efficacy of 1-0 Douglas-fir were lifted from the first operational trial of April sowing in Humboldt Nursery (*table 20*).

Sizes of seedlings in the March and May, 1979 sowings were evaluated in December (see Seed Chilling and Seedling Emergence). Seedlings were lifted, graded to a stem diameter of 2.5 mm (0.1 in), root-pruned 23 cm (9 in) below the cotyledon nodes, washed clean in running water, and culled for damage. Ten seedlings per plot were evaluated for

top height, stem diameter 1 cm below the cotyledon node, and oven dry weights (65° C, 140° F) of the top and roots separated at the node. Seed source, chilling, and sowing date effects were assessed using variance analysis program BMD P8V and a split-split plot design with effects fixed and blocks random (Jennrich and Sampson 1985).

Sowing date significantly affected seedling height, stem diameter, and top and root weights, and seed source significantly affected height, diameter, top weight, and top-root ratio (*table 21*). Seed chilling

time had no practical effect on any size trait.

Seedling height and top weight decreased with increase in seed source latitude and distance from the Pacific Ocean (*table 22*). From south to north, seedlings of sources KI 390.20 and OK 321.30 from the North Coast Range and Klamath Mountains of California were taller and heavier than their Oregon counterparts, sources AL 252.15 and MK 472.30 from the Oregon Coast Range and Oregon Cascades. From the coast inland, seedlings of sources AL and KI from the Oregon Coast Range and North Coast Range, were taller and heavier than their inland counterparts, sources MK and OK from the Oregon Cascades and Klamath Mountains.

Seedlings from March sowings were taller, stouter, and heavier than those from May sowings (*fig. 32*). Gains of 20 to 35 percent in height were associated with gains of 30 to 45 percent in stem diameter, 65 to 110 percent in top weight, and 25 to 85 percent in root weight. Gains were proportional except for source AL from the Oregon Coast Range, in which root weight failed to keep pace with top weight.

To evaluate field performance, seedlings in the March, 1979 and April, 1982 sowings were lifted in winter, graded to a stem diameter of 2.5 mm, root-pruned 23 cm below the cotyledon node, stored at 1 ° C (34° F), and planted in spring on cleared sites in the seed zones of origin (see Assessing Planting Stock Quality, Standard Testing Procedures). First-year

Table 20—Survival and growth in field performance tests of 1-0 Douglas-fir from April sowings in Humboldt Nursery¹

Seed source ² (planting date)	Performance, by lifting date				LSD ³
	Dec 22	Jan 19	Feb 16	Mar 16	
Oregon Coast Range, N					
HE 053.20 83 (Mar 31)					
1-yr survival, <i>pct</i>	92	95	94	99	11.8
height, <i>cm</i>	20.4	23.1	24.1	22.8	2.20
diam, <i>mm</i>	2.9	3.3	3.6	3.5	.33
2-yr survival, <i>pct</i>	91	93	92	96	12.1
height, <i>cm</i>	48.3	53.8	57.0	55.1	4.62
leader, <i>cm</i>	30.3	33.2	35.7	35.4	3.96
diam, <i>mm</i>	6.1	6.9	7.2	7.1	.80
3-yr survival, <i>pct</i>	88	91	90	91	13.8
height, <i>cm</i>	73.6	77.3	83.5	78.5	7.25
leader, <i>cm</i>	28.3	27.4	29.4	27.9	4.41
diam, <i>mm</i>	9.3	10.2	10.6	10.8	1.44
WA 061.20 83 (Apr 1)					
1-yr survival, <i>pct</i>	99	99	92	98	5.2
height, <i>cm</i>	18.6	20.8	19.2	19.0	2.37
leader, <i>cm</i>	7.7	8.7	7.7	7.3	1.30
2-yr survival, <i>pct</i>	98	98	88	97	5.5
height, <i>cm</i>	41.4	40.6	40.1	41.4	5.31
leader, <i>cm</i>	20.9	19.5	20.4	21.1	4.02
AL 061.20 83 (Apr 19)					
1-yr survival, <i>pct</i>	71	98	94	95	9.4
height, <i>cm</i>	15.8	19.8	19.3	19.1	1.68
leader, <i>cm</i>	5.8	7.7	6.7	7.2	1.42
diam, <i>mm</i>	3.6	4.0	4.1	4.2	.21
2-yr survival, <i>pct</i>	71	98	92	93	9.0
height, <i>cm</i>	34.5	38.3	38.0	40.0	4.32
leader, <i>cm</i>	18.8	18.8	19.0	20.5	3.47
diam, <i>mm</i>	4.9	5.1	5.5	5.5	.50
3-yr survival, <i>pct</i>	70	98	92	93	9.3
height, <i>cm</i>	57.9	59.3	60.0	62.6	5.98
leader, <i>cm</i>	22.7	21.5	22.6	22.6	3.37
diam, <i>mm</i>	6.6	7.1	7.6	7.8	.79

¹ Seedlings were stored at 1 ° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*.

³ Least significant difference ($p = 0.05$).

Table 21—Significance of seed source, chilling, and sowing date effects on size and balance of 1-0 Douglas-fir in Humboldt Nursery¹

Source of variation	Degrees freedom	Variance (mean square) for...				
		Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top-root ratio
Sowing date, D	1	235.71 **	12.848 **	13.041 **	3.232 **	0.496
Seed source, S	3	104.37 **	2.994 *	1.745 **	.040	1.934 **
Seed chilling, T	1	8.18 *	.013	.128	.005	.086
Block, B	4	3.23	.062	.110	.035	.249
DS	3	2.41	.122	.337	.114	.080
DT	1	2.51	.011	.044	.035	.151
ST	3	1.70	.118	.164	.037	.031
BD	4	.65	.257	.138	.025	.120
BS	12	4.02	.552	.118	.061	.109
BT	4	.82	.078	.024	.031	.039
DST	3	1.44	.097	.058	.039	.013
BDS	12	5.13	.161	.144	.046	.069
BDT	4	1.18	.181	.022	.063	.083
BST	12	2.50	.076	.073	.016	.061
BDST	12	1.37	.085	.098	.046	.024

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seeds from coastal and inland sources in western Oregon and northern California were chilled 30 or 90 days at 1° C (34° F) and sown in March and May, 1979; see table 22.

Table 22—Size and balance of 1-0 Douglas-fir from March and May sowings in Humboldt Nursery¹

Seed source ² and sowing date	Seedling height	Stem diam	Top weight	Root weight	Top-root ratio
	cm	mm	g	g	
Oregon Coast Range, N					
AL 252.15 80					
Mar 14	16.0 a	2.8 a	1.58 a	1.14 a	1.4
May 15	13.2 b	2.2 b	.97 b	.92 b	1.1
Oregon Cascades, W					
MK 472.30 80					
Mar 14	13.6 a	3.4 a	1.48 a	1.19 a	1.3
May 15	10.7 b	2.6 b	.88 b	.82 b	1.2
N Coast Range, coastal					
KI 390.20 80					
Mar 14	19.5 a	3.8 a	2.40 a	1.29 a	1.9
May 15	15.7 b	2.9 b	1.25 b	.71 b	1.9
Klamath Mtns, E					
OK 321.30 80					
Mar 14	16.2 a	3.0 a	1.69 a	1.14 a	1.5
May 15	12.0 b	2.1 b	.82 b	.71 b	1.3

¹ Means followed by unlike letters differ significantly ($p = 0.01$).

² See fig. 10, and table 21.

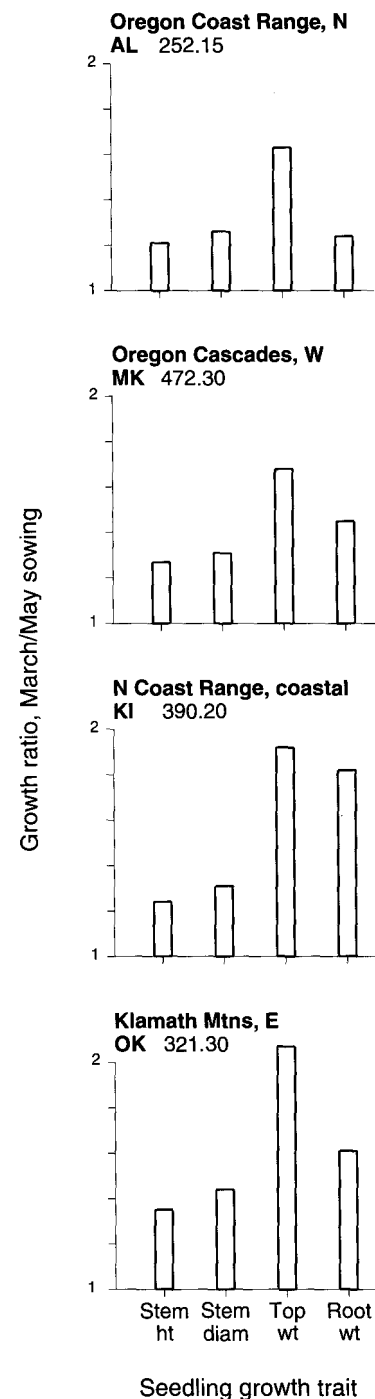


Figure 32—Seed source and sowing date effects on first-year growth of Douglas-fir in Humboldt Nursery. Seedlings of coastal and inland sources from western Oregon and northern California grew much larger in an early sowing (March 14) than in a traditional sowing (May 15).

survivals within the seed source lifting windows consistently showed that 1-0 Douglas-fir is a viable planting option. High survival and rapid growth in the first 2 years after planting verified its potential for successful reforestation in the coastal and inland regions of western Oregon and northern California.

Seed source lifting windows proved to be wide for the 1-0 seedlings in March sowings (see Seed

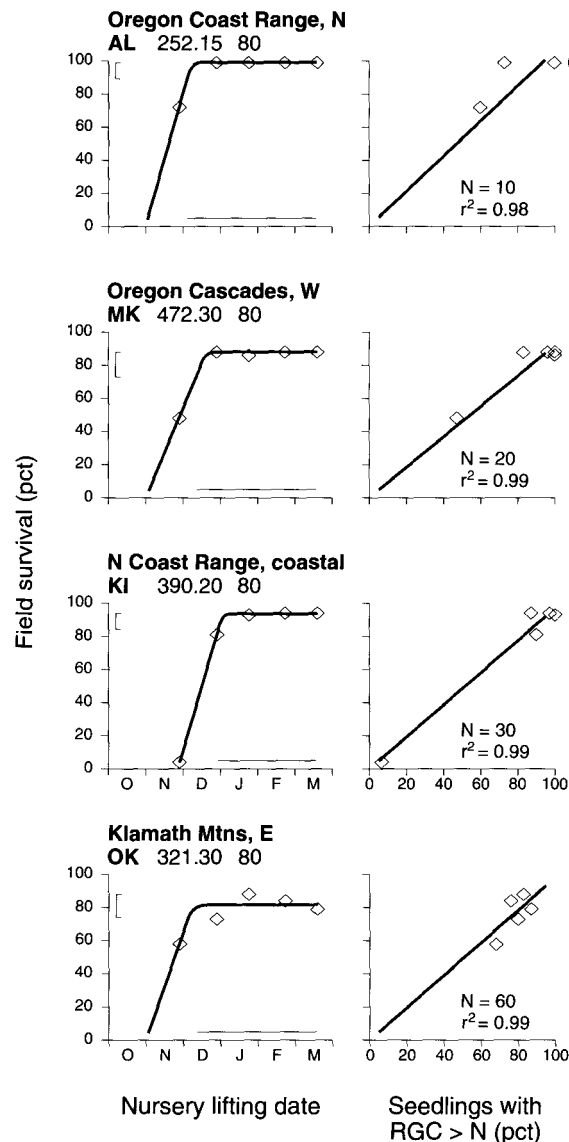


Figure 33—Critical root growth capacity (RGC) for first-year survival of 1-0 Douglas-fir from Humboldt Nursery. Survivals and critical RGC (N = roots elongated) were determined in field performance tests of coastal and inland seed sources from western Oregon and northern California. Critical RGC was higher on inland than on coastal sites, and higher on southern than on northern sites. The percentages of seedlings with RGC greater than critical explain most of the variation in survival. Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.

Source Assessments—Douglas-fir, *table 3*). First-year survival indicated that the lifting window was about 4 months wide for source AL 252.15 from the Oregon Coast Range, more than 3 months wide for sources MK 472.30 and OK 321.30 from the Oregon Cascades and Klamath Mountains, and 2.5 months wide for source KI 390.20 from the North Coast Range. Within the lifting windows, survival averaged 99 and 87 percent for sources AL and MK in coastal and inland Oregon, respectively, and 94 and 81 percent for sources KI and OK in coastal and inland California.

Root growth capacity (RGC) after cold storage, at spring planting time, explained 98 to 99 percent ($r^2 = 0.98$ to 0.99) of the variation in first-year survival (*fig. 33*). Critical RGC, expressed as the number of elongating roots per seedling, was 10 and 20 on coastal and inland sites in Oregon, and 30 and 60 on coastal and inland sites in California. Critical RGC reflected the usual environmental gradients in evaporative stress and summer drought, doubling from coastal to inland sites (compare coastal sources AL and KI against inland sources MK and OK) and tripling from northern to southern sites (compare Oregon sources AL and MK against California sources KI and OK).

Within the source lifting windows in the Oregon Coast Range and North Coast Range tests, leader length averaged 11 and 6 cm, and stem diameter, 3.5 and 6 mm, respectively, the first year after planting (*table 19*). In the Oregon Cascades test, Phomopsis canker (Kliejunas and Smith 1989, Smith 1975) killed more than half of the leaders, but stem diameter still averaged 5.2 mm. In the Klamath Mountains test, leader length averaged 7 cm, and stem diameter, 5 mm.

Survival and growth after 2 years depended on the amount of browse damage and intensity of plant competition. Seedlings in the coastal tests were immediately protected with vexar tubes against elk or deer, and were cleared of competing vegetation the second year. The inland tests were not protected.

In the Oregon Cascades test, survival was still 83 percent, reduced only 4 percent, even though the seedlings had to compete with a dense ground cover of shrubs and herbs. Many seedlings also had to grow new leaders to replace those lost to Phomopsis canker or deer, yet the average survivor was 28 cm tall, had grown 9 cm in height, and measured 6.7 mm in stem diameter.

In the Klamath Mountains test, most seedlings were injured by deer or cattle and had to compete with a dense stand of perennial grass. Survival was reduced 15 percent, to 66 percent. The average survivor, however, was 31 cm tall, had grown 12 cm in height, and measured 8.7 mm in stem diameter.

About 13 percent of the survivors escaped serious injury, and surpassed 40 cm in height and 12 mm in diameter. The largest was 60 cm tall and 16 mm in diameter.

In the Oregon Coast Range test, where seedlings were protected in vexar tubes and cleared of competing vegetation, survival averaged 96 percent, down only 3 percent from the first year, and growth was excellent. The seedlings averaged 54 cm in height and 7 mm in stem diameter. About 31 percent were taller than 60 cm and over 8 mm in diameter. The largest had grown 73 cm in height, and was 107 cm tall and 16 mm in diameter.

In the North Coast Range test, on a ridgetop in the King Range, seedlings were protected in vexar tubes and repeatedly cleared of bracken and grass. Survival averaged 77 percent, down 17 percent from the first year, and practically all of the mortality within the source lifting window was caused by competition from the root systems of six old tanoaks and Douglas-firs growing along the north and west edges of the planting site. Survival was just 8 percent in one block that was located partly beneath a tanoak crown.

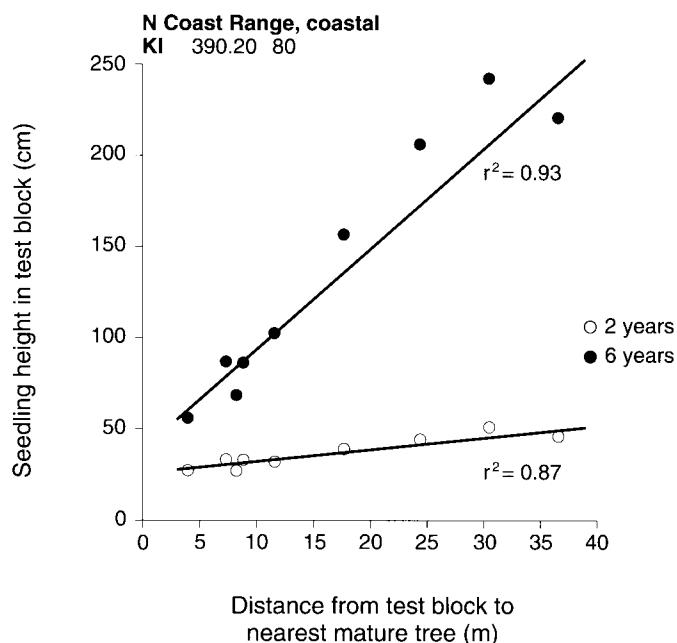


Figure 34—Root competition effects on growth of 1-0 Douglas-fir from Humboldt Nursery in a field performance test in the North Coast Range. Height growth increased with distance away from mature Douglas-firs and tanoaks that were left along the north and west edges of the planting site. Distance from edge of block to nearest tree explained most of the variation in 2- and 6-year heights. Seedlings were measured in nine test blocks ($n = 24$ to 39), as only four survived in the block beneath a tanoak crown.

Seedling growth was greatly reduced in five of the other nine blocks, and clearly showed that mature trees have extensive root systems that compete fiercely for soil water and nutrients. Distance from the nearest tree explained 87 percent of the variation in 2-year height of the survivors (*fig. 34*). Seedling height averaged as low as 27 cm in blocks that were within 40 ft (12 m) of a tree bole and as high as 51 cm in blocks that were more than 80 ft (24 m) away. The best performer had grown 65 cm in height, and was 89 cm tall and 19 mm in stem diameter.

After 6 years, survival still averaged 77 percent, but root competition had drastically reduced sapling height and radial growth. Mean height and stem diameter ranged from 56 cm and 9.4 mm in blocks within 40 ft of a tree bole up to 242 cm and 40 mm in blocks more than 80 ft away. Stem volumes of free-to-grow saplings averaged more than 70 times those of suppressed saplings. Implications for reforestation are clear. Expect high mortality and persistently slow growth of seedlings planted in the root zones of mature trees, those next to clearcuts or in seed-tree units, partial cuts, or shelterwoods.

Unprecedented growth in the first Oregon Coast Range test (*table 19*) led to the 1983 tests of 1-0 Douglas-fir on the Hebo, Waldport, and Mapleton Ranger Districts (*table 20*). All seedlings were immediately protected with vexar tubes, and were cleared of competing vegetation the following spring. Though the seedlings came from April sowings and were smaller than those from the March sowings, survival and growth were again excellent. Field performances 2 and 3 years after planting confirmed 1-0 Douglas-fir as a useful stock type for reforestation in the Oregon Coast Range.

The lifting windows determined for 1-0 seedlings of coastal sources HE 053.20, WA 061.20, and AL 061.20 in the April, 1982 sowings were narrower than that of inland source AL 252.15 in the March, 1979 sowings. Width of the lifting window was just over 3 months for sources HE and WA and 2.5 months for source AL 061.20, against 3.5 months for source AL 252.15. Regardless, survivals within the source windows were consistently high. First-year survivals of sources HE, WA, and AL 061.20 averaged 95, 97, and 96 percent, respectively, and 2-year survivals, 93, 95, and 94 percent. These survivals practically matched the 99 and 96 percent obtained for source AL 252.15 (*table 19*).

Seedling height and stem diameter after 1 year on the planting site averaged 22 cm and 3.3 mm for source HE 053.20, 19 cm for source WA 061.20 (diameter was not measured), and 19 cm and 4 mm for source AL 061.20 (*table 20*). Leader growth in the second year was outstanding and increased seedling height by 145, 116, and 105 percent for sources HE, WA, and AL, respectively. Height and

diameter after 2 years averaged 54 cm and 6.8 mm for source HE, 41 cm for source WA (diameter was not measured), and 39 cm and 5.4 mm for source AL. After 3 years, height and diameter averaged 78 cm and 10.2 mm for source HE, and 61 cm and 7.5 mm for source AL.

Yet a third series of field performance tests of 1-0 Douglas-fir was undertaken in 1984. Seed sources were chosen from those in Humboldt's second trial of April sowing, and tests were installed in the seed zones of origin on the Coos Bay and Roseburg Resource Areas in southwest Oregon and the Ukiah Resource Area in northwest California. These field tests were an integral part of a nursery fertilization study designed to assess effects of granular ammonium phosphate sulfate (NPS) topdressings on the size, survival, and growth of 1-0 planting stock. The nursery and field results are presented in the next section.

TOPDRESSING EARLY SOWINGS WITH NPS

To produce 1-0 Douglas-fir consistently, it was necessary to alter the traditional fertilization regime. Past trials in Humboldt Nursery and a persistent autumn chlorosis in 2-0 seedlings indicated that low levels of available nitrogen (N) and phosphorus (P) were limiting seedling growth. The evidence suggested that current fertilization was not replacing the N and P extracted by past seedling crops.

Testing in Humboldt's early years had shown that, on once-cropped ground, heavy applications of a granular nitrogen fertilizer before sowing and again the following spring produced large 2-0 Douglas-fir (Strothmann and Doll 1968). Effects on growth were the same as those obtained by applying equivalent amounts of N through the sprinkler irrigation system, using two sets after sowing and two more sets the following spring. Later experience at the Institute of Forest Genetics repeatedly showed that heavy spring topdressings of granular ammonium phosphate sulfate (NPS) promote rapid growth and produce large 1-0 seedlings of ponderosa, Jeffrey, and sugar pines (Jenkinson 1980, Jenkinson and others 1982).

Heavy postsowing applications of granular NPS fertilizer were first tested on Douglas-fir in 1983. April sowings of southern Oregon Coast Range source CO 072.10, northern Klamath Mountains source RO 270.20, and coastal North Coast Range source KI 390.20 were topdressed with granular NPS in May only, in May and July, and in July only. The 1-0 seedlings were evaluated for size, growth capacity before and after cold storage, and survival

and growth in the seed zones of origin (see Assessing Planting Stock Quality, Standard Testing Procedures).

Seeds were soaked 30 hours in aerated water at 22° C (72° F), chilled 60 days at 1° C (34° F), and sown on April 12. Each source was sown the length of one of three adjacent seedbeds, in soil amended with monoammonium phosphate (NPK 11-48-0) at a rate to supply 38 lb N per acre (43 kg N per ha). The test layout in each bed consisted of four blocks of six treatment and two check plots. Blocks were located in all quarters of the bed, and plots were 5 ft (1.5 m) long and marked with color-coded stakes. Granular NPS (16-20-14) was applied at rates of 100 and 200 lb N per acre (112 and 224 kg N per ha) on May 19 only, on May 19 and July 7, and on July 7 only, after seedling emergence was complete and after growth was accelerating. Granules in weighed amounts were banded between the seedling rows and raked into the surface soil.

In July, check seedlings were uniformly chlorotic and the topdressed seedlings were dark green. By November, the check and topdressed seedlings were all dark green, and showed no visible differences in height, regardless of treatment. Hence, to evaluate treatment effects, dormant seedlings were sampled in the check plots, in the plots topdressed with 200 lb N per acre in May, that is, the early 2N treatment, and in the plots topdressed with 400 lb N per acre (200 lb each in May and July), the 4N treatment.

Seedlings in each of the field performance tests were immediately protected against browse damage, and were cleared of competing vegetation at least once the first summer. Vexar tubes were installed in the tests of source CO 072.10 in the Oregon Coast Range and source KI 390.20 in the coastal North Coast Range, and a deer fence enclosed the test of source RO 270.20 in the northern Klamath Mountains.

Topdressing seedlings with NPS in May-July had no significant effect on 1-0 height, stem diameter, or growth capacity ($p = 0.10$), but did have significant effects on field performance (*table 23*). Both the 2N and 4N treatments tended to increase 1-0 stem volume slightly, with respective gains ranging from 4 and 7 percent in Oregon Coast Range source CO 072.10 to 13 and 18 percent in Klamath Mountains source RO 270.20.

Nursery NPS did not alter the width of the seed source lifting window (*table 24*). The windows determined for sources CO 072.10 and RO 270.20 were more than 3 months wide. The window for North Coast Range source KI 390.20 was 2.5 months wide, and verified that determined 4 years earlier (see Seed Source Assessments—Douglas-fir, *table 3*).

Nursery NPS did not affect survival within the source lifting window, as first-year survival averaged 96 percent within each source window. Nursery

Table 23—Significance of NPS topdress and lifting date effects on survival and growth in field performance tests of 1-0 Douglas-fir from April sowings in Humboldt Nursery¹

Seed source ² (planting date) and source of variation ³	Variance (mean square) for...			
	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
Oregon Coast Range, S				
CO 072.10 84 (Apr 10)				
1 yr: NPS topdress, T	12.89 **	303.6 **	137.9 **	7.87**
Lifting date, D	73.32 **	113.8 **	95.8 **	2.32**
Block, B	1.62	53.4	18.6	.61
TD	10.45 **	53.5 **	12.6 **	1.00**
BT	.90	13.6	2.8	.37
BD	1.21	12.3	3.1	.35
BTD	.68	12.2	3.2	.30
2 yr: NPS topdress, T	7.58 **	867.0 **	173.9 **	16.00**
Lifting date, D	71.91 **	586.3 **	237.3 **	11.58**
Block, B	2.71	489.5	245.5	2.59
TD	11.67 **	156.3 **	49.4 *	2.27**
BT	1.19	54.4	20.1	.54
BD	1.46	64.5	30.8	1.20
BTD	.87	50.0	22.3	.68
Klamath Mtns, N				
RO 270.20 84 (Mar 28)				
1 yr: NPS topdress, T	7.79 **	32.2 *	17.83**	2.11**
Lifting date, D	53.08 **	80.2 **	37.36**	3.61**
Block, B	3.44	38.8	4.23	2.37
TD	8.28 **	19.1 **	1.12	.65**
BT	.77	6.0	.69	.18
BD	2.06	6.2	.86	.23
BTD	.86	5.9	.57	.22
2 yr: NPS topdress, T	6.91 **	49.2 **	2.6	3.02**
Lifting date, D	59.03 **	129.2 **	18.6 **	8.56**
Block, B	6.70	70.6	20.1	4.63
TD	7.65 **	20.1 **	1.5	1.31**
BT	1.13	7.5	1.3	.50
BD	2.60	6.6	4.4	.60
BTD	1.02	6.2	2.2	.38
N Coast Range, coastal				
KI 390.20 84 (Apr 12)				
1 yr: NPS topdress, T	3.12 *	9.9	6.8 *	0.98
Lifting date, D	208.03 **	141.1 **	59.9 **	12.89**
Block, B	4.82	76.4	32.9	4.04
TD	1.34	44.6 **	3.6	5.86**
BT	.70	5.2	1.9	1.00
BD	1.83	7.6	4.6	1.92
BTD	.96	6.9	1.9	1.34
2 yr: NPS topdress, T	2.11	40.2	39.2	2.25
Lifting date, D	202.58 **	639.6 **	373.9 *	21.42**
Block, B	5.17	99.7	406.8	6.76
TD	1.38	130.3 **	41.5	3.96**
BT	.66	50.2	24.6	.95
BD	1.91	122.2	110.1	2.41
BTD	1.03	47.1	23.7	.71

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings were topdressed with granular NPS at 0, 200, or 400 lb N per acre, lifted monthly in autumn to spring, stored at 1° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 24.

³ Degrees freedom were 2, 4, 9, 8, 18, 36, and 72 for T, D, B, TD, BT, BD, and BTD, respectively.

NPS did affect survival outside the window, however, and the effect depended on seed source. The 2N treatment improved survival for source KI, whereas the 4N treatment reduced survival for sources CO and RO.

Nursery NPS significantly improved growth on the planting site, but gains depended on seed source and growth trait (table 24). Greatest gains were obtained in the test of source CO in the Oregon Coast Range. There, first-year gains in leader length, height, stem diameter, and volume were 32, 20, 17, and 64 percent greater, respectively, for seedlings topdressed with NPS in the nursery. In the test of source RO in the Klamath Mountains, first-year gains in the respective traits were 16, 7, 9, and 27 percent greater for NPS seedlings. In the test of source KI in the North Coast Range, by contrast, the only gain was in leader length, which was 10 percent greater for NPS seedlings.

Benefits of nursery NPS were still evident 2 years after planting. In the test of Oregon Coast Range source CO, NPS seedlings had just 9 percent greater leader length the second year, yet retained advantages of 14, 13, and 46 percent in height, diameter, and volume. Similarly, in the test of Klamath Mountains source RO, NPS seedlings had just 8 percent greater leader length, yet held advantages of 6, 7, and 23 percent in height, diameter, and volume. In the test of North Coast Range source KI, by contrast, NPS and check seedlings were fully equivalent after 2 years on the site.

Critical RGC in the test of Oregon Coast Range source CO was higher for NPS seedlings, which had more abundant shoot growth and greater transpiring surfaces than check seedlings (table 25). By contrast, critical RGC was not affected by NPS treatment in the test of Klamath Mountains source RO, probably because shoot growth was slowed in this warm, dry environment.

Superior growth of NPS seedlings in the field may reflect luxury uptake

Table 24—Survival and growth in field performance tests of 1-0 Douglas-fir from April sowings topdressed with NPS in Humboldt Nursery¹

Seed source ² (planting date), trait, and topdress ³	Performance, by nursery lifting date ⁴					Mean ⁴	
	Nov 28	Dec 27	Jan 23	Feb 21	Mar 19		
Oregon Coast Range, S							
CO 072.10 84 (Apr 10)							
1-yr survival, <i>pct</i>	0N	79	97	96	96	99	93.4 a
	2N	70	98	96	95	95	90.8 a
	4N	35	96	94	96	97	83.6 b
		61.3 b	97.0 a	95.3 a	95.7 a	97.0 a	
height, <i>cm</i>	0N	17.0	20.5	20.1	21.7	21.6	20.2 b
	2N	22.3	24.8	28.3	23.9	19.4	23.7 a
	4N	19.9	26.2	25.7	25.9	26.6	24.9 a
		19.7 b	23.8 a	24.7 a	23.8 a	22.5 a	
leader, <i>cm</i>	0N	6.0	9.0	9.9	10.4	9.7	9.0 b
	2N	9.7	12.9	14.9	11.9	9.5	11.8 a
	4N	8.6	12.6	13.6	12.9	12.3	12.0 a
		8.1 d	11.5b	12.8 a	11.7b	10.5c	
diam, <i>mm</i>	0N	3.4	3.8	4.0	4.0	4.3	3.9 c
	2N	4.2	4.4	4.9	4.6	4.0	4.4 b
	4N	4.0	4.6	4.7	4.8	5.2	4.7 a
		3.9 b	4.3 a	4.5 a	4.5 a	4.5 a	
2-yr survival, <i>pct</i>	0N	78	93	92	95	95	90.6 a
	2N	68	97	93	94	93	89.0 a
	4N	34	97	92	96	97	83.2 b
		60.0 b	95.7 a	92.3 a	95.0 a	95.0 a	
height, <i>cm</i>	0N	42.1	51.7	53.4	55.0	57.8	52.0 b
	2N	56.2	60.0	67.0	60.4	53.1	59.3 a
	4N	50.1	60.0	62.6	62.4	60.3	59.1 a
		49.4 b	57.2 a	61.0 a	59.3 a	57.1 a	
leader, <i>cm</i>	0N	25.2	31.4	34.1	33.3	36.4	32.1 b
	2N	33.8	35.4	39.8	36.4	33.2	35.7 a
	4N	29.7	34.1	37.2	36.7	34.5	34.4 a
		29.6 c	33.6 b	37.0 a	35.5 ab	34.7 ab	
diam, <i>mm</i>	0N	6.3	6.8	7.4	7.3	7.9	7.2 b
	2N	7.3	7.8	9.1	8.5	7.7	8.1 a
	4N	6.7	8.4	8.3	8.6	8.9	8.2 a
		6.8 c	7.7 b	8.3 a	8.1 ab	8.2 ab	
Klamath Mtns, N							
RO 270.20 84 (Mar 28)							
1-yr survival, <i>pct</i>	0N	84	88	99	96	98	93.0 a
	2N	71	98	96	99	97	92.2 a
	4N	46	89	99	97	98	85.8 b
		67.0 b	91.7 a	98.0 a	97.3 a	97.7 a	
height, <i>cm</i>	0N	15.0	15.6	17.8	17.6	18.7	16.9 b
	2N	16.5	16.4	20.9	18.7	14.9	17.5 ab
	4N	16.1	17.4	20.2	20.8	18.1	18.5 a
		15.8 b	16.5 b	19.6 a	19.0 a	17.3 b	
leader, <i>cm</i>	0N	4.1	5.6	6.7	7.0	6.0	5.9 b
	2N	5.3	6.7	8.1	7.4	6.0	6.7 a
	4N	5.4	6.5	8.4	8.0	6.8	7.0 a
		5.0 c	6.3 b	7.7 a	7.5 a	6.3 b	
diam, <i>mm</i>	0N	2.9	2.8	3.3	3.5	3.8	3.2 b
	2N	3.2	3.0	3.9	3.6	3.2	3.4 ab
	4N	3.2	3.2	3.8	4.2	3.8	3.6 a
		3.1 b	3.0 b	3.7 a	3.7 a	3.6 a	

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see *table 6* in Appendix B for TGC and RGC evaluations.

² See *fig. 10, table 23*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ NPS (200 lb N/acre) was applied in May (2N), or in May and July (4N).

⁴ Means followed by unlike letters differ significantly ($p = 0.05$).

Table 24—Survival and growth in field performance tests of 1-0 Douglas-fir from April sowings topdressed with NPS in Humboldt Nursery-continue¹

Seed source ² (planting date), trait, and topdress ³		Performance, by nursery lifting date ⁴					Mean ⁴	
		Nov 28	Dec 27	Jan 23	Feb 21	Mar 19		
Klamath Mtns, N								
RO 270.20 84 (Mar 28)								
2-yr survival, <i>pct</i>		0N	80	84	99	97	97	91.4 a
		2N	71	97	98	98	97	92.2 a
		4N	45	89	100	97	96	85.4 b
			65.3 c	90.0 b	99.0 a	97.3 ab	96.7 ab	
height, <i>cm</i>		0N	18.5	20.4	23.3	23.0	24.7	22.0 b
		2N	21.1	21.9	25.4	24.4	20.8	22.8 ab
		4N	20.5	22.6	26.0	27.0	23.8	24.0 a
			20.1 d	21.6 c	24.9 a	24.8 a	23.1 b	
leader, <i>cm</i>		0N	4.0	5.0	5.9	5.9	6.5	5.4
		2N	4.8	5.9	5.6	6.3	6.5	5.8
		4N	4.6	5.6	6.3	6.9	5.9	5.9
			4.4 b	5.5 ab	5.9 a	6.4 a	6.3 a	
diam, <i>mm</i>		0N	4.6	4.9	5.7	5.6	6.1	5.4 b
		2N	5.3	5.4	6.1	6.0	5.5	5.7 ab
		4N	4.8	5.5	6.2	6.8	6.0	5.9 a
			4.9 c	5.3 b	6.0 a	6.1 a	5.9 a	
N Coast Range, coastal								
KI 390.20 84 (Apr 12)								
1-yr survival, <i>pct</i>		0N	34	84	99	92	96	81.0 b
		2N	41	93	97	98	94	84.6 a
		4N	31	81	94	98	95	79.8 b
			35.3 c	86.0 b	96.7 a	96.0 a	95.0 a	
height, <i>cm</i>		0N	14.9	18.5	20.6	19.9	20.3	18.9
		2N	17.7	19.1	20.7	20.1	13.3	18.2
		4N	18.3	17.6	22.5	21.5	15.3	19.0
			17.0 c	18.4b	21.3 a	20.5 a	16.3c	
leader, <i>cm</i>		0N	4.1	5.7	8.2	6.9	6.1	6.2 b
		2N	5.7	7.0	8.1	7.3	5.8	6.8 a
		4N	5.5	6.2	8.8	8.6	5.5	6.9 a
			5.1 b	6.3 b	8.4 a	7.6 a	5.8 b	
diam, <i>mm</i>		0N	4.9	5.2	6.4	6.2	6.9	5.9
		2N	5.7	5.9	6.8	6.2	4.3	5.8
		4N	5.1	5.8	7.1	7.0	5.3	6.1
			5.2 b	5.7 ab	6.8 a	6.4 a	5.5 b	
2-yr survival, <i>pct</i>		0N	34	84	98	91	96	80.6 ab
		2N	41	91	97	96	92	83.4 a
		4N	31	80	94	97	95	79.4 b
			35.3 c	85.0 b	96.3 a	94.7 a	94.3 a	
height, <i>cm</i>		0N	31.1	36.0	45.7	43.6	42.9	39.9
		2N	40.6	40.6	46.8	43.1	35.1	41.2
		4N	37.9	39.8	49.2	45.9	35.0	41.6
			36.5 c	38.8 be	47.3 a	44.2 ab	37.7 c	
leader, <i>cm</i>		0N	17.2	19.0	26.6	26.2	24.5	22.7
		2N	22.8	22.9	28.3	25.6	22.1	24.3
		4N	19.7	22.7	29.9	27.9	20.5	24.1
			19.9 c	21.5 be	28.3 a	26.6 ab	22.4 be	
diam, <i>mm</i>		0N	5.4	6.8	8.0	8.1	8.0	7.3
		2N	6.9	7.3	8.6	7.7	6.3	7.4
		4N	6.7	7.5	8.8	8.3	7.0	7.7
			6.3 c	7.2 b	8.5 a	8.0 a	7.1 be	

¹Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see *table 6* in Appendix B for TGC and RGC evaluations.

² See *fig. 10, table 23*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ NPS (200 lb N/acre) was applied in May (2N), or in May and July (4N).

⁴ Means followed by unlike letters differ significantly ($p = 0.05$).

of N in the nursery, although luxury uptake of P and S cannot be ruled out. Seedlings topdressed with NPS in May were dark green in June, indicating that N was readily available. By contrast, check seedlings were chlorotic until November, indicating that N was in short supply. Periodic sampling in the nursery revealed that seedlings in March and April sowings elongate many lateral roots by June, before the first seedlings in traditional May sowings emerge. Seedlings in early sowings generate greater absorbing surfaces, form mycorrhizae sooner, and tap larger soil volumes for longer periods of time. Consequently, they are much more able and likely to take up nutrients in luxury amounts than seedlings in late sowings.

Differential growth of Douglas-firs from April sowings topdressed with granular NPS at rates of 0, 200, and 400 lb N per acre shows that nursery fertilization regimes should be evaluated by field performance tests, and not solely by the color and size of 1-0 seedlings. The NPS did not significantly improve seedling size, but did improve growth on the planting site. The greater field growth of NPS seedlings show that May topdressings can insure superior growth potentials in 1-0 Douglas-fir. The field tests demonstrated that nursery topdressings at rates of 200 lb N per acre are sufficient, and not detrimental to seedlings of any source.

Table 25—Critical root growth capacity (RGC) in field performance tests of 1-0 Douglas-fir from April sowings topdressed with NPS in Humboldt Nursery¹

Seed source ² (planting date) and topdress ³	Critical RGC	Regression ⁴	
		b	r ²
	cm		
Oregon Coast Range, S			
CO 072.10 84 (Apr 10)			
0N	1	1.02	0.91
2N	5	1.00	.98
Klamath Mtns, N			
RO 270.20 84 (Mar 28)			
0N	1	1.02	0.98
2N	1	1.06	.99

¹Stored seedlings were tested for RGC on May 7; see *table 24*, and *table 6* in Appendix B.

²See *fig. 10*.

³NPS (200 lb N/acre) as applied in May (2N).

⁴ $Y = bX$, where Y is first-year survival (pct) and X is the percent of seedlings with RGC higher than critical; b is line slope and r^2 is coefficient of determination.

USING 1-0 STOCK IN PLANTING PROGRAMS

Humboldt Nursery can produce successful 1-0 Douglas-fir—and 1-0 sugar, Jeffrey, and ponderosa pines—for reforestation on the Pacific Slope. High survival and superior growth characterize its performance on diverse sites in coastal and inland regions of western Oregon and northern California. With effective protection, establishment is readily achieved within 2 years of planting.

The success of 1-0 Douglas-fir in field tests clearly warrants its use in tree planting programs. Using 1-0 Douglas-fir in place of the traditional 2-0 cuts at least 1 year off the needed response times, reduces costs of seedling production, cold storage, shipping, and planting, and should improve plantation establishment where seedlings are protected.

Seed source lifting windows for 1-0 seedlings are stable, like those for 2-0 (see *Seed Source Assessments—Douglas-fir, table 3*). Lifting windows determined for 1-0 seedlings of sources CO 072.10, KI 390.20, and RO 270.20 from the southern Oregon Coast Range, coastal North Coast Range, and northern Klamath Mountains in 1983-84, for example, opened and closed at practically the same times as those of sources AL 252.15, KI 390.20, and OK 321.30 from the northern Oregon Coast Range, coastal North Coast Range, and eastern Klamath Mountains in 1979-80.

Overall, 1-0 Douglas-fir survives as well as 2-0. In western Oregon and northern California, in seed zones of coastal and inland regions where both stock types were tested, first- and second-year survivals of 1-0 stock averaged 92.3 and 87.1 percent, and those of 2-0 stock, 90.8 and 86.9 percent (*table 26*). Deer caused most of the mortality in inland regions, including that of 1-0 in zone 321 and that of 2-0 in zone 472. In an independent test on five separate planting units in zone 081 in southwest Oregon, 1-0 Douglas-fir survived and grew as well as 2-0, and heavy browse damage in known deer areas proved the need to protect both stock types (Boughton 1989).

Testing shows that browse damage can be worse for 1-0 stock (*table 16*), however, and that survival may hinge on seedling protection. For example, 2-year survival within the lifting window averaged 95 to 96 percent in tests of sources AL 252.15 and RO 270.20 in the northern Oregon Coast Range and Klamath Mountains, where seedlings were protected, against 83 and 66 percent in those of sources MK 472.30 and OK 321.30 in the Oregon Cascades and

eastern Klamath Mountains, where browsing was heavy (tables 19, 24).

Barring harsh planting sites, tough competing vegetation, and chronic browse damage, growth performances of 1-0 Douglas-fir are often superior (tables 19, 20, 24). Growth is faster on mesic coastal sites than on xeric inland sites, and normally reflects prevailing regional climate. In the tests of sources CO, KI, and RO in the Oregon Coast Range, North Coast Range, and Klamath Mountains, for example, seedling heights increased by 144, 123, and 38 percent the second year, to average 59, 41, and 23 cm, respectively (table 24). Stem diameters increased by 80, 27, and 66 percent, to average 8.1, 7.5, and 5.8 mm.

Having proved the efficacy of 1-0 Douglas-fir, we found ourselves obligated to develop management guides for two new cultural regimes. The first had to produce 1-0 seedlings consistently and the second

had to carry holdover 1-0 for 2-0 (see Determining Nursery Sowing Windows, Carrying 1-0 for 2-0 Planting Stock, and Undercutting Early Sowings for 2-0 Stock). The designed regimes were flexible and efficient, and operationally replaced the traditional 2-0 regime. Experience soon pointed out the need to develop a third regime, one to produce successful 1-1 stock. The finished regimes were integrated to permit Humboldt to deliver high-quality 1-0, 2-0, and 1-1 stock on demand, in maximum numbers of plantable seedlings per thousand seeds sown (see the next chapter, Moving into the '90's).

DETERMINING NURSERY SOWING WINDOWS

Seed source sowing windows for Douglas-fir, calendar periods to sow for efficient production of large 1-0 seedlings, were determined in Humboldt Nursery for 3 consecutive years. Tests were designed to assess seed source and sowing date effects on seedling size and quantity. Of necessity, the initial test was also designed to assess methods for safeguarding newly sown beds against heavy rains.

Seeds of coastal and inland sources GQ 091.25 and SA 311.40 from the North Coast Range and central Klamath Mountains of California were sown monthly in January-May, 1985-87. The sources were repeated to examine stability of the sowing windows. To compare sowing windows of Oregon sources, coastal and inland sources HE 053.10 and MK 472.45 from the northern Oregon Coast Range and western Oregon Cascades were sown with the California sources the third year.

Seedlings of each source and sowing were sampled monthly during their first winter, graded for 1-0 planting stock, and tested for field survival and growth. Seedlings in the same sowings were held in place for a second growing season and evaluated as 2-0 planting stock. Results were used to formulate management guides for producing 1-0 Douglas-fir and carrying 1-0 seedlings for 2-0 (see Carrying 1-0 for 2-0 Planting Stock).

Table 26—Survivals on cleared sites in the seed zones of origin for 1-0 and 2-0 Douglas-fir from Humboldt Nursery¹

Forest region and seed zone ¹	Survival ²			
	1-0 stock		2-0 stock	
	1 yr	2 yr	1 yr	2 yr
	-----pct -----			
Oregon				
Coast Range, N				
053	95	93	98	98
252	99	96	98 (3)	94
061	96 (2)	94	96 (2)	94
Coast Range, S				
072	96	94	95	93
Cascades, W				
472	88	83	82 (2)	66
California				
N Coast Range				
390	94 (2)	86	80 (2)	77
Klamath Mtns, E				
321	84	66	90 (2)	88
Klamath Mtns, S				
312	90	85	87 (3)	85
Cascades, W				
521	89	—	—	—
Grand mean	92.3	87.1	90.8	86.9

¹See figs. 2, 3, and 10.

² Average within the seed source lifting window. Multiple tests are noted in parentheses.

Winter and Spring Sowings

The sowing window tests consisted of either three or six randomized complete blocks of split plots, with sowing date split for seed source. The blocks were 200 or 400 ft (61 or 122 m) long and used up to three seedbeds (*fig. 35A*). Sowing date plots were 40 or 80 ft (12.2 or 24.4 m) long, and source plots were 20 ft (6.1 m), the minimum length needed to achieve uniform sowings with available nursery equipment. The seedbeds were prepared as already described (see Soil Preparation for Early Sowing).

Seeds were soaked 40 hours in aerated water at 22° C (72° F), drained, chilled 30 days in unsealed polyethylene bags at 1° C (34° F), surface-dried 2 to 4 hours at room temperature, rebagged, and returned to the cooler for 60 additional days (Danielson and Tanaka 1978, Edwards 1982; see *fig. 41* in the next chapter, Moving into the '90's).

Fully chilled seeds—90 days at 1° C—were sown monthly in midwinter to late spring on the following dates:

Year	Jan	Feb	Mar	Apr	May
1985	15	19	21	23	17
1986	30	28	26	18	30
1987	21	19	25	9	21

A migrating flock of juncos ruined the January sowings in 1985. Early sowings thereafter were protected by spraying the newly sown plots with a bird repellent, thiram fungicide. Standard impact sprinklers were used to keep the bed surface moist during emergence, and to irrigate the beds and developing seedlings to below root depth twice weekly in summer-autumn. In every sowing, as soon as seedlings were expanding epicotyls, soil between the rows was scarified and topdressed with granular ammonium phosphate sulfate (NPS 16-20-14) at a rate of 100 lb N per acre (112 kg N per ha).

Seed source plots in 1985 were split for an untreated control and three different treatments to prevent rainsplash, soil puddling, and sheet erosion. A woven paper mat was laid directly on the bed, a plastic screen (30 percent shade) was positioned 6 inches (15 cm) above the bed, and white hydromulch was sprayed on the bed (Landis and others 1984).

The January sowings in 1985 underwent four heavy rainstorms, and the February and March sowings, two storms, in the course of Humboldt's

typical winter weather patterns (*fig. 36*). Each time, rainfall totalled 5 cm (2 in) or more in 48 hours and saturated the beds. Periodic inspections revealed no visible erosion and no loss of seeds or germinants, indicating that our soil preparation methods had secured rapid profile drainage. Two of the erosion control treatments failed to work, however, and were abandoned. The paper mat entangled emerging seedlings and the plastic screen promoted damping-off. By contrast, hydromulch caused no problems, and was routinely used thereafter to safeguard early sowings, except those in January 1986 when persistent rains prevented application.

Seedling emergence in 1985 began 4 weeks after sowing in January, 3 weeks after sowing in February, and 18, 9, and 6 days after sowing in March, April, and May, respectively. Speed of emergence thus increased with later sowing, and repeated the patterns seen in our first sowings of seeds chilled 90 days (*fig. 31*). By April, however, all seedlings in the January sowings were expanding shoots and those in the February sowings had shed seedcoats. Seedlings in the winter sowings were up and growing 3 to 6 weeks or more before emergence began in the April and May sowings. Subsequent sowings in winter to early spring have always shown the same large advantages in onset of emergence and early growth (*fig. 35B-F*).

Seedling height was measured in July, August, and September, and both height and stem diameter were measured in October-November. Standard nursery inventory frames were used to sample two locations per treatment per source plot in 1985, and three locations per source plot in 1986 and 1987. Sampling frames 6 inches (15 cm) wide and 4 ft (1.2 m) long were placed across the beds, and seedlings in rows one-four and five-eight were measured as two separate samples.

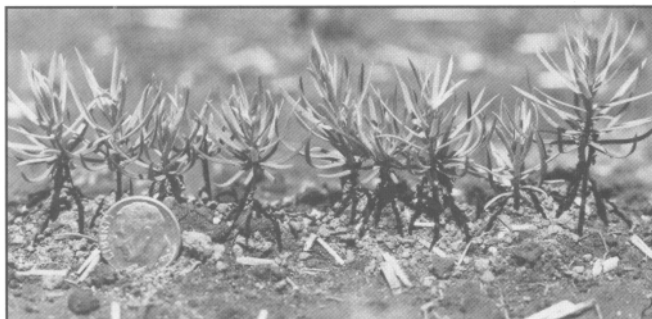
Seed source and sowing date effects on 1-0 size and stocking were assessed using variance analysis program BMD P8V for a split-split plot design in 1985 and split plot designs in 1986 and 1987, with sources and dates fixed and blocks random (Jennrich and Sampson 1985). Cull percentages for each source and sowing were estimated from frequency distributions of stem diameter, calculated using program BMD P5D (Chasen 1985). Relations of seedling height and stem volume to sowing date and onset of emergence were assessed by coefficients of determination, r^2 (Ryan and others 1981).

DETERMINING NURSERY SOWING WINDOWS FOR 1-0 DOUGLAS-FIR

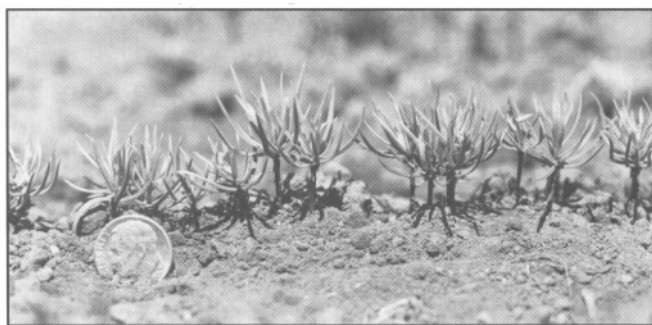
A Test layout, looking west in A Block



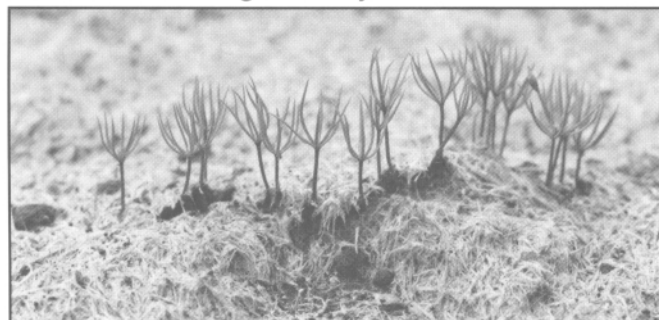
B January sowing



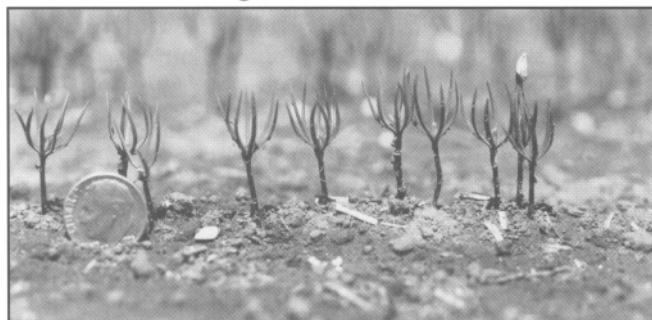
C February sowing



D March sowing, with hydromulch



D March sowing



E April sowing



Figure 35—Overview of the seedbeds and closeups of young and newly emerged seedlings in the winter and spring sowings of a test to determine sowing windows for 1-0 Douglas-fir in Humboldt Nursery. Seedlings in the January-April sowings were photographed in May, just before the traditional May sowings were installed.

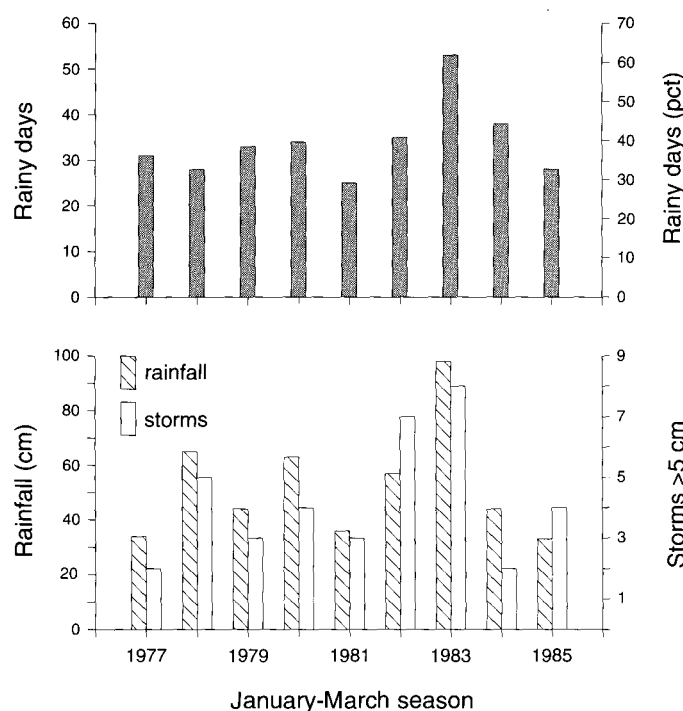


Figure 36—Winter rainfall in Humboldt Nursery. Pacific weather patterns usually bring two to five major storms during the lifting season, but still provide 50 to 65 clear days in the critical months of January-March. The wettest 3-month period was recorded in 1983, when there were eight major storms and only 36 clear days.

Seedling Growth, Stocking, and Grade

Variance analyses indicated that erosion control significantly affected 1-0 seedling stocking, and that seed source and sowing date significantly affected height, stem diameter, and stocking (*table 27*). The July-September analyses were similar to those of October-November and are not presented.

The pattern of increase in seedling height through the first growing season varied from sigmoidal in the February sowings to exponential in the May sowings. In summer, seedlings of sources GQ 091.25 and SA 311.40, from coastal and inland regions of California, respectively, grew much faster in the February sowings than in the May sowings (*fig. 37*). In autumn, seedlings of both sources showed decreasing growth rates in the February sowings and accelerating rates in the May sowings. In the March and April sowings, however, seedlings of coastal source GQ showed constant rates in summer and autumn, whereas those of inland source SA showed slower rates in autumn than in summer.

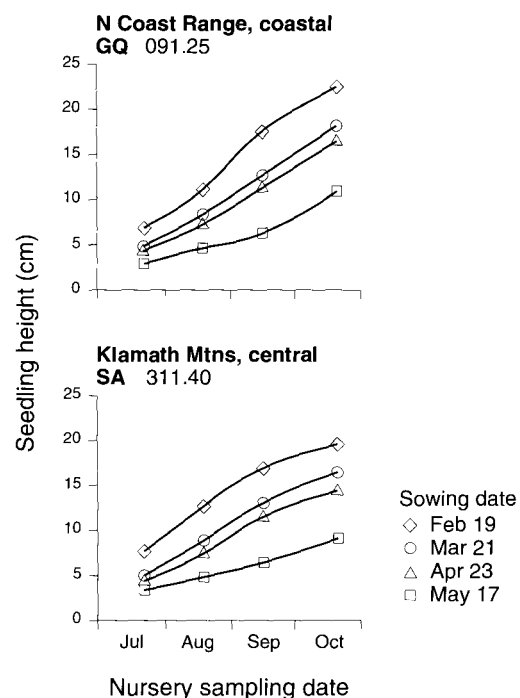


Figure 37—Sowing date effects on the seasonal pattern of first-year height growth of Douglas-fir in Humboldt Nursery. Seedlings of seed sources from coastal and inland regions in northern California tend to trace sigmoid patterns in February sowings, as against exponential patterns in May sowings.

Sowing early commonly resulted in 1-0 seedlings with twice the height and stem diameter of seedlings in May sowings (*table 28*). Winter sowing increased height and diameter by up to 112 and 100 percent for source GQ from the coastal North Coast Range, 114 and 100 percent for source SA from the central Klamath Mountains, 73 and 67 percent for source HE 053.10 from the northern Oregon Coast Range, and 66 and 69 percent for source MK 472.45 from the western Oregon Cascades. Depending on seed source and nursery year, stem volumes were four to eight times greater in winter and early-spring sowings than in the traditional May sowings.

First-year stocking in 1985 depended on seed source, sowing date, and soil erosion control. Stocking decreased with earlier sowing, and losses were greater for coastal source GQ than for inland source SA. Stockings of sources GQ and SA in the February sowings were reduced 38 and 18 percent, respectively, compared to those in the May sowings.

Coastal sources have smaller seeds than inland sources (12 mg per seed for source GQ against 15 mg for source SA), and the greater losses of coastal

seedlings may reflect seed loss at sowing time. Sowing depth is critical for seedling emergence (Minore 1985), and smaller seeds are more difficult to sow precisely, especially in a bareroot nursery during the rainy season.

The hydromulch and plastic screen treatments improved stocking for coastal source GQ by 24 and 41 percent, respectively, whereas neither treatment improved that for inland source SA (table 29).

Hydromulch was chosen for operational use in Humboldt Nursery because it is cheaper and easier to apply and does not promote damping-off. With or without it, however, stockings of coastal and inland sources were on target in the January-April (midwinter-midspring) sowings in 1986 and 1987 (table 28). Improved soil management practices probably account for the uniformly high stocking obtained.

Table 27—Significance of seed source, sowing date, and soil erosion control effects on size and stocking of 1-0 Douglas-fir in Humboldt Nursery¹

			Variance (mean square) for...		
Sowing year and source of variation	Error term	Degrees freedom	Seedling height (cm)	Stem diam (mm)	Stems per ft ²
1985					
Sowing date, D	BD	3	1511.28 **	32.670**	741.1**
Seed source, S	BS	1	349.80	2.000	803.3
Soil control, T	BT	2	1.58	.241	759.8
Block, B	P	2	262.50 **	7.094**	176.3*
DS	BDS	3	5.28	.058	185.1**
DT	BDT	6	26.91 **	.097	199.9
ST	BST	2	31.72	.029	149.0
BD	P	6	9.27 *	.152	72.9
BS	P	2	37.74 **	1.214**	12.9
BT	P	4	34.87 **	.731**	62.5
DST	BDST	6	13.17 *	.862*	179.8
BDS	P	6	18.77 **	.207	15.7
BDT	P	12	5.26	.230	142.0**
BST	P	4	10.78 *	.233	132.6*
BDST	P	12	4.14	.201	159.8**
P(BDST)		216	4.15	.162	48.1
1986					
Sowing date, D	BD	4	1893.96 **	67.633**	1125.0**
Seed source, S	BS	1	2117.68 **	2.888*	350.0
Block, B	P	5	444.27 **	9.371 **	85.7
DS	BDS	4	46.31 *	.258	114.4
BD	P	20	46.91 **	1.135**	130.3**
BS	P	5	11.63 *	.392*	47.0
BDS	P	20	15.94 **	.582**	78.7**
P(BDS)		660	4.36	.153	38.1
1987					
Sowing date, D	BD	4	460.05 **	12.635**	323.5
Seed source, S	BS	3	483.73 *	3.090	724.4**
Block, B	P	2	291.26 **	1.841 **	7.7
DS	BDS	12	20.33 *	.186	162.5**
BD	P	8	8.56 *	.246*	177.2**
BS	P	6	67.86 **	.801 **	42.0
BDS	P	24	6.90 *	.133	46.4
P(BDS)		180	3.88	.102	36.0

*, ** Significant at p <0.05, p <0.01.

¹ Seeds from coastal and inland sources in northern California and western Oregon (1987 only) were chilled 90 days at 1° C (34° F) and sown monthly in January-May; see table 28.

By sowing early, Humboldt can consistently produce 1-0 seedlings that are large enough to outplant. The size of planting stock is a vital concern because thin and whippy seedlings mostly perform poorly on the planting site. California experience has shown that 1-0 stock is successful when seedlings are graded to a stem diameter of 2.5 mm (0.1 in).

In the January-March sowings of coastal and inland California sources GQ and SA, 77 to 95 percent of the 1-0 seedlings had stem diameters ≥2.5 mm (table 28). In the January-March sowings of Oregon sources, 79 percent of the 1-0 seedlings made grade for coastal source HE, but only 56 to 67 percent of those for inland source MK. The latter yields suggest that seedlings of high-elevation sources from the Oregon Cascades grow too slowly to produce 1-0 Douglas-fir efficiently. First-year seedlings of sources like MK should be grown a second year in the nursery to produce either 2-0 stock or, preferably, 1-1 stock (see Carrying 1-0 for 2-0 Planting Stock, and the next chapter, Moving into the '90's).

Sowing Windows and 1-0 Stock Yield

The amounts of graded 1-0 seedlings produced per thousand viable seeds determine when the source sowing window opens and closes. For efficient production of 1-0 Douglas-fir, the earliest and latest sowing dates used in the nursery should delimit calendar periods in which at least 75 to 95 percent of the germinants develop into seedlings with stem diameters ≥ 2.5 mm. These specific yield and grade criteria were used to determine earliest and latest safe sowing dates for coastal and inland sources from western Oregon and northern California. Stem volume, stocking, and cull rate for individual sources were graphed against sowing date. To emphasize the growth gained by sowing early, stem volumes, mm^3 per seedling, in each of the January-May sowings were expressed as a ratio

of that for the May sowing. Stocking was expressed as the number of seedlings per square foot of bed, and cull rate, as percentage of seedlings with stems < 2.5 mm thick (*fig. 38*).

Graphical determinations of first and last safe dates indicated that, for most sources, sowing windows for 1-0 Douglas-fir in Humboldt Nursery are fully open in midwinter and practically closed by midspring. The windows for coastal and inland California sources GQ 091.25 and SA 311.40 remained open until early April, and the window for coastal Oregon source HE 053.10, until late March. There was no satisfactory window for inland Oregon source MK 472.45. May sowings of all sources were disastrous, as expected, because 72 to 90 percent of the seedlings produced were too small to outplant (*table 28*).

Table 28—Size, stocking, and cull rate of 1-0 Douglas-fir in winter and spring sowings in Humboldt Nursery¹

Seed source ²	Seedling traits, by sowing date					LSD ³
1985 sowings	Feb 19	Mar 21	Apr 23	May 17		
N Coast Range, coastal						
GO 091.25						
1-0 height, cm	22.5	18.2	16.5	10.9		2.61
diam, mm	3.49	2.94	2.65	1.92		—
stem vol, mm^3	861	494	364	126		—
stems per ft^2	18.7	21.7	25.9	29.3		4.40
cull rate, pct	14.0	19.0	34.0	77.0		—
Klamath Mtns, central						
SA 311.40						
1-0 height, cm	19.5	16.4	14.3	9.1		1.58
diam, mm	3.40	2.77	2.42	1.74		—
stem vol, mm^3	708	395	263	87		—
stems per ft^2	24.6	27.8	27.2	29.2		3.13
cull rate, pct	15.0	23.0	40.0	85.0		—
1986 sowings	Jan 30	Feb 28	Mar 26	Apr 18	May 30	
N Coast Range, coastal						
GQ 091.25						
1-0 height, cm	20.4	17.9	17.0	14.0	9.6	1.46
diam, mm	3.77	3.35	3.07	2.65	1.93	—
stem vol, mm^3	906	631	503	309	112	—
stems per ft^2	23.2	29.2	28.8	30.4	24.7	2.21
cull rate, pct	4.6	11.0	17.1	34.0	72.3	—
Klamath Mtns, central						
SA 311.40						
1-0 height, cm	15.4	14.5	13.5	10.4	7.8	2.34
diam, mm	3.53	3.32	2.95	2.46	1.87	—
stem vol, mm^3	603	502	369	198	86	—
stems per ft^2	21.4	26.6	28.5	27.2	25.8	4.51
cull rate, pct	13.1	12.5	22.9	45.9	77.4	—

¹ Cull rate is the percent of seedlings with stem diameter < 2.5 mm; see *tables 7, 8* in Appendix B for TGC and RGC evaluations.

² See *fig. 10*, and *table 27*.

³ Least significant difference ($p = 0.05$).

Experience in Humboldt Nursery has shown that earliest safe sowing dates depend primarily on soil and seedbed preparation methods that promote rapid drainage, and secondarily on seedbed protection schemes that use hydromulch or rice straw to prevent soil erosion and seed loss. Any choice of earliest sowing date should heavily favor the marked advantages of large 1-0 stock against the slight risk of reduced seedling yields. Most of the seedlings produced in winter sowings are big enough to outplant, so any likely loss is already covered by the nursery's accepted cull rates. Repeated testing of early sowing of Douglas-fir in Humboldt Nursery consistently indicates that all sources should be sown by March 20, to insure that 75 to 95 percent of the 1-0 seedlings will have stems ≥ 2.5 mm thick.

Table 29—Stocking of 1-0 Douglas-fir in a test of soil erosion control in winter and spring sowings in Humboldt Nursery¹

Seed source ²	Check	Stems per square ft, for...		
		Hydro mulch	Plastic screen	Mean
N Coast Range, coastal				
GQ 091.25	19.4 c	24.1 b	27.4 a	23.6 b
Klamath Mtns, central				
SA 311.40	27.5	27.6	29.0	28.0 a

¹ Sowings were inventoried monthly in summer-autumn.

Means followed by unlike letters differ significantly ($p = 0.05$).

² See *fig. 10*, and *tables 27, 28*.

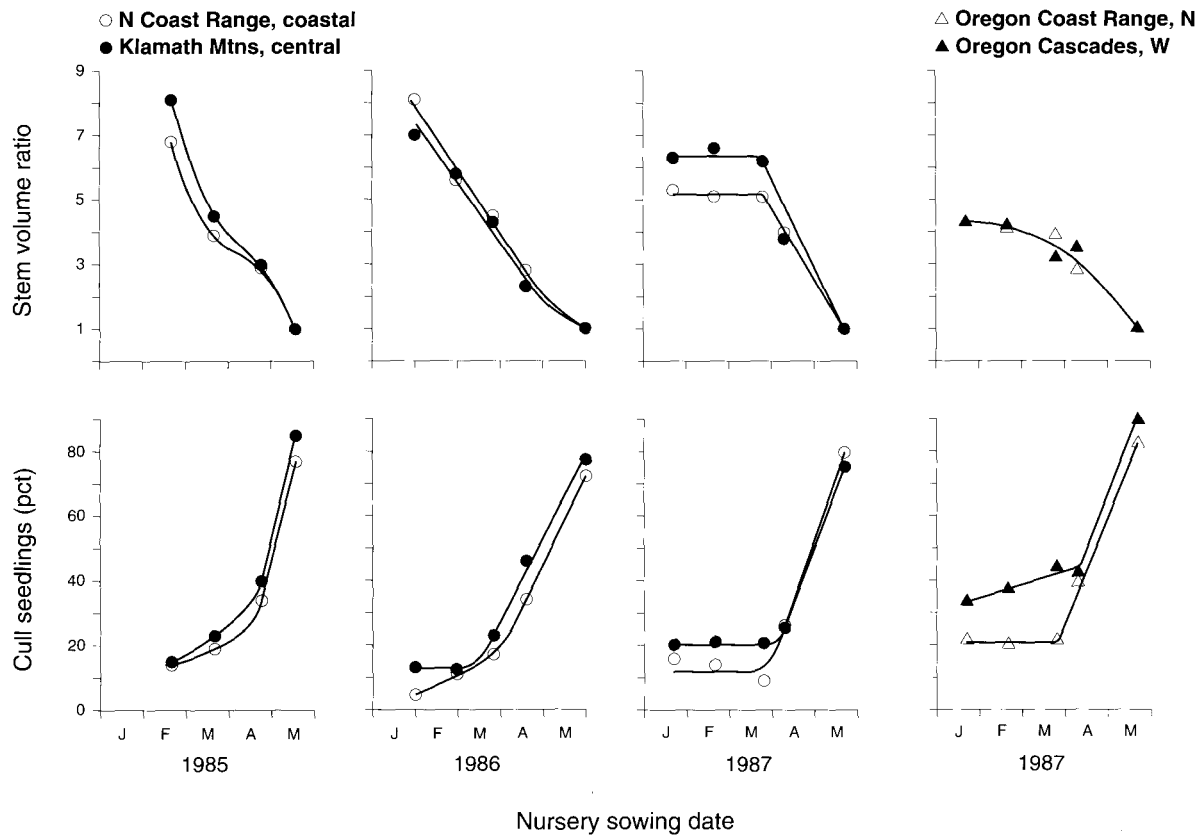
Table 28—Size, stocking, and cull rate of 1-0 Douglas-fir in winter and spring sowings in Humboldt Nursery—continued¹

Seed source ²	Seedling traits, by sowing date					LSD ³
1987 sowings	Jan 21	Feb 19	Mar 25	Apr 9	May 21	
N Coast Range, coastal						
GQ 091.25						
1-0 height, cm	21.3	21.3	20.8	16.8	10.5	2.59
diam, mm	3.15	3.23	3.16	2.83	1.78	.53
stem vol, mm ³	664	698	653	423	105	—
stems per ft ²	27.6	26.8	28.8	27.1	25.2	8.34
cull rate, pct	16.0	14.0	9.1	26.3	79.7	—
Klamath Mtns, central						
SA 311.40						
1-0 height, cm	16.6	16.4	17.8	15.4	10.3	1.79
diam, mm	3.16	3.11	2.98	2.77	1.74	.28
stem vol, mm ³	521	498	497	371	98	—
stems per ft ²	24.3	27.3	30.9	28.9	26.0	6.86
cull rate, pct	20.3	21.1	20.7	25.5	75.2	—
Oregon Coast Range, N						
HE 053.10						
1-0 height, cm	16.9	17.8	16.6	15.3	10.3	2.70
diam, mm	2.98	2.88	2.88	2.53	1.85	.34
stem vol, mm ³	472	464	433	308	111	—
stems per ft ²	36.1	37.7	32.5	38.2	26.0	11.3
cull rate, pct	21.4	20.0	21.4	39.2	82.3	—
Oregon Cascades, W						
MK 472.45						
1-0 height, cm	12.1	12.8	11.7	12.1	7.7	2.94
diam, mm	2.67	2.53	2.35	2.42	1.61	.31
stem vol, mm ³	271	257	203	223	63	—
stems per ft ²	30.2	33.7	31.2	31.8	26.8	4.78
cull rate, pct	33.3	37.1	44.0	42.3	89.6	—

¹ Cull rate is the percent of seedlings with stem diameter < 2.5 mm; see *tables 7, 8* in Appendix B for TGC and RGC evaluations.

² See *fig. 10*, and *table 27*.

³ Least significant difference ($p = 0.05$).



January sowing



February sowing



March sowing



April sowing



May sowing



Figure 38—Sowing date effects on first-year stem volume and cull loss of Douglas-fir in Humboldt Nursery. Seedlings of coastal and inland seed sources from western Oregon and northern California show spectacular gains in size, quality, and yield in January-March sowings, compared to May sowings.

Sowing Windows and Field Survival and Growth

Experience in most forest regions has shown that large planting stock survives as well as or better than small stock, and often grows faster than small stock. Because 1-0 seedling size increased markedly with earlier sowing (*table 28*), we had to determine whether field survival and growth might suggest earlier closures of the sowing windows than those indicated by 1-0 yields alone. Accordingly, field performance tests were run using 1-0 seedlings lifted from the February-May, 1985 and January-April, 1987 sowings. Stored seedlings were planted in spring, 1986 and 1988, on prepared ground in unused fields at Humboldt Nursery.

Seedlings of all sowings survived and grew well on the planting sites. Yet seedlings from the January-March sowings invariably were larger and grew faster than those from the April-May sowings. The field tests demonstrated that

- Field survival potential is not a critical factor in the determination of nursery sowing windows
- Greatest growth potential is obtained by sowing early within the windows, in January-March

Seedlings in the 1985 sowings of coastal and inland California sources GQ 091.25 and SA 311.40 were sampled on December 16, January 13, and February 10, graded to a stem diameter of 2.5 mm, root-pruned 23 cm below the cotyledon scars, and stored at 1° C until late spring. Stored seedlings were planted on fallow ground in E Block on April 28, 1986.

Seedlings in the 1987 sowings of the California sources and coastal and inland Oregon sources HE 053.10 and MK 472.45 were sampled on December 13, January 11, February 8, and March 7, and as described above, were graded, root-pruned, and stored until late spring. Stored seedlings were planted on a cleared site in an undeveloped field on April 27, 1988.

The layout consisted of nine randomized complete blocks of split-split plots, with sowing date split for seed source and lifting date. Planting holes were made with a powered soil auger, and seedlings were spaced 2 ft (0.6 m) apart in rows of 10.

Field survival and growth were reduced by tough competing vegetation, hungry gophers, and browsing deer. Weeds and grasses were allowed to form a

dense ground cover, to deplete soil water and develop adverse conditions typical of unprotected plantings. Gophers killed 10 percent of the seedlings in both tests, fed on the roots of an undetermined number of survivors, and were finally controlled by trapping. Resident deer browsed the 1988 planting on a regular basis.

In both plantings, seed source and sowing date significantly affected seedling height, leader length, and stem diameter, and lifting date affected survival and growth (*table 30*). Mortality was higher in the December lifts than in the January-March lifts, but growth differences between lifts were too small to be of any practical importance. Growth was therefore tabulated to focus on the seed source and sowing date effects.

Large seedlings from early sowings survived as well as or better than small seedlings from late sowings (*table 31*). First-year survival averaged 88 percent for both source GQ and source SA in 1986, and 89, 93, 87, and 90 percent for sources GQ, SA, HE, and MK, respectively, in 1988. If gopher damage is set aside, survivals of seedlings from the February-May, 1985 and January-April, 1987 sowings average 97 to 99 percent, matching the highest survivals of seedlings from the March, 1979 and April, 1982 and 1983 sowings (see *tables 16, 19, 20, 24*).

Growth increased with planting stock size, which increased with earlier sowing (*table 28*). In the 1986 planting, seedlings from the February and March sowings markedly outgrew those from April and May sowings (*table 31*). After 2 years, stem volumes of seedlings from the February sowing of coastal source GQ averaged 17, 57, and 137 percent greater than those from the March, April, and May sowings, respectively. Similarly, stem volumes of seedlings from the February sowing of inland source SA averaged 3, 70, and 83 percent greater than those from the March, April, and May sowings.

In the 1988 planting, seedlings from the January-March sowings outgrew those from the April sowings. After 2 years, stem volumes of seedlings from the January-March sowings of California and Oregon sources GQ, SA, HE, and MK averaged 32, 28, 49, and 60 percent greater, respectively, than those from the April sowings. Growth was uniformly high for seedlings from the January-March sowings of coastal sources GQ and HE, but slightly higher for the January than for the February and March sowings of inland sources SA and MK.

Table 30—Significance of seed source, sowing date, and lifting date effects on survival and growth in field performance tests of 1-0 Douglas-fir from Humboldt Nursery¹

Planting year and source of variation		Degrees freedom	Variance (mean square) for...							
			1 year				2 years			
			Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
1986										
Sowing date, D	3	1.60	904.98 **	36.30**	29.21 **	3.88	2122.2 **	390.3 **	100.51**	
Seed source, S	1		447.21 **	16.06**	46.02**	6.69	12132.0 **	8201.7 **	142.76**	
Lifting date, L	2	3.76 *	102.35 **	22.33**	15.70**	12.72 *	626.9 **	271.2 **	39.18**	
Block, B	8	12.38	37.41	8.57	3.56	34.27	366.7	242.8	8.70	
DS	3	1.30	13.54	1.06	3.05**	1.11	132.1	63.5	8.13	
DL	6	1.47	4.14		.22	2.56	61.1	44.4	1.57	
SL	2	3.92 *	6.63	5.49**	.37	2.74	21.2	8.5	.44	
BD	24	2.82	8.33	2.81	.70	7.04	79.6	50.2	6.66	
BS	8	4.07	8.88	1.05	1.22	7.75	66.1	41.3	4.05	
BL	16		8.31		.54	2.76	39.5	30.2	1.88	
DSL	6	1.55	5.15	1.21	.78*	1.49	43.6	27.4	1.98	
BDS	24	1.89	6.38	1.95	.29	3.17	48.6	26.6	2.39	
BDL	48	1.30	4.75		.26	2.58	52.2	32.1	1.73	
BSL	16	1.03	3.31		.27	1.74	95.8	77.1	2.22	
BDSL	48		3.30		.26	1.24	36.0	19.4	1.49	
1988										
Sowing date, D ²	3	4.08	208.86 **	4.54	7.40**	18.54	518.03	142.22	53.97	
Seed source, S	3	10.20	665.45 **	64.25**	11.13**	7.23	7207.99 **	3818.47**	155.01**	
Lifting date, L	3	168.12 **	194.18 **	169.86**	7.33**	171.73 **	669.25 **	223.66**	49.66**	
Block, B	8	15.71	409.43	57.70	6.64	46.28	1784.32	546.61	49.17	
DS	9	1.30	5.23	1.80	.63	1.14	23.22	25.54	2.76	
DL	9		4.73	3.19	.14	1.35	47.12	22.38	1.90	
SL	9	16.48 **	16.12 *	5.66	.42*	16.34 **	53.85 *	27.78*	2.90*	
BD	24	1.45	11.33	8.10	1.09	4.88	227.27	184.31	23.21	
BS	24	3.43	13.18	5.19	.43	4.78	69.03	42.56	2.37	
BL	24	11.80	10.12	2.47	.29	10.04	31.69	8.78	1.99	
DSL	27	1.90	8.17	1.87	.23	2.94	50.05 *	20.61	1.57*	
BDS	72	1.61	10.68	3.86	.39	3.42	59.44	34.40	3.58	
BDL	72	1.09	6.72	1.68	.15	1.81	37.05	20.88	1.46	
BSL	72	3.48	6.60	2.09	.18	3.71	24.15	12.96	1.11	
BDSL	216	1.16	5.94	1.62	.16	1.62	28.87	16.40	.96	

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings in winter and spring sowings of coastal and inland sources from northern California and western Oregon (1988 only) were lifted monthly in winter, stored at 1° C (34° F), and planted in spring in an unused field at Humboldt Nursery; see *table 31*.

² Growth trait degrees freedom the second year were 7 for B, 21 for BD, BS, and BL, 63 for BDS, BDL, and BSL, and 189 for BDSL.

Table 31—Survival and growth infield performance tests of 1-0 Douglas-fir from winter and spring sowings in Humboldt Nursery¹

Seed source ² (planting date)	Performance, by sowing date				LSD ³
1985 sowings	Feb 19	Mar 21	Apr 23	May 17	
N Coast Range, coastal					
GQ 091.25 86 (Apr 28)					
1-yr survival, <i>pct</i>	88.2	91.8	85.9	87.0	6.7
height, <i>cm</i>	34.4	30.4	27.8	23.6	1.64
leader, <i>cm</i>	9.2	9.2	8.6	7.3	1.08
diam, <i>mm</i>	7.82	6.96	6.31	5.56	
stem vol, <i>cm</i> ³	6.61	4.63	3.48	2.29	—
2-yr survival, <i>pct</i>	79.6	78.5	73.3	73.3	9.6
height, <i>cm</i>	70.0	67.2	62.0	54.4	4.27
leader, <i>cm</i>	37.6	38.2	35.1	32.3	3.44
diam, <i>mm</i>	14.4	13.6	12.2	10.6	1.17
stem vol, <i>cm</i> ³	45.6	39.0	29.0	19.2	—
Klamath Mtns, central					
SA 311.40 86 (Apr 28)					
1-yr survival, <i>pct</i>	85.2	89.3	88.5	89.6	10.2
height, <i>cm</i>	30.3	27.8	24.7	21.9	1.40
leader, <i>cm</i>	8.8	8.4	7.9	7.1	
diam, <i>mm</i>	6.27	6.08	5.44	5.17	
stem vol, <i>cm</i> ³	3.74	3.23	2.30	1.84	—
2-yr survival, <i>pct</i>	71.9	76.7	70.7	71.5	15.2
height, <i>cm</i>	53.6	53.7	43.4	42.9	4.72
leader, <i>cm</i>	25.0	26.9	19.9	22.2	3.53
diam, <i>mm</i>	12.1	11.9	10.3	10.0	1.22
stem vol, <i>cm</i> ³	4.7	23.9	14.5	3.5	—
1987 sowings					
	Jan 21	Feb 19	Mar 25	Apr 9	
N Coast Range, coastal					
GQ 091.25 88 (Apr 27)					
1-yr survival, <i>pct</i>	89.7	87.2	89.4	88.6	6.7
height, <i>cm</i>	29.6	28.9	29.1	26.7	1.18
leader, <i>cm</i>	10.2	10.4	10.3	10.0	1.19
diam, <i>mm</i>	5.06	4.86	5.00	4.63	
stem vol, <i>cm</i> ³	2.38	2.14	2.29	1.80	—
2-yr survival, <i>pct</i>	85.6	80.6	86.4	80.8	16.2
height, <i>cm</i>	66.0	65.1	64.5	60.1	10.0
leader, <i>cm</i>	38.2	37.3	37.4	35.2	8.89
diam, <i>mm</i>	11.7	11.5	11.2	10.4	3.39
stem vol, <i>cm</i> ³	28.2	26.8	25.6	20.4	—

¹ Seedlings were lifted monthly in winter, stored at 1° C (34° F), and planted in an unused field at Humboldt Nursery; see *tables 7, 8* in Appendix B for TGC and RGC evaluations.

² See *fig. 10*, and *table 30*.

³ Least significant difference ($p = 0.05$).

Table 31—Survival and growth in field performance tests of 1-0 Douglas-fir from winter and spring sowings in Humboldt Nursery—continued ¹

Seed source ² (planting date)		Performance, by sowing date				LSD ³
1987 sowings		Feb 19	Mar 21	Apr 23	May 17	
Klamath Mtns, central						
SA 311.40 88 (Apr 27)						
1-yr	survival, <i>pct</i>	95.8	90.0	95.0	91.4	5.6
	height, <i>cm</i>	26.5	26.7	25.7	24.3	1.80
	leader, <i>cm</i>	9.3	9.1	9.2	9.1	1.04
	diam, <i>mm</i>	4.92	4.61	4.49	4.38	.29
	stem vol, <i>cm</i> ³	2.02	1.78	1.63	1.46	—
2-yr	survival, <i>pct</i>	89.7	81.1	87.5	83.1	19.1
	height, <i>cm</i>	51.8	49.2	49.5	47.6	7.13
	leader, <i>cm</i>	27.8	24.6	25.9	25.4	5.95
	diam, <i>mm</i>	10.0	9.1	9.8	8.7	2.20
	stem vol, <i>cm</i> ³	16.3	12.6	14.9	11.4	—
Oregon Coast Range, N						
HE 053.10 88 (Apr 27)						
1-yr	survival, <i>pct</i>	90.0	87.2	83.9	85.6	6.4
	height, <i>cm</i>	28.7	27.8	26.6	25.5	1.66
	leader, <i>cm</i>	10.6	10.9	10.4	10.5	1.05
	diam, <i>mm</i>	4.64	4.65	4.81	4.18	.42
	stem vol, <i>cm</i> ³	1.94	1.89	1.93	1.40	—
2-yr	survival, <i>pct</i>	86.4	80.3	82.2	75.6	22.2
	height, <i>cm</i>	60.1	59.3	58.0	54.9	10.5
	leader, <i>cm</i>	32.7	32.7	33.0	30.9	8.27
	diam, <i>mm</i>	10.4	10.2	10.6	8.9	3.16
	stem vol, <i>cm</i> ³	20.4	19.3	20.7	13.5	—
Oregon Cascades, W						
MK 472.45 88 (Apr 27)						
1-yr	survival, <i>pct</i>	92.2	91.1	88.6	86.7	5.7
	height, <i>cm</i>	24.9	24.1	23.1	22.0	1.85
	leader, <i>cm</i>	9.6	9.5	9.8	8.8	1.02
	diam, <i>mm</i>	4.59	4.19	4.20	3.84	.25
	stem vol, <i>cm</i> ³	1.65	1.33	1.28	1.02	—
2-yr	survival, <i>pct</i>	84.4	80.6	81.7	75.0	19.5
	height, <i>cm</i>	49.1	46.7	47.9	43.4	10.8
	leader, <i>cm</i>	26.0	24.1	26.7	22.7	8.90
	diam, <i>mm</i>	9.4	8.5	8.8	7.4	2.28
	stem vol, <i>cm</i> ³	13.6	10.6	11.7	7.5	—

Management Implications

Whatever the source of Douglas-fir, coastal or inland, western Oregon or northern California, sowing early greatly improved the size, quality, and quantity of the seedlings produced in Humboldt Nursery (*fig. 38*). Most of the diseases and crippling stunting problems that have plagued past seedling crops are readily avoided by chilling seeds for extended periods and sowing early enough to capture the natural germination environment. The benefits of sowing fully chilled seeds in cool soils have been proven repeatedly, and the gains achieved in growth and yield are as dramatic for Douglas-fir as they are for sugar pine (Jenkinson and others 1982).

Sowing chilled seeds in midwinter-early spring (January-March), as against late spring-early summer (May-June), captures critical months at the start of Humboldt Nursery's natural growing season, even though cold soil conditions prevail and prolong seedling emergence. Developing seedlings grow larger, more robust root systems and larger, more uniform tops in an initially cool but extended growing season than in an initially warm but shortened season. Seedlings in early sowings form abundant mycorrhizae with the ubiquitous *Laccaria laccata* and *Thelephora terrestris*, and develop profuse networks of mycelia in the rhizosphere and adjacent soil. Moreover, because early-sow seedlings emerge in cool conditions and grow to large sizes the first year, they practically escape the chronic disease and mortality problems caused by *Fusarium* root rot and *Phoma* blight (Frankel 1989, Johnson and others 1989, Srago and others 1989).

Seedlings that emerge in the warm conditions of late spring-early summer (May-June) in Humboldt Nursery invariably display incipient to severe problems with damping-off and *Fusarium* disease (Kliejunas and Allison 1982). Even worse, survivors in late sowings consistently exhibit a classic mosaic pattern of stunting that is symptomatic of poor or

spotty mycorrhizal development (Molina and Trappe 1984). Besides being too small to lift, the resulting first-year seedlings are highly susceptible to *Phoma* blight, and require biweekly spraying from midautumn to midspring to prevent catastrophic mortality.

The physiological condition and storability of the 1-0 seedlings produced are closely related to length of the growing season. As already noted, sowing in winter to early spring (January-March) captures almost all of the calendar period in which the nursery climate permits growth. Sowing early is essential if seed source lifting windows are to open at the same time for 1-0 as for 2-0 seedlings. Most 1-0 seedlings in early sowings attain the degree of autumn dormancy needed for safe overwinter cold storage, and permit confident use of the source lifting windows determined for 2-0 seedlings.

In all three tests of nursery sowing windows, the seasonal pattern of height growth and the first safe lifting date for the seed source depended on sowing date. In late autumn (October-November), growth rates of coastal and inland seedlings decreased in winter sowings, remained high in early-spring sowings, and increased in late-spring sowings (for example, see *fig. 37*). Decreasing rates imply physiological states that speed development of autumn dormancy, cold hardiness, and readiness for cold storage, whereas increasing rates imply states that delay dormancy, hardiness, and readiness for storage.

Field performance tests demonstrated that the first safe lifting dates for 1-0 Douglas-fir in Humboldt Nursery are appreciably delayed in April sowings. The source lifting windows determined for 1-0 seedlings in March sowings tended to open just shortly after those determined for 2-0 seedlings of the same or nearby seed zones (see Seed Source Assessments—Douglas-fir, *table 3*). By contrast, the windows determined for 1-0 seedlings in April sowings opened at least 1 month later (see *table 20*).

CARRYING 1-0 FOR 2-0 PLANTING STOCK

Postponed logging and inclement weather can cancel or delay planting site preparation and force changes in planting schedules. When that happens, seedlings destined for those regeneration units must be carried for another growing season. Unlike 2-0 seedlings, which must be transplanted and saved as 2-1 stock, holdover 1-0 seedlings can be either held in place to produce 2-0 stock or transplanted to produce 1-1 stock (see the next chapter, Moving into the '90's). Testing in Humboldt Nursery has shown that carrying 1-0 seedlings in place can result in high cull rates, up to 25 percent or more depending on seed source, sowing date, and stocking.

Sizes and yields of the 2-0 Douglas-fir produced by holding 1-0 seedlings in place were determined in the 1985 and 1987 sowing window tests (*table 15*). Second-year seedlings in these sowings were undercut twice in spring and evaluated for 2-0 height, stem diameter, volume, and stocking in fall, after root growth had ceased. Spring undercutting is essential for balancing top and root growth in early sowings, and was done by using a March-May combination that had proven successful earlier (see Undercutting Early Sowings for 2-0 Stock).

In the 1985 test of California sources, seed source and sowing date significantly affected spring leader length, summer lammas length, and 2-0 height, whereas sowing date alone affected stem diameter

and stocking (*table 32*). In the 1987 test of California and Oregon sources, seed source and sowing date significantly affected height, diameter, and stocking (*table 33*). Seedlings of coastal sources, that is, California source GQ 091.25 and Oregon source HE 053.10, had greater height, leader length, and stem volume than those of their inland counterparts, California source SA 311.40 and Oregon source MK 472.45. Regardless of source, however, the 2-0 seedlings produced in winter and early-spring sowings were consistently taller and stouter than those produced in later sowings (*table 34*).

Lammas growth, summer-autumn extension of the leader, characterizes May-June sowings of Douglas-fir in Humboldt Nursery. This innate tendency is pronounced in coastal but not inland sources, suggests harmful delays in the onset of seedling dormancy, and has periodically troubled clientele. In the January-March sowings, however, spring leaders mostly set winter resting buds and lammas growth is rare.

Lammas growth in the January-March, 1985 sowings accounted for just 1 to 4 percent of the gain in height of second-year seedlings of inland source SA, and just 2 to 7 percent of that of coastal source GQ. In the April-May sowings, however, the coastal seedlings doubled and tripled in height, and lammas growth supplied one-fifth and one-third of the gains, respectively. Such catch-up growth in spring and lammas growth in summer-autumn typified second-year seedlings in the traditional cultural regime.

The 2-0 seedlings produced in 1986 were largest in the January sowings, nearly as large in February-March sowings, and smallest in the May sowings.

Table 32—Significance of seed source and sowing date effects on growth, size, and stocking of 2-0 Douglas-fir in Humboldt Nursery¹

Source of variation	Error term	Degrees freedom	Variance (mean square) for...					Stems per ft ²
			Seedling height (cm)	Spring leader (cm)	Summer lammas (cm)	Stem diam (mm)		
Sowing date, D	BD	4	716.0 **	174.0 **	49.2 **	33.62 **	733.4 **	
Seed source, S	BS	1	2516.3 **	406.6 **	218.4 *	10.21	106.4	
Block, B	P	2	172.2 **	5.3	10.9 **	.28	84.2	
DS	BDS	4	20.9	19.1	40.8 **	1.30	13.6	
BD	P	8	9.8	7.1	3.5 *	1.35 *	49.2	
BS	P	2	14.9	1.1	9.8 **	.87	32.7	
BDS	P	8	23.7	7.4	3.5 *	2.14 **	82.0	
P(BDS)		90	13.5	4.2	1.7	.53	38.1	

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings in January-May sowings of coastal and inland sources from northern California were undercut in March and May; see *tables 28, 34*.

Table 33—Significance of seed source and sowing date effects on size and stocking of 2-0 Douglas-fir in Humboldt Nursery¹

Source of variation	Error Degrees of freedom	Variance (mean square) for...		
		Seedling height (cm)	Stem diam (mm)	Stems per 2 ft ²
Sowing date, D BD	4	690.01 **	9.817 **	2895.9 **
Seed source, S BS	3	2106.25 **	4.091 **	1055.9 **
Block, B	P	392.94 **	.157	358.6 **
DS	BDS	19.94	.276	212.7
BD	P	25.12 **	.256 **	161.8 **
BS	P	81.95 **	.335 **	105.2
BDS	P	15.14 **	.291 **	79.7
P(BDS)	120	6.94	.094	59.0

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings in January-May sowings of coastal and inland sources from western Oregon and northern California were undercut in March and May; see *tables 28, 34*.

The thick stems and low cull rates in the January sowings reflected the low stocking, which, as noted earlier, was caused by juncos shortly after sowing (see Winter and Spring Sowings). Cull rates in the February-March sowings averaged 9 to 14 percent. By contrast, cull rates in the May sowings averaged 32 percent for coastal source GQ and 24 percent for inland source SA, percentages typical of traditional sowings in good years.

Within the sowing window in the 1987 test, 2-0 seedling size decreased gradually with later sowing for coastal and inland California sources GQ and SA and for coastal Oregon source HE, but remained constant for inland Oregon source MK. Stocking within the window averaged 24 stems per square foot for the California sources, and 31 and 25 stems per square foot for the coastal and inland Oregon sources, respectively.

Table 34—Growth, size, stocking, and cull rate of 2-0 Douglas-fir in winter and spring sowings in Humboldt Nursery¹

Seed source ²	Seedling traits, by sowing date					LSD ³
1985 sowings	Jan 15	Feb 19	Mar 21	Apr 23	May 17	
N Coast Range, coastal						
GQ 091.25						
2-0 height, cm	46.4	42.8	37.5	38.2	31.6	4.29
leader, cm	23.4	19.7	17.8	17.8	14.2	1.74
lammas, cm	1.7	.4	1.3	4.2	7.2	2.82
diam, mm	8.38	5.89	5.45	5.69	4.75	.80
stem vol, cm ³	10.24	4.66	3.50	3.89	2.24	—
stems per ft ²	10.2	21.0	21.8	21.4	23.5	5.16
cull rate, pct	4.9	9.4	13.8	17.2	24.0	—
Klamath Mtns, central						
SA 311.40						
2-0 height, cm	34.7	34.5	30.6	29.6	21.2	3.19
leader, cm	16.7	16.0	15.7	14.8	11.2	2.16
lammas, cm	.4	.1	.1	.2	.5	.66
diam, mm	7.04	5.54	5.32	5.02	4.33	.49
stem vol, cm ³	5.40	3.33	2.72	2.34	1.25	—
stems per ft ²	12.0	20.9	23.1	23.8	27.5	4.95
cull rate, pct	2.8	11.5	14.0	16.1	32.1	—

¹ Seedlings were undercut at 13 cm in March and 18 cm in May. Cull rate is the percent of seedlings with stem diameter <4.5 mm.

² See *fig. 10*, and *tables 28, 32, 33*.

³ Least significant difference ($p = 0.05$).

Associated cull rates averaged 8 and 15 percent for the coastal and inland California sources, and 19 and 24 percent for the coastal and inland Oregon sources.

Outside the window, overwinter mortality markedly reduced stocking, and cull rates were excessive and unacceptable. Stocking in the May sowings ranged from 15 to 18 stems per square foot, down one-third from the 25 to 27 stems per square foot recorded for 1-0 seedlings (see *table 28*). Even worse, half of the 2-0 survivors were still too small to outplant (*table 34*). Cull rates averaged 53 and 48 percent for coastal and inland sources GQ and SA, and 37 and 57 percent for coastal and inland sources HE and MK.

First-year seedlings in Humboldt's traditional May-June sowings have always been plagued by mycorrhizal deficiency, stunting, and Phoma blight. Overwinter losses caused by Phoma in the 1979-1983 crops, for example, totalled more than 10 million seedlings (Frankel 1989). Humboldt now prevents such disastrous losses by sowing anytime in January-March, by April 10 at the latest, as soil and weather conditions permit. Sizes and yields of the 2-0 seedlings produced in early sowings in the 1985 and 1987 tests show that Humboldt can readily supply large, healthy 2-0 Douglas-fir for coastal and inland regions of western Oregon and northern California.

Table 34—Growth, size, stocking, and cull rate of 2-0 Douglas-fir in winter and spring sowings at Humboldt Nursery—continued¹

Seed source ²		Seedling traits, by sowing date					LSD ³
1987 sowings		Jan 21	Feb 19	Mar 25	Apr 9	May 21	
N Coast Range, coastal							
GQ 091.25							
2-0	height, cm	50.1	46.3	47.4	43.9	34.5	5.59
	leader, cm	28.8	25.0	26.6	27.1	24.0	—
	diam, mm	5.64	5.36	5.44	5.38	3.99	.64
	stem vol, cm ³	5.01	4.18	4.41	3.99	1.73	—
	stems per ft ²	23.7	24.9	24.1	24.5	15.6	5.15
	cull rate, pct	8.2	9.2	6.0	6.6	53.2	—
Klamath Mtns, central							
SA 311.40							
2-0	height, cm	35.1	34.1	36.3	31.5	25.7	2.86
	leader, cm	18.5	17.7	18.5	16.1	15.4	—
	diam, mm	5.27	5.09	4.93	4.87	3.69	.56
	stem vol, cm ³	3.06	2.78	2.77	2.35	1.10	—
	stems per ft ²	21.7	23.3	27.3	22.9	17.9	8.11
	cull rate, pct	12.6	15.0	16.1	15.5	48.1	—
Oregon Coast Range, N							
HE 053.10							
2-0	height, cm	40.4	38.4	38.0	35.3	29.5	3.58
	leader, cm	23.5	20.6	21.4	20.0	19.2	—
	diam, mm	4.91	4.62	4.92	4.61	4.06	.68
	stem vol, cm ³	3.06	2.58	2.89	2.36	1.53	—
	stems per ft ²	29.0	34.6	30.2	29.2	15.4	6.42
	cull rate, pct	17.2	20.4	16.7	20.6	36.8	—
Oregon Cascades, W							
MK 472.45							
2-0	height, cm	30.3	30.3	29.1	29.8	22.3	5.58
	leader, cm	18.2	17.5	17.4	17.7	14.6	—
	diam, mm	4.90	4.66	4.52	4.56	3.64	.40
	stem vol, cm ³	2.29	2.07	1.87	1.95	.93	—
	stems per ft ²	21.9	25.6	26.4	27.3	16.7	10.15
	cull rate, pct	24.6	23.2	29.0	20.5	56.8	—

UNDERCUTTING EARLY SOWINGS FOR 2-0 STOCK

Humboldt Nursery can efficiently supply 1-0 Douglas-fir that survives and grows well, but for various orthodox reasons, 2-0 Douglas-fir is still the principal order. To fill requests for 2-0 stock, Humboldt holds what is essentially 1-0 stock in place for a second growing season (see the next chapter, Moving into the '90's).

Once the advantages of early sowing had been proven, Humboldt began to sow everything early. Sowing in most years now is completed by April 10, to prevent stunting and reduce mortality. As we had anticipated, sowing early negated the standard practice of midsummer undercutting, Humboldt's chief means of balancing the top and root growth of second-year seedlings. Because first-year seedlings in early sowings already averaged 20 cm (8 in) tall (see *tables 16, 22, 28*), spring leader extensions rapidly surpassed the target heights set for 2-0 planting stock.

Appropriate testing demonstrated that double spring undercutting could provide the means to control growth and carry large 1-0 seedlings over for balanced 2-0 stock. The first round of undercutting is done in March, when seedlings resume root elongation, and the second round is done in May, before the leaders approach target height.

Single and Double Undercuts Compared

Field experience had shown that 2-0 Douglas-fir from the traditional May sowings survived well when top-root ratios averaged 2 or less (dry weight basis). Balance was achieved by undercutting second-year seedlings at a depth of 20 cm (8 in) in July or August, before the leaders reached target height (see *fig. 9*). This single undercut effectively induced budset and increased root mass and fibrosity. Nursery research on Monterey pine (*Pinus radiata* D. Don) in New Zealand has since indicated that undercut seedlings preferentially translocate photosynthate and nitrogen to the roots. There, a summer undercut of first-year seedlings reduced top height, stem diameter, and total nitrogen content, but increased the mass and nitrogen content of lateral roots (Coker 1984).

To develop an effective undercutting regime for producing balanced 2-0 stock from seedlings in early sowings, variously timed single and double undercuts were applied to second-year seedlings in the March, 1978 and April, 1979 sowings (*table 15*). Our first test compared single undercuts in May and

July with double undercuts in March-July and May-July combinations. The July undercut was far too late to prevent excessive height growth, but the March-July combination resulted in 2-0 seedlings with acceptable top-root ratios. Our second test focused on spring undercuts, with single undercuts in March, April, and May compared with a double undercut in a March-May combination.

Successive undercuts in both tests were timed to coincide with observed stages of seedling top and root growth. March undercuts were made when the roots were resuming elongation. April undercuts were made after budburst, when root elongation was extensive. May undercuts were made when the shoots were succulent and expanding rapidly, and July undercuts, when the shoots were forming buds.

The first undercut in each double combination was set shallow in order to force lateral root growth in the lifting zone. The second undercut was set 5 cm (2 in) deeper, to save the new roots generated by cut taproots. In 1979, the first undercut was made at a depth of 15 cm (6 in) on March 14 and May 10, and the second, at 20 cm (8 in) on July 6. In 1980, the first undercut was made at 12 cm (5 in) on March 24, and the second, at 17 cm (7 in) on May 28. Harvest undercuts were made at the standard depth of 25 cm (10 in).

Seedlings undercut in the first test were sources HA 312.25 and HA 312.50 from the southern Klamath Mountains. Those undercut in the second test were sources typical of coastal and inland regions in western Oregon and northern California, sources AL 252.10 and OA 482.30 from the northern Oregon Coast Range and western Oregon Cascades, respectively, and sources GQ 091.20 and OK 321.30 from the coastal North Coast Range and eastern Klamath Mountains.

The test layout in each source consisted of two randomly located blocks of treatment plots, with untreated controls at the ends of each block. Undercut plots were 30 ft (9 m) long, and treatments were sequenced to limit damage caused by insertion and removal of the undercutting blade. Seedlings were irrigated to a depth of 30 cm (12 in) just after undercutting and whenever predawn xylem water potentials reached -5 bars (0.5 mP), except -8 bars in late summer when moderate stress was permitted to induce dormancy (Blake and others 1979, Zaerr and others 1981).

Seedlings were evaluated for 2-0 size, top and root growth capacity before and after cold storage, and survival and growth in the seed zones of origin (see Assessing Planting Stock Quality, Standard Testing Procedures). Seedlings were dug monthly in November-March, graded to a stem diameter of 4 mm (0.16 in), root-pruned 25 cm (10 in) below the cotyledon scars, and stored at 1° C (34° F) until

spring planting time. Undercut treatment and lifting date effects on 2-0 size and growth capacity were assessed using variance analysis program BMD P2V, and effects on field survival and growth, program BMD P8V, with treatments and dates fixed and blocks random (Jennrich and others 1985, Jennrich and Sampson 1985).

The single spring undercuts all produced balanced planting stock, but double undercuts

produced the best balanced stock (*table 35*). Given the March-July combination, seedlings of sources HA 312.25 and HA 312.50 from the southern Klamath Mountains averaged 35 and 38 cm tall and had top-root ratios of 1.6 and 1 .9, respectively. The single May undercut and May-July combination were almost as good, as seedlings in those treatments averaged 38 cm tall and had top-root ratios of 2.1 and 1.8. By contrast, the July undercut was

disastrously late, producing seedlings that averaged 56 cm tall, had top-root ratios of 2.1 and 2.5, and were too big to fit in the standard packing bag.

The double spring undercut, or March-May combination, produced shorter, better-balanced seedlings than any single undercut. Seedlings of coastal sources AL 252.10 and GQ 091.20 from the northern Oregon Coast Range and North Coast Range averaged 36 and 31 cm tall and had top-root ratios of 1.9 and 2.0, respectively. Those of inland sources OA 482.30 and OK 321.30 from the western Oregon Cascades and eastern Klamath Mountains averaged 26 and 24 cm tall and had top-root ratios of 1.8 and 1.6.

Seedling top and root growth capacity (TGC, RGC) were affected more by seed source and lifting date than by undercut treatment, but double undercuts were better than single undercuts. Compared to the May undercut, the March-July combination increased RGC at lifting and after cold storage for source HA 312.25 from the southern Klamath Mountains (*tables 36, 37*), and the March-May combination increased RGC at lifting for coastal and inland California sources GQ and OK (*table 38*). Given the May undercut and lifting within the source windows, coastal and inland sources AL and OA from Oregon and GQ and OK from California all had high RGC after cold storage (*table 39*).

Table 35—Size and balance of 2-0 Douglas-fir from tests of single and double undercuts in Humboldt Nursery¹

Seed source ² and undercut date ³	Seedling height	Stem diam	Top weight	Root weight	Top-root ratio
	cm	mm	g	g	
Klamath Mtns, S					
HA 312.25 80					
Mar, Jul	34.6 b	5.52 b	7.22 b	4.96 ab	1.62 b
May, Jul	37.2 b	5.84 ab	7.10 b	3.74 b	2.06 a
May only	38.0 b	6.26 ab	8.92 b	4.40 ab	2.12 a
Jul only	56.0 a	6.74 a	12.48 a	6.33 a	2.08 a
HA 312.50 80					
Mar, Jul	37.5 b	8.78	17.46 b	9.70	1.86 b
May, Jul	38.4 b	8.59	16.05 b	9.30	1.81 b
May only	37.4 b	8.68	17.62 b	10.18	1.84 b
Jul only	55.7 a	8.51	22.91 a	9.83	2.49 a
Oregon Coast Range, N					
AL 252.10 81					
Mar, May	36.2 b	6.78	10.67 b	5.87	1.91 c
Mar only	38.8 b	7.35	11.51 ab	5.49	2.23 ab
Apr only	42.2 a	7.29	13.03 a	5.80	2.41 a
May only	38.5 b	7.25	12.27 ab	6.22	2.12 b
Oregon Cascades, W					
OA 482.30 81					
Mar, May	26.0 d	5.00 b	5.48 b	3.17 ab	1.82 c
Mar only	35.7 a	5.69 a	7.23 a	3.22 a	2.29 a
Apr only	33.1 b	5.75 a	7.50 a	3.57 a	2.14 ab
May only	29.8 c	5.24 b	5.79 b	2.97 b	2.03 be
N Coast Range, coastal					
GQ 091.20 81					
Mar, May	30.8 b	4.70 b	4.72 b	2.50 b	1.95 b
Mar only	35.0 a	5.21 a	6.25 a	3.05 a	2.12 a
Apr only	31.1 b	5.03 ab	5.35 b	2.97 a	1.88 b
May only	31.4 b	5.04 ab	5.24 b	2.63 ab	2.01 ab
Klamath Mtns, E					
OK 321.30 81					
Mar, May	23.9 b	4.78	4.61 b	2.94	1.64 b
Mar only	24.9 ab	4.92	5.18 ab	2.92	1.84 a
Apr only	25.3 ab	5.05	5.52 a	3.19	1.79 a
May only	25.9 a	4.83	5.11 ab	3.12	1.73 ab

¹ Means followed by unlike letters differ significantly (p = 0.01).

² See *fig. 10*, and *table 1* in Appendix B.

³ Sources HA were undercut at 15 cm in March or May and at 20 cm in July; sources AL, OA, GQ, and OK were undercut at 13 cm in March or April and at 18 cm in May.

Table 36—Significance of single- and double-undercut effects on top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² test, and source of variation	Degrees freedom	Variance (mean square) for...			
		Budburst (pct)	Shoot length (cm)	Roots elongated	
				≥1.5 cm	<1.5 cm
Klamath Mtns, S					
Fresh					
Undercut, T	1	0.005	0.13	1385.4 **	4507
Lifting date, D	4	1.422**	65.26 **	428.7	6245
TD	4	.011 **	.07	22.2	480
Error	19	.002	.18	117.2	1460
Stored (May 6)					
Undercut, T	1	0.008	1.04	309.8 *	3331 *
Lifting date, D	4	.531 **	16.87 **	321.2 **	3823 **
TD	4	.005	.80	8.6	229
Error	20	.013	1.08	51.9	471

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings of source HA 312.25 were undercut in March and July or in May only, lifted monthly in autumn to spring, and stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 37*.

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings of source HA 312.25 were undercut in March and July or in May only, lifted monthly in autumn to spring, and stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 37.

Table 37—Top and root growth capacity (TGC, RGC) of single- and double-undercut 2-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² test, and undercut date ³	TGC and RGC, by nursery lifting date					LSD ⁴
	Nov 19	Dec 17	Jan 14	Feb 11	Mar 10	
Klamath Mtns, S						
Fresh						
Mar, Jul						
TGC budburst, <i>pct</i>	0.0	0.0	86.7	100.0	100.0	7.8
shoot length, cm	.0	.0	.4	3.6	7.4	.7
RGC roots ≥1.5 cm	41.3	45.5	59.9	39.3	32.5	18.5
<1.5 cm	120.3	178.9	206.3	158.2	109.4	65.3
May only						
TGC budburst, <i>pct</i>	0.0	6.7	70.0	96.7	100.0	7.8
shoot length, cm	.0	.0	.3	4.0	7.7	.7
RGC roots ≥1.5 cm	28.8	32.6	39.1	27.8	20.5	18.5
<1.5 cm	107.5	129.4	171.4	133.4	105.9	65.3
Stored (Apr 21)						
Mar, Jul						
TGC budburst, <i>pct</i>	30.0	100.0	90.0	100.0	93.3	19.2
shoot length, cm	.7	4.0	3.5	4.7	4.5	1.8
RGC roots ≥1.5 cm	8.5	27.1	23.1	24.7	21.5	12.3
<1.5 cm	34.6	109.5	75.7	90.3	79.5	37.0
May only						
TGC budburst, <i>pct</i>	26.7	93.3	83.3	93.3	100.0	19.2
shoot length, cm	.3	3.2	3.0	3.7	5.4	1.8
RGC roots ≥1.5 cm	3.2	21.9	14.1	21.0	12.7	12.3
<1.5 cm	16.7	67.7	54.7	80.9	64.2	37.0

¹ Seedlings of source HA 312.25 were stored at 1° C (34°F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 36.

³ Seedlings were undercut at 15 cm in March or May and at 20 cm in July.

⁴ Least significant difference (p = 0.05).

Table 38—Significance of seed source, undercut, and lifting date effects on top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² test, and source of variation	Degrees freedom	Variance (mean square) for...				
		Budburst (pct)	Shoot length (cm)	Root length (cm)	Roots elongated	
					≥1.5 cm	<1.5 cm
Oregon						
AL 252.10, OA 482.30						
Fresh						
Seed source, S	1	0.161 *	1.56	25810*	4446 **	14127 *
Undercut, T	1	.021	.01	7865	1552	975
Lifting date, D	4	3.995 **	150.04 **	22981 **	17156 **	48741 **
ST	1	.005	.00	3265	163	1360
SD	4	.128 **	.64	3465	622	1725
TD	4	.008	1.64	2777	433	368
STD	4	.009	.19	8437	1039	876
Error	100	.031	1.06	4177	596	2282
Stored (Apr 6)						
Seed source, S	1	0.037	39.62 **	14216	2959 *	18706 **
Lifting date, D	4	1.231 **	37.81 **	57206**	7905 **	30958 **
SD	4	.050	8.19 **	5001	951	3183
Error	48	.034	1.25	4208	625	2067
California						
GQ 091.20, OK 321.30						
Fresh						
Seed source, S	1	0.048	20.75 **	7274	1460	2
Undercut, T	1	.012	.85	14703**	1963	538
Lifting date, D	4	4.595 **	128.69 **	67664**	8487 **	14213 **
ST	1	.001	.09	4711	326	3060
SD	4	.031	3.71 **	9103**	1297	1519
TD	4	.045	.37	3544	478	680
STD	4	.008	1.47	1615	331	342
Error	100	.019	.62	3453	493	1221
Stored (May 4)						
Seed source, S	1	0.237 **	96.64 **	18262*	3128 **	11419 **
Lifting date, D	4	.936 **	46.35 **	34003**	5031 **	16378 **
SD	4	.089 **	4.89 **	6336	869	1754
Error	48	.006	1.28	2944	403	896

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings undercut in March and May or in May only were tested monthly in autumn to spring; those undercut in May only were tested after cold storage at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 39*.

Table 39—Top and root growth capacity (TGC, RGC) of May-undercut 2-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² and test	TGC and RGC, by nursery lifting date					LSD ³
1980-81	Nov 10	Dec 8	Jan 5	Feb 2	Mar 2	
Oregon Coast Range, N; AL 252.10						
Fresh						
TGC budburst, <i>pct</i>	0.0	56.7	56.7	93.3	100.0	20.1
shoot length, <i>cm</i>	.0	.4	.6	4.1	5.6	1.2
RGC root length, <i>cm</i>	41.5	258.4	183.4	200.6	259.2	74.1
roots ≥1.5 <i>cm</i>	17.3	95.4	74.4	76.7	107.9	28.0
<1.5 <i>cm</i>	73.3	197.3	173.5	168.0	218.2	54.8
Stored (Apr 6)						
TGC budburst, <i>pct</i>	12.0	80.0	100.0	96.7	100.0	21.3
shoot length, <i>cm</i>	.2	4.6	5.0	4.4	5.5	1.3
RGC root length, <i>cm</i>	16.1	115.2	209.6	227.9	206.9	75.5
roots ≥1.5 <i>cm</i>	6.8	44.5	80.6	90.8	80.0	29.1
<1.5 <i>cm</i>	14.8	105.8	158.6	174.3	168.3	52.9
Oregon Cascades, W; OA 482.30						
Fresh						
TGC budburst, <i>pct</i>	0.0	20.0	63.3	93.3	100.0	20.1
shoot length, <i>cm</i>	.0	.0	.6	3.3	5.6	1.2
RGC root length, <i>cm</i>	58.9	252.0	190.8	185.0	161.9	74.1
roots ≥1.5 <i>cm</i>	22.5	89.0	70.5	74.5	66.0	28.0
<1.5 <i>cm</i>	81.2	177.0	154.2	172.2	171.0	54.8
Stored (Apr 6)						
TGC budburst, <i>pct</i>	26.7	60.0	86.7	90.0	100.0	21.3
shoot length, <i>cm</i>	.5	1.1	2.1	2.3	5.4	1.3
RGC root length, <i>cm</i>	33.2	117.1	135.6	154.5	178.4	75.5
roots ≥1.5 <i>cm</i>	15.0	44.1	50.2	57.0	64.8	29.1
<1.5 <i>cm</i>	29.7	73.2	102.5	99.7	136.8	52.9
1980-81						
	Nov 17	Dec 15	Jan 12	Feb 9	Mar 9	
N Coast Range, coastal; GQ 091.20						
Fresh						
TGC budburst, <i>pct</i>	0.0	36.7	70.0	100.0	100.0	15.8
shoot length, <i>cm</i>	.0	.3	.5	1.9	4.9	.9
RGC root length, <i>cm</i>	98.0	189.0	210.0	248.4	137.3	67.4
roots ≥1.5 <i>cm</i>	38.8	74.3	79.0	101.2	54.5	25.5
<1.5 <i>cm</i>	97.2	145.7	162.0	161.7	123.0	40.1
Stored (May 4)						
TGC budburst, <i>pct</i>	12.0	96.7	80.0	100.0	100.0	9.2
shoot length, <i>cm</i>	.1	4.6	2.8	3.3	5.4	1.3
RGC root length, <i>cm</i>	14.6	190.8	91.1	179.3	162.7	63.1
roots ≥1.5 <i>cm</i>	5.9	69.6	32.2	67.7	62.1	23.4
<1.5 <i>cm</i>	8.0	127.2	66.2	115.0	114.6	34.8
Klamath Mtns, E; OK 321.30						
Fresh						
TGC budburst, <i>pct</i>	0.0	46.7	76.7	100.0	100.0	15.8
shoot length, <i>cm</i>	.0	.4	.6	4.2	6.1	.9
RGC root length, <i>cm</i>	86.6	221.4	261.1	169.7	128.8	67.4
roots ≥1.5 <i>cm</i>	37.4	82.2	94.4	65.5	50.0	25.5
<1.5 <i>cm</i>	124.7	158.2	196.5	151.2	110.8	40.1
Stored (May 4)						
TGC budburst, <i>pct</i>	53.3	100.0	100.0	100.0	100.0	9.2
shoot length, <i>cm</i>	1.9	6.2	6.4	7.6	7.1	1.3
RGC root length, <i>cm</i>	105.6	220.4	168.9	162.9	160.4	63.1
roots ≥1.5 <i>cm</i>	39.3	86.4	62.3	62.1	61.6	23.4
<1.5 <i>cm</i>	73.7	124.8	99.3	143.3	131.8	34.8

¹ Seedlings undercut at 18 cm in May were tested monthly in autumn to spring and after cold storage at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 38*.

³ Least significant difference (p = 0.05).

Table 40—Significance of undercut and lifting date effects on survival and growth in field performance tests of 2-0 Douglas-fir from Humboldt Nursery ¹

Seed source ² (planting date) and source of variation ³	Variance (mean square) for...			
	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
Oregon Coast Range, N				
AL 252.10 81 (Apr 13)				
1 yr: Undercut, T	2.66	99.5 **	25.38*	2.96 **
Lifting date, D	261.41 **	294.8 **	154.07**	.34
Block, B	1.50	28.6	8.68	.52
TD	3.67 **	16.3	15.62**	.57
BT	1.05	21.2	6.21	.52
BD	1.55	39.2	7.25	.54
BTD	.82	29.6	5.38	.63
2 yr: Undercut, T	1.80	175.5 *	31.3 *	5.01 *
Lifting date, D	261.21 **	428.2 **	56.2	2.78
Block, B	2.02	154.6	220.5	4.49
TD	3.82 **	35.0	20.0	1.39
BT	.98	41.5	10.6	1.32
BD	1.40	64.2	46.7	2.02
BTD	.86	54.3	14.6	1.11
3 yr: Undercut, T	1.99	270.6 *	24.0	7.70
Lifting date, D	250.34 **	1032.1 **	104.9 *	18.57
Block, B	2.31	951.0	340.7	21.13
TD	4.74 **	65.6	11.8	1.49
BT	.96	78.7	14.2	3.20
BD	1.36	139.0	35.5	5.34
BTD	.84	103.6	19.7	1.95
4 yr: Undercut, T	2.86	479.6 *	30.9	13.15 **
Lifting date, D	250.03 **	1798.3 **	211.0 **	29.57 **
Block, B	1.99	2157.8	252.4	73.88
TD	4.64 **	131.8	19.9	3.01
BT	1.08	127.3	22.4	2.68
BD	1.58	270.9	47.7	7.61
BTD	.82	198.0	35.6	3.74
N Coast Range, coastal				
GQ 091.20 81 (Apr 8)				
1 yr: Undercut, T	3.21	28.2	13.3	3.64
Lifting date, D	105.28 **	498.0 *	92.5	23.46 **
Block, B	39.23	304.8	76.8	21.11
TD	2.99	49.9	27.2	2.95
BT	3.01	54.5	14.8	1.39
BD	7.36	136.7	41.3	5.91
BTD	2.58	60.4	17.7	2.22
2 yr: Undercut, T	2.34	17.4	4.8	3.55
Lifting date, D	103.84 **	416.4 **	80.5	24.68
Block, B	39.55	132.8	88.4	14.18
TD	2.94	32.6	22.8	2.98
BT	3.18	35.4	11.2	1.82
BD	7.43	95.5	49.5	6.88
BTD	2.58	30.6	17.5	2.03

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings were undercut in March, April, May, or March and May, lifted monthly in autumn to spring, stored at 1° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 41.

³ Degrees freedom were 3, 4, 9, 12, 27, 36, and 108 for T, D, B, TD, BT, BD, and BTD, respectively.

Double undercuts improved field survivals of inland sources, but not coastal sources (*tables 40, 41*). First-year survival within the lifting windows of southern Klamath Mountains sources HA 312.25 and HA 312.50 was 15 percent greater for the March-July combination than for the July undercut alone. Similarly, survivals within the lifting windows of sources OA and OK from the western Oregon Cascades and eastern Klamath Mountains were 12 and 10 percent greater, respectively, for the March-May combination than for the May undercut alone.

Although double-undercut seedlings survived better, survival was mostly disappointing. Survivals of double-undercut seedlings averaged 47 and 53 percent in the southern Klamath Mountains tests and 65, 75, and 83 percent in the North Coast Range, Oregon Cascades, and eastern Klamath Mountains tests, respectively. Expectation was achieved only in the Oregon Coast Range test, where survival averaged a solid 96 percent.

Field reviews found that poor root placement caused most of the mortality. Robust seedlings with bushy roots were forced into wedge-shaped holes, repeatedly demonstrating that planting hoes should not be used to plant large stock. Taproots of dead and fading seedlings were J-rooted, lateral roots grew either horizontally or only slightly downward, and lethal water stress developed as the surface soil dried. By contrast, the Oregon Coast Range seedlings thrived despite being the second-largest tested (*table 35*). These seedlings were planted with shovels, following standard practice on the Siuslaw National Forest, and survival within the source lifting window averaged 95 to 98 percent, regardless of undercut treatment.

Critical RGC is greatly inflated when roots are crammed into small planting holes. In the North Coast Range, Oregon Cascades, and Klamath Mountains tests, where planting hoes were used and J-rooting was common, mortality was high and

Table 40—Significance of undercut and lifting date effects on survival and growth in field performance tests of 2-0 Douglas-fir from Humboldt Nursery—continued¹

Seed source ² (planting date) and source of variation ³	Variance (mean square) for...			
	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
Oregon Cascades, W				
OA 482.30 81 (Mar 27)				
1 yr: Undercut, T	31.53 **	345.2**	34.6	—
Lifting date, D	176.19 **	264.0**	68.5 **	—
Block, B	11.62	21.5	18.8	—
TD	2.26	44.0*	24.0	—
BT	2.16	23.6	17.0	—
BD	5.78	25.8	17.5	—
BTD	2.76	19.2	14.9	—
Klamath Mtns, E				
OK 321.30 81 (Apr 4)				
1 yr: Undercut, T	11.16 *	49.0*	3.98	1.68**
Lifting date, D	105.66 **	54.2*	3.72	1.57
Block, B	16.07	37.8	11.94	6.21
TD	4.09 *	23.6	2.09*	.43
BT	3.14	15.0	1.11	.25
BD	5.05	14.0	2.96	1.42
BTD	2.08	13.0	1.00	.44

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings were undercut in March, April, May, or March and May, lifted monthly in autumn to spring, stored at 1° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 41*.

³ Degrees freedom were 3, 4, 9, 12, 27, 36, and 108 for T, D, B, TD, BT, BD, and BTD, respectively.

critical RGC was 1 10, 115, and 125 cm, respectively. In the Oregon Coast Range test, where shovels were used and root placement was good, survival was superior and critical RGC was 1 cm (*table 42*).

Spring undercut treatment had little practical effect on the growth of seedlings lifted and stored within the source lifting window (*table 41*). Growth was determined largely by seed source and planting site, and was greater on the cooler sites of coastal regions than on the warmer sites of inland regions. In the test of Oregon Coast Range source AL 252.10, height and stem diameter the first year averaged 49 cm and 6 mm, respectively, and leader length, 16 cm, for an increase in height of 48 percent. In the test of North Coast Range source GQ 091.20, height and diameter averaged 44 cm and 10.8 mm, and leader length, 19 cm, for an increase in height of 76 percent. In the test of Oregon Cascades source OA 482.30, height averaged 35 cm and leader length, 10 cm, for an increase in height of 40 percent. Double undercutting source OA seedlings in the nursery reduced height growth on the planting site by 13 percent, but improved survival by 14 percent. Lastly, in the test of Klamath Mountains source OK 321.30, height and diameter averaged 27 cm and 5.8 mm, and leader length, 5.9 cm, for an increase in height of 28 percent.

The continued high survival and strong growth of seedlings in the Oregon Coast Range test epitomized rapid establishment. Within the source lifting window, survival averaged 94 percent after 4 years, down just 2 percent from the first year. Tree height and stem diameter averaged 65 cm and 9.1 mm after 2 years, 100 cm and 14.6 mm after 3 years, and 147 cm and 20.6 mm after 4 years. Leader length averaged 18, 36, and 47 cm in years 2, 3, and 4, for height increases of 47, 56, and 47 percent, respectively. By contrast, growth conditions in the North Coast Range test suggested incipient failure. Survivors were severely browsed the first winter and had to compete with a fierce regrowth of sprouting tanoak and madrone the second year. While survival held at 64 percent, the net gains in growth were practically zero. Height and diameter averaged 46 cm and 11 mm after 2 years, and the regenerated leaders, 19 cm, barely enough for a net height increase of 2 cm.

Management Implications

In Humboldt Nursery, spring undercutting is essential to hold 1-0 Douglas-fir in place for 2-0. Delaying undercutting until midsummer, the earliest that second-year seedlings in traditional May sowings could be undercut, results in excessive top heights and top-root ratios, and is not a viable option.

Effects of spring undercutting on field survival depend on seed source. Seedlings of inland sources survived better with double undercutting, whereas those of coastal sources survived the same whether they were undercut once in March, April, or May, or twice using a March-May combination. Double spring undercuts produce seedlings with shorter tops, bushier roots, lower top-root ratios, and higher RGC after cold storage than single undercuts. Such traits should improve survival and growth on coastal sites as well as inland sites, especially in years of prolonged summer drought. Hence, double undercutting is recommended for coastal as well as inland sources.

To obtain balanced 2-0 Douglas-fir either from the January-March sowings originally scheduled for 1-0 stock or from the March-April sowings planned for 2-0, second-year seedlings of every source should be undercut twice in spring, as follows:

- March, at a depth of 15 cm (6 in), anytime from shortly before to shortly after seedlings resume root elongation
- May, at a depth of 20 cm (8 in), when seedling leaders are still at least 8 to 10 cm (3 to 4 in) short of target height

This is not a rigid prescription. If warm weather permits seedlings to resume growth early, which happens in some years, the paired undercuts could be advanced to February and April. On the other hand, if cold weather delays growth, which also happens, the undercuts might be postponed until April and June.

All seedlings should be vertically root-pruned 4 weeks after the first undercut, or midway between undercuts, and certainly before top growth closes between rows. After undercutting and after vertical pruning, and preferably on the same day, seedlings

should be deep-irrigated to settle and reseal the beds. To promote root growth, predawn xylem water potentials should be kept above -5 bars (0.5 mP) for at least 6 to 8 weeks after the second undercut. Experience in Humboldt Nursery has shown that the summer water stress used to induce seedling dormancy can be safely delayed until August and narrowed to 1 month or less (Blake and others 1979).

Double undercutting produces 2-0 seedlings with high survival and growth potentials. Necessarily, however, the seedlings also have more massive root systems than those to which most tree planters are accustomed. Large root systems demand wide, deep planting holes, and experience repeatedly teaches that the best tool for digging such holes is not the ubiquitous planting hoe. To insure the survival and growth of large stock, planting holes should be dug with shovels, or better yet, powered soil augers.

Table 42—Critical root growth capacities (RGC) determined in field performance tests of May-undercut 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date)	Critical RGC	Regression ³	
		b	r ²
	cm		
Oregon Coast Range, N			
AL 252.10 81 (Apr 13)	1	1.01	0.99
Oregon Cascades, W			
OA 482.30 81 (Mar 27)	115	1.01	0.98
N Coast Range, coastal			
GQ 091.20 81 (Apr 8)	110	1.01	0.91
Klamath Mtns, E			
OK 321.40 81 (Apr 4)	125	1.00	0.98

¹ Seedlings were undercut at 18 cm in May, lifted monthly from autumn to spring, stored at 1° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and Seed Source Assessments—Douglas-fir, table 3.

³ Y = bX, where Y is field survival (pct) and X is the percent of seedlings with RGC higher than critical; b is line slope and r² is coefficient of determination.

Table 41—Survival and growth in field performance tests of double- and single-undercut 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date) and undercut date ³		Performance, by nursery lifting date ⁴					Mean ⁴
1979-80		Nov 19	Dec 17	Jan 14	Feb 11	Mar 10	
Klamath Mtns, S							
HA 312.25 80 (May 6)							
1-yr	survival, pct						
	Mar, Jul	9	44	49	58	37	39.4 a
	May, Jul	22	28	28	45	34	31.4 ab
	May only	6	30	24	26	14	20.0 c
	Jul only	10	29	26	39	35	27.8 bc
		11.8 b	32.8 a	31.8 a	42.0 a	30.0 a	
HA 312.50 80 (May 13)							
1-yr	survival, pct						
	Mar, Jul	8	50	42	54	65	43.8 a
	May, Jul	22	50	46	54	38	42.0 ab
	May only	3	41	41	45	41	34.2 bc
	Jul only	5	28	31	45	46	31.0 c
		9.5 b	42.2 a	40.0 a	49.5 a	47.5 a	

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 40.

³ Sources HA were undercut at 15 cm in March or May and at 20 cm in July.

⁴ Means followed by unlike letters differ significantly (p = 0.05).

Table 41—Survival and growth in field performance tests of double- and single-undercut 2-0 Douglas-fir from Humboldt Nursery—continued¹

Seed source ² (planting date) and undercut date ³	Performance, by nursery lifting date ⁴					Mean ⁴
1980-81	Nov 10	Dec 8	Jan 5	Feb 2	Mar 2	
Oregon Coast Range, N						
AL 252.10 81 (Apr 13)						
1-yr survival, pct	57	91	98	96	98	88.0
Mar, May						
Mar only	28	96	96	99	99	83.6
Apr only	37	94	97	97	96	84.2
May only	34	94	94	93	99	82.8
	39.0 b	93.8 a	96.2 a	96.2 a	98.0 a	
height, cm						
Mar, May	43.0	48.1	49.4	50.9	45.5	47.4 ab
Mar only	42.6	45.7	46.9	47.6	48.0	46.2 b
Apr only	44.3	47.6	48.1	52.9	50.1	48.6 ab
May only	44.3	50.2	50.0	52.5	49.9	49.4 a
	43.5 b	47.9 a	48.6 a	51.0 a	48.4 a	
leader, cm						
Mar, May	14.7	16.1	15.2	17.3	16.4	16.0 ab
Mar only	10.2	13.8	16.4	17.7	15.7	14.7 b
Apr only	12.1	12.7	14.9	17.4	17.0	14.8 ab
May only	12.5	17.1	16.5	18.2	16.1	16.1 a
	12.4c	14.9b	15.8b	17.6 a	16.3ab	
diam, mm						
Mar, May	5.9	6.3	5.6	6.3	5.8	6.0 ab
Mar only	5.6	5.7	5.9	5.6	5.6	5.7 b
Apr only	6.2	5.5	5.9	6.1	5.8	5.9 ab
May only	6.4	6.4	6.1	6.2	6.3	6.3 a
	6.1	6.0	5.9	6.1	5.9	
2-yr survival, pct						
Mar, May	56	91	95	93	97	86.4
Mar only	28	93	95	99	99	82.8
Apr only	36	92	97	96	94	83.0
May only	32	93	93	94	99	82.2
	38.0 b	92.2 a	95.0 a	95.5 a	97.2 a	
height, cm						
Mar, May	58.6	65.8	63.7	67.7	62.7	63.7 ab
Mar only	54.2	61.8	63.4	62.7	63.9	61.2 b
Apr only	57.6	62.6	65.9	67.6	68.0	64.4 ab
May only	61.6	68.6	65.0	67.2	66.0	65.7 a
	58.0 b	64.7 a	64.5 a	66.3 a	65.2 a	
leader, cm						
Mar, May	16.7	19.8	16.5	18.9	19.4	18.2 ab
Mar only	14.1	16.8	17.8	17.8	18.0	16.9 b
Apr only	15.0	17.4	18.6	16.7	20.0	17.5 ab
May only	19.0	20.8	17.4	16.5	19.7	18.7 a
	16.2	18.7	17.6	17.5	19.2	
diam, mm						
Mar, May	8.6	9.4	8.9	9.5	9.0	9.1 ab
Mar only	7.5	9.0	9.0	8.8	8.7	8.6 b
Apr only	8.5	8.5	9.0	9.3	9.1	8.9 ab
May only	9.5	9.6	9.1	9.2	9.4	9.4 a
	8.5	9.1	9.0	9.2	9.1	

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 40.

³ Sources AL, OA, GQ, and OK were undercut at 13 cm in March or April and at 18 cm in May.

⁴ Means followed by unlike letters differ significantly (p = 0.05).

Table 41—Survival and growth in field performance tests of double- and single-undercut 2-0 Douglas-fir from Humboldt Nursery—continued¹

Seed source ² (planting date) and undercut date ³		Performance, by nursery lifting date ⁴					Mean ⁴
1980-81		Nov 10	Dec 8	Jan 5	Feb 2	Mar 2	
Oregon Coast Range, N							
AL 252.10 81 (Apr 13)							
3-yr survival, pct							
Mar, May		59	91	95	91	97	86.6 a
Mar only		28	94	95	99	99	83.0 ab
Apr only		36	91	97	96	94	82.8 ab
May only		33	93	93	94	98	82.2 b
		39.0 b	92.2 a	95.0 a	95.0 a	97.0 a	
height, cm							
Mar, May		89.4	101.6	97.7	101.2	96.8	97.4 ab
Mar only		84.2	94.9	98.5	97.3	97.1	94.4 b
Apr only		86.2	96.7	101.6	101.9	101.4	97.5 ab
May only		93.4	105.5	100.0	100.1	101.5	100.1 a
		88.3 b	99.7 a	99.5 a	100.1 a	99.2 a	
leader, cm							
Mar, May		38.3	36.1	35.3	35.6	36.3	35.3 ab
Mar only		32.8	35.4	36.4	35.1	36.1	35.2 ab
Apr only		30.1	34.9	37.0	35.8	34.8	34.5 b
May only		33.8	38.6	36.4	34.9	37.2	36.2 a
		32.5 b	36.3 a	36.3 a	35.3 a	36.1 a	
diam, mm							
Mar, May		13.4	15.0	14.3	14.8	14.5	14.4 ab
Mar only		12.3	14.3	14.5	14.1	13.9	13.8 b
Apr only		12.9	13.9	14.7	15.0	14.3	14.1 ab
May only		13.6	15.6	14.7	14.6	15.1	14.7 a
		13.1 b	14.7 a	14.5 a	14.6 a	14.5 a	
4-yr survival, pct							
Mar, May		59	91	95	92	96	86.6 a
Mar only		28	93	94	98	99	82.4 ab
Apr only		36	90	96	95	94	82.2 b
May only		31	92	92	93	98	81.2 b
		38.5 b	91.5 a	94.2 a	94.5 a	96.7 a	
height, cm							
Mar, May		131.7	151.7	144.4	148.9	143.9	144.1 b
Mar only		127.4	140.6	146.0	143.9	144.4	140.5 b
Apr only		127.9	142.7	147.9	149.7	148.8	143.4 b
May only		141.2	153.8	147.7	147.9	149.4	148.0 a
		132.0 b	147.2 a	146.5 a	147.6 a	146.6 a	
leader, cm							
Mar, May		41.2	50.4	46.9	47.8	46.8	46.6
Mar only		40.9	46.4	46.5	45.5	47.4	45.3
Apr only		41.4	45.9	47.6	48.4	47.7	46.2
May only		45.4	47.5	48.1	47.0	47.8	47.2
		42.2 b	47.6 a	47.3 a	47.2 a	47.4 a	
diam, mm							
Mar, May		18.7	20.9	20.2	20.8	20.5	20.2 b
Mar only		17.6	19.8	20.7	20.3	19.8	19.6 b
Apr only		18.3	19.9	20.5	20.8	20.7	20.0 b
May only		20.0	22.0	20.9	20.5	20.8	20.9 a
		18.7 b	20.7 a	20.6 a	20.6 a	20.4 a	

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 40.

³ Sources AL, OA, GQ, and OK were undercut at 13 cm in March or April and at 18 cm in May.

⁴ Means followed by unlike letters differ significantly (p = 0.05).

Table 41—Survival and growth in field performance tests of double- and single-undercut 2-0 Douglas-fir from Humboldt Nursery—continued ¹

Seed source ² (planting date) and undercut date ³	Performance, by nursery lifting date ⁴					Mean ⁴
	Nov 17	Dec 15	Jan 12	Feb 9	Mar 9	
1980-81						
N Coast Range, coastal						
GQ 091.20 81 (Apr 8)						
1-yr survival, <i>pct</i>						
Mar, May	27	64	51	71	75	57.6
Mar only	35	62	48	58	66	53.8
Apr only	33	70	54	60	76	58.6
May only	29	77	62	61	69	59.6
	31.0 c	68.2 ab	53.7 b	62.5 ab	71.5 a	
height, <i>cm</i>						
Mar, May	38.2	45.3	40.6	50.2	45.2	43.9
Mar only	41.3	42.6	38.6	42.7	46.2	42.3
Apr only	37.4	44.5	41.9	46.0	42.7	42.5
May only	36.3	43.4	40.9	48.2	47.8	43.3
	38.3 b	43.9 ab	40.5 ab	46.8 a	45.5 ab	
leader, <i>cm</i>						
Mar, May	14.2	18.6	17.0	21.0	17.9	17.9
Mar only	14.3	18.5	17.6	18.2	19.3	17.6
Apr only	19.0	19.0	20.1	17.5	18.4	18.8
May only	14.7	19.3	17.3	19.6	20.4	18.3
	15.6	18.9	18.0	19.3	19.0	
diam, <i>mm</i>						
Mar, May	8.9	11.1	9.7	10.7	10.6	10.2
Mar only	9.2	11.0	10.8	10.8	11.6	10.7
Apr only	10.6	10.7	10.1	11.1	11.4	10.8
May only	8.5	10.2	10.7	10.4	11.8	10.3
	9.3b	10.7ab	10.3ab	10.8ab	11.3a	
2-yr survival, <i>pct</i>						
Mar, May	27	64	51	71	75	57.6
Mar only	35	62	51	58	66	54.4
Apr only	33	70	54	60	75	58.4
May only	29	77	62	60	69	59.4
	31.0 b	68.2 a	54.5 a	62.2 a	71.2 a	
height, <i>cm</i>						
Mar, May	38.9	45.9	43.2	50.2	45.1	44.7
Mar only	41.3	47.3	44.5	47.2	49.1	45.9
Apr only	41.0	44.5	46.0	45.7	46.2	44.7
May only	36.3	44.1	45.1	49.1	48.3	44.6
	39.4 b	45.5 a	44.7 a	48.1 a	47.2 a	
leader, <i>cm</i>						
Mar, May	14.7	19.1	17.4	21.3	18.4	18.2
Mar only	15.6	19.9	19.0	19.2	19.4	18.6
Apr only	19.0	19.3	20.6	17.1	18.8	19.0
May only	14.5	19.8	17.7	20.0	20.5	18.5
	15.9	19.5	18.7	19.4	19.3	
diam, <i>mm</i>						
Mar, May	9.3	11.3	9.7	11.0	10.5	10.4
Mar only	9.3	11.2	10.8	11.6	11.6	10.9
Apr only	10.3	10.7	10.5	11.6	11.6	10.9
May only	8.5	10.2	10.9	10.9	12.1	10.5
	9.4b	10.9 a	10.5 a	11.3 a	11.4a	

Table 41—Survival and growth in field performance tests of double- and single-undercut 2-0 Douglas-fir from Humboldt Nursery-continued ¹

Seed source ² (planting date) and undercut date ³	Performance, by nursery lifting date ⁴					Mean ⁴
	Nov 10	Dec 8	Jan 5	Feb 2	Mar 2	
1980-81						
Oregon Cascades, W						
OA 482.30 81 (Mar 27)						
1-yr survival, <i>pct</i>						
Mar, May	35	74	70	76	79	66.8 a
Mar only	6	54	56	64	66	49.2 b
Apr only	13	62	49	69	62	51.0 b
May only	20	56	63	70	62	54.2 b
	18.5b	61.5 a	59.5 a	69.8 a	67.2a	
height, <i>cm</i>						
Mar, May	24.3	30.3	28.7	32.8	32.2	29.7 b
Mar only	27.5	36.9	35.2	36.6	37.2	35.3 a
Apr only	1.5	36.9	32.6	36.5	34.1	34.3 a
May only	35.0	34.4	35.0	36.8	34.0	35.0 a
	29.6 c	34.6 ab	32.9 b	36.4 a	34.4 ab	
leader, <i>cm</i>						
Mar, May	7.6	9.1	8.8	13.9	11.6	10.2
Mar only	6.4	10.0	9.5	10.7	8.8	9.1
Apr only	10.9	12.5	8.3	13.2	9.0	10.8
May only	8.3	8.6	9.8	9.5	9.5	9.1
	8.3b	10.0ab	9.1 ab	11.8 a	9.8ab	
1980-81	Nov 17	Dec 15	Jan 12	Feb 9	Mar 9	
Klamath Mtns, E						
OK 321.30 81 (Apr 4)						
1-yr survival, <i>pct</i>						
Mar, May	54	87	78	83	83	77.0 a
Mar only	30	70	70	77	86	66.6 b
Apr only	43	77	71	73	88	70.4 ab
May only	44	81	57	80	75	67.4 ab
	42.8 b	78.8 a	69.0 a	78.2 a	83.0 a	
height, <i>cm</i>						
Mar, May	24.2	25.4	25.7	25.9	26.0	25.4
Mar only	23.9	25.4	26.5	25.0	26.3	25.4
Apr only	23.3	25.6	25.7	29.5	30.7	27.0
May only	26.5	26.9	29.2	27.9	26.1	27.3
	24.5 b	25.8 ab	26.8 ab	27.1 a	27.3 a	
leader, <i>cm</i>						
Mar, May	6.2	6.7	6.1	5.8	5.2	6.0 a
Mar only	4.8	5.5	5.5	5.8	5.5	5.4 b
Apr only	5.5	6.0	6.2	6.5	6.0	6.0 a
May only	6.3	6.2	5.7	6.0	4.7	5.8 ab
	5.7	6.1	5.9	6.1	5.3	
diam, <i>mm</i>						
Mar, May	5.6	5.8	5.5	5.7	6.1	5.7 bc
Mar only	5.3	5.7	5.3	5.7	5.8	5.6 c
Apr only	5.6	5.6	5.6	6.2	6.3	5.9 ab
May only	6.0	6.3	5.8	6.0	5.8	6.0 a
	5.6	5.9	5.6	5.9	6.0	

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 40*.

³ Sources HA were undercut at 15 cm in March or May and at 20 cm in July; sources AL, OA, GQ, and OK were undercut at 13 cm in March or April and at 18 cm in May.

⁴ Means followed by unlike letters differ significantly (p = 0.05).

TESTING PROPOSED PRACTICES

The testing program was barely underway when the first of a number of possibly beneficial practices was proposed. Mycorrhizal inoculation of seedbeds just before sowing, root wrenching of second-year seedlings in summer, immediate freeze storage of graded planting stock, and extended precooler storage of freshly lifted seedlings were explored for Humboldt Nursery as time and circumstances allowed (*table 15*). The practices were assessed using coastal and inland seed sources of Douglas-fir and our standard sampling and testing scheme (see *fig. 8*). Field performance tests justified extended precooler storage, but revealed serious drawbacks for mycorrhizal inoculation, root wrenching, and immediate freeze storage.

Mycorrhizal Inoculation

The issue of whether mycorrhizal inoculation of seedbeds just before sowing might improve seedling growth and planting stock quality had often been raised. To explore this practice, nursery trials were installed using inland source IL 512.35 from the northern Klamath Mountains in 1977 and coastal source MA 062.10 from the northern Oregon Coast

Range in 1978. Inoculation markedly improved first-year growth and eliminated the severe stunting seen in traditional May sowings. The resulting 2-0 stock, however, was not only large, but had high top-root ratios and survived poorly on the planting site. Testing indicated that, to produce balanced stock with high survival potentials, inoculated seedlings would have to be undercut in spring rather than summer.

Inoculation was done just before sowing in May. Roots were pruned from 2-0 Douglas-fir in winter, stored at 1° C (34° F) until May, and hammermilled into short segments. Using hand tools, root segments were incorporated to a depth of 15 cm (6 in) in newly prepared seedbeds, in three randomly located plots that were 3 m (10 ft) long. In effect, as a nursery practice, inoculation was simply inserted into the traditional cultural regime (see *fig. 6*).

The resulting 2-0 seedlings in inoculated plots and those in adjacent check plots were sampled monthly in autumn to spring, processed normally, and evaluated for size, top and root growth capacity, and survival and growth in the seed zone of origin (see Assessing Planting Stock Quality, Standard Testing Procedures). Inoculation stimulated luxurious shoot growth in the nursery and resulted in planting stock with large tops and abundant winter buds. Top-root ratios of inland source IL and coastal source MA respectively averaged 1.9 and 3.3 with inoculation against 1.5 and 1.7 without it (*table 43*).

Table 43—Size and balance of 2-0 Douglas-fir from mycorrhizal inoculation and root wrenching trials in Humboldt Nursery¹

Seed source ² and treatment	Seedling height	Stem diam	Top weight	Root weight	Top-root ratio
	cm	mm	g	g	
<i>Mycorrhizal inoculation³</i>					
Klamath Mtns, N					
IL 512.35 78					
Check	24 b	4.5 b	2.6 b	1.9 b	1.5 b
Inoculated	29 a	4.8 a	3.8 a	2.2 a	1.9 a
Oregon Coast Range, N					
MA 062.10 79					
Check	27 b	4.9 b	6.8 b	3.9 b	1.7 b
Inoculated	54 a	7.5 a	19.8 a	6.0 a	3.3 a
<i>Root wrenching⁴</i>					
Oregon Coast Range, S					
GO 081.20 79					
Check	37 a	5.4 a	9.4 a	3.9	2.4 a
Wrenched	34 b	4.9 b	7.5 b	4.1	1.8 b
Klamath Mtns, N					
IL 512.40 79					
Check	24	5.5 a	6.9 a	4.2 b	1.7 a
Wrenched	24	4.7 b	5.8 b	4.8 a	1.2 b

¹ Means followed by unlike letters differ significantly ($p = 0.05$).

² See *fig. 10*, and *tables 44, 45*.

³ Milled roots of 2-0 Douglas-fir were incorporated into seedbeds; inoculated and check plots were undercut in August.

⁴ Beds were undercut August 2 and wrenched August 23; check plots were neither undercut nor wrenched.

Table 44—Significance of mycorrhizal inoculation or root wrenching and lifting date effects on survival and growth in field performance tests of 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date) and source of variation ³	Variance (mean square) for...			
	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
Mycorrhizal inoculation				
Oregon Coast Range, N				
MA 062.10 79 (Apr 24)				
2 yr: Inoculation, T	265.69 **	822.0**	6488.3**	134.32**
Lifting date, D	38.62 **	293.2 *	169.1 *	14.07
Block, B	3.05	141.8	136.6	19.21
TD	11.62 **	49.5	65.3	.95
BT	.47	67.1	61.2	1.98
BD	2.14	97.6	61.3	5.89
BTD	2.28	55.2	64.5	2.30
3 yr: Inoculation, T	289.00 **	5733.5 **	3102.5 **	—
Lifting date, D	36.94 **	570.9	155.0	—
Block, B	2.43	278.8	76.2	—
TD	11.42 **	169.6	73.1	—
BT	.29	204.7	59.2	—
BD	2.48	254.4	69.5	—
BTD	2.32	154.1	64.1	—
Root wrenching				
Oregon Coast Range, S				
GO 081.20 79 (Apr 5)				
2 yr: Wrenching, T	20.25 *	25.50	0.137	0.19
Lifting date, D	42.86 **	5.12	.066	1.96
Block, B	5.71	20.96	3.558	4.22
TD	3.92	9.16	.597	6.65
BT	3.61	17.68	.619	2.82
BD	3.80	19.74	.905	3.81
BTD	2.92	20.01	.966	2.57
Klamath Mtns, N				
IL 512.40 79 (Apr 24)				
1 yr: Wrenching, T	158.76 **	16.03	0.58	—
Lifting date, D	3.06	21.98	2.74	—
Block, B	27.60	15.58	9.61	—
TD	19.38 **	2.98	1.87	—
BT	5.52	10.07	.73	—
BD	4.14	8.44	1.22	—
BTD	4.61	8.17	1.64	—
2 yr: Wrenching, T	132.25 **	135.9	24.89	0.36
Lifting date, D	4.79	19.5	4.46	2.93
Block, B	47.13	41.2	10.10	3.33
TD	6.85	19.3	7.68	1.63
BT	8.98	37.9	7.57	.97
BD	3.96	18.7	4.51	.88
BTD	2.67	15.8	1.58	.64

First-year mortalities of inland source IL and coastal source MA were respectively two and five times greater for inoculated seedlings than for check seedlings (tables 44, 45). At planting time, RGC was as high in inoculated as in check seedlings, but inoculated seedlings had much greater foliar surface, especially after budburst, and apparently survived poorly because they transpired more and developed higher water stress.

Survivals within the lifting window of inoculated and check seedlings of inland source IL averaged 61 and 82 percent the first year, and 42 and 54 percent after plant competition and browse damage the second year. Similarly, survivals within the window of inoculated and check seedlings of coastal source MA averaged 66 and 93 percent the first year, and 62 and 90 percent the third year. Besides showing higher survivals, check seedlings of source MA also grew faster, and after 3 years were 16 percent taller and had 31 percent longer leaders than inoculated seedlings.

Inoculating seedbeds with mycorrhizal roots from the previous crop markedly enhanced seedling growth, and effectively alleviated the first-year stunting and winter disease problems typical of May sowings. Unfortunately, inoculated seedlings grew so rapidly the second year that the usual summer undercut was too

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and tables 43, 45.

³ Degrees freedom were 1, 4, 9, 4, 9, 36, and 36 for T, D, B, TD, BT, BD, and BTD, respectively.

late to control shoot growth. Large tops and reduced survivals showed that, if mycorrhizal inoculation were adopted, undercutting would have to be shifted to spring to force extended root growth and limit shoot growth.

Ultimately, we dropped the notion of mycorrhizal inoculation. Early sowing proved to be effective and much easier, cheaper, and faster than pruning, storing, milling, and incorporating mycorrhizal roots. Spring undercutting also proved successful, and was adopted as described earlier. In summary, key studies in Humboldt Nursery showed that

- Superior advantages of natural mycorrhizal inoculation are consistently captured by sowing fully chilled seeds early (see Determining Nursery Sowing Windows)
- Judicious use of double spring undercuts can control the growth of 1-0 Douglas-fir and produce 2-0 stock of high quality (see Undercutting Early Sowings for 2-0 Stock)

Root Wrenching

Root wrenching, as developed in New Zealand to improve field survival of nursery seedlings of Monterey pine, is customarily scheduled 2 to 4 weeks after undercutting. Wrenching is done at the same depth as or lower than the undercut, and by using the same equipment (see *fig. 7L-M*), except that the blade is locked at a downward angle of 20-30°. The tipped blade lifts and ripples the bed and seedlings, shattering soil and breaking the finer lateral roots. Wrenching, like undercutting, usually causes transient high water stress, and reduces height growth, improves root mass and fibrosity, and decreases top-root ratio.

Before we developed 1-0 Douglas-fir, summer undercuts were standard practice for producing 2-0 planting stock in Humboldt Nursery (see *fig. 6*). The question of whether multiple undercuts or wrenches might increase the field survival of Humboldt's 2-0 Douglas-fir was first explored in 1974. Then, second-year seedlings of a southwest Oregon seed source were undercut either biweekly or monthly in August-September (Koon and O'Dell 1977). These multiple undercuts increased first-year survival by up to 25 percent, and led the Siskiyou National Forest to request additional trials.

Accordingly, trials were installed in second-year seedlings of coastal source GO 081.20 from the southern Oregon Coast Range and inland source IL 512.40 from the northern Klamath Mountains. One bed per source was undercut at a depth of 20 cm (8 in) on August 2 and wrenched 3 weeks later, on

August 23, 1978. Seedlings in adjacent beds of the same sources were used as checks, but were not undercut, an unfortunate oversight. Otherwise, seedlings were grown using the traditional cultural regime (see *fig. 6*). Seedlings in the wrenched and unwrenched beds were sampled monthly in autumn to spring, processed normally, held in cold storage to spring planting time, and evaluated for size, top and root growth capacity, and survival and growth in the seed zone of origin (see Assessing Planting stock Quality, Standard Testing Procedures).

Wrenched seedlings had smaller tops, heavier roots, and lower top-root ratios than check seedlings (*table 43*). Check seedlings survived better in the test of coastal source GO, whereas wrenched seedlings survived better in the test of inland source IL (*tables 44, 45*). Within the lifting window, survivals of check and wrenched seedlings of source GO averaged 66 and 54 percent the first year and 51 and 41 percent the second year. By contrast, survivals of check and wrenched seedlings of source IL averaged 41 and 71 percent the first year and 28 and 51 percent the second year. Plant competition and browse damage were severe. Heights of survivors after 2 years in the inland test averaged the same as at planting time, and in the coastal test, less than at planting time (*table 43*).

Past experience with Humboldt's traditional 2-0 Douglas-fir had shown that summer undercutting improved survival. Results of the tests here indicated that wrenching 3 weeks after undercutting had no value for inland sources, and worse, was detrimental for coastal sources. Wrenching temporarily disrupts root function, reduces uptake of water and nutrients, and limits photosynthesis. Wrenching coastal sources in late summer probably delays buildup of stored reserves and cold hardiness, and impairs development of the growth capacity and survival potential that characterize successful planting stock.

In western Oregon as in California, wrenching has failed to improve field survival of Douglas-fir. In D. L. Phipps State Forest Nursery, wrenching either biweekly in June-August or once in August improved neither survival nor growth of seedlings undercut in April (Duryea and Lavender 1982, Stein 1984). Multiple wrenchings of Douglas-fir in nurseries at more northern latitudes have yielded mixed results. In western Washington, wrenching in August-October improved survival of stock planted on a south slope, but not on a north slope (Tanaka and others 1986). On Vancouver Island, wrenching in August-September improved survival of stock lifted and stored in October, but not December, for which lift survival was 98 percent without wrenching (Van Den Driessche 1983).

Table 45—Survival and growth in field performance tests of 2-0 Douglas-fir from mycorrhizal inoculation and root wrenching trials in Humboldt Nursery¹

Seed source ² (planting date) and treatment	Performance, by nursery lifting date					Mean ³
1977-78	Nov 14	Dec 12	Jan 9	Feb 6	Mar 6	
<i>Mycorrhizal inoculation</i>						
Klamath Mtns, N						
IL 512.35 78 (May 16)						
1-yr survival, <i>pct</i>						
Aug 15						
Check	57	84	85	85	75	77.2 a
Inoculated	40	69	59	52	65	57.0 b
Sep 12						
Check	43	70	78	75	62	65.6 a
Inoculated	32	51	48	43	53	45.4 b
Oct 24						
Check	34	59	55	61	43	50.4 a
Inoculated	24	49	38	34	47	38.4 b
1978-79	Nov 8	Dec 7	Jan 4	Feb 1	Mar 1	
<i>Mycorrhizal inoculation</i>						
Oregon Coast Range, N						
MA 062.10 79 (Apr 24)						
1-yr survival, <i>pct</i>						
Check	77	87	97	93	93	89.4 a
Inoculated	19	59	59	71	74	56.2 b
2-yr survival, <i>pct</i>						
Check	77	83	94	91	93	87.6 a
Inoculated	19	56	59	70	71	55.0 b
height, <i>cm</i>						
Check	68.8	70.9	73.9	74.1	75.2	72.6 a
Inoculated	60.0	65.2	70.1	65.5	73.6	66.9 b
leader, <i>cm</i>						
Check	37.3	39.4	39.1	42.0	42.7	40.1 a
Inoculated	19.1	24.4	28.2	22.8	29.4	24.8 b
diam, <i>mm</i>						
Check	14.8	14.9	15.1	15.8	16.5	15.4 a
Inoculated	11.9	13.1	13.5	12.9	14.6	13.2 b
3-yr survival, <i>pct</i>						
Check	77	83	94	90	93	87.4 a
Inoculated	18	55	57	68	69	53.4 b
height, <i>cm</i>						
Check	111.1	108.3	111.3	111.9	118.0	112.1 a
Inoculated	87.2	95.6	100.0	93.9	108.4	97.0 b
leader, <i>cm</i>						
Check	49.0	44.3	45.4	46.1	50.8	47.1 a
Inoculated	31.3	36.0	36.0	35.0	41.5	36.0 b

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *tables 43, 44*.

³ Means followed by unlike letters differ significantly ($p = 0.01$). Deer ate the new growth of sources GO and IL; see Seed Source Assessments—Douglas-fir, *table 8*.

Table 45—Survival and growth years in field performance tests of 2-0 Douglas-fir from mycorrhizal inoculation and root wrenching trials in Humboldt Nursery—continued¹

Seed source ² (planting date) and treatment	Performance, by nursery lifting date					Mean ³
	Nov 8	Dec 7	Jan 4	Feb 1	Mar 1	
1978-79	Nov 8	Dec 7	Jan 4	Feb 1	Mar 1	
Root wrenching						
Oregon Coast Range, S						
GO 081.20 79 (Apr 5)						
1-yr survival, <i>pct</i>						
Check	29	64	72	67	60	58.4 a
Wrenched	20	44	64	51	58	47.4 b
2-yr survival, <i>pct</i>						
Check	25	55	67	58	49	50.8 a
Wrenched	21	38	60	39	51	41.2 b
height, <i>cm</i>						
Check	30.8	29.2	28.8	30.3	29.3	29.7
Wrenched	29.4	30.6	30.8	31.8	30.9	30.7
leader, <i>cm</i>						
Check	3.1	3.1	2.7	2.7	2.9	2.9
Wrenched	2.7	2.7	3.1	2.9	2.7	2.8
diam, <i>mm</i>						
Check	5.7	5.7	4.6	5.5	5.1	5.3
Wrenched	3.9	5.2	5.6	5.5	6.0	5.2
1978-79	Nov 27	Dec 21	Jan 18	Feb 15	Mar 15	
Root wrenching						
Klamath Mtns, N						
IL 512.40 79 (Apr 24)						
1-yr survival, <i>pct</i>						
Check	36	30	48	42	51	41.4 b
Wrenched	85	73	61	71	67	71.4 a
height, <i>cm</i>						
Check	23.7	23.6	23.9	22.5	25.7	23.9
Wrenched	25.7	24.3	23.9	23.6	26.0	24.7
leader, <i>cm</i>						
Check	2.9	3.6	3.6	4.3	3.8	3.6
Wrenched	3.2	3.2	3.7	3.2	4.3	3.5
2-yr survival, <i>pct</i>						
Check	26	17	28	29	39	27.8 b
Wrenched	64	48	48	47	47	50.8 a
height, <i>cm</i>						
Check	21.6	23.8	24.3	24.5	25.0	23.8
Wrenched	26.7	24.9	26.7	24.5	28.0	26.2
leader, <i>cm</i>						
Check	3.8	5.3	3.2	3.5	4.4	4.0
Wrenched	5.1	4.4	5.7	4.2	5.8	5.0
diam, <i>mm</i>						
Check	5.9	6.7	6.9	6.0	7.2	6.5
Wrenched	6.9	6.4	6.6	6.2	7.1	6.6

Freeze Storage

Besides raising the obvious concerns about freeze damage, accidental freezings of cold-stored planting stock have always sparked client interest in the possible advantages of freeze storage. Research in temperate forest regions of North America had repeatedly shown that overwinter storage at -1°C (30°F) or -2°C (28°F) keeps stock in better condition than cold storage at $+1^{\circ}\text{C}$ (34°F). Clients therefore asked whether Humboldt Nursery might use freeze storage to improve stock survival and growth potentials, particularly for inland sites at high elevations where winter snowpacks melt late and prolong seedling cold storage.

Acting on client requests, top and root growth capacity (TGC, RGC) of freeze-stored 2-0 Douglas-fir were evaluated for seed sources in the northern Sierra Nevada and North Coast Range in 1981 and 1982. Seedlings that had been lifted in January and stored at $+1^{\circ}\text{C}$ were frozen to -1°C in April and tested in May to December. Results consistently showed that TGC and RGC remained high through October, then plummeted to zero. Seedlings destined for spring planting were thus freeze-stored safely 3 to 4 months past the site planting windows at highest elevations (Jenkinson 1980). Seedlings should not be stored for fall planting, however, as they are programmed for budburst and increasingly long, warm days, not cool, short days and autumn dormancy.

To determine whether immediate freeze storage is safe for Douglas-fir in Humboldt Nursery, freeze-stored and cold-stored seedlings were evaluated for TGC and RGC, and for survival and growth in the seed zone of origin (see Assessing Planting Stock Quality, Standard Testing Procedures). Dormant 2-0 seedlings of source MA 062.10 from the northern Oregon Coast Range and source OK 321.40 from the eastern Klamath Mountains were dug on December 27, January 24, and February 22, within the source lifting windows (see Seed Source Assessments—Douglas-fir, *table 3*). Seedlings were processed normally and then immediately frozen at -1°C or cold stored at $+1^{\circ}\text{C}$. Testing showed that immediate freezing damaged seedlings of both sources.

Storage type significantly affected TGC and RGC, and lifting date and interactions of seed source and storage type affected TGC (*table 46*). Freeze storage reduced TGC and RGC at planting time for coastal source MA and for inland source OK (*table 47*). The TGC of freeze-stored seedlings was lowest in the January lifts. The RGC of freeze-stored seedlings of source MA was half that of cold-stored seedlings and was lowest in the January lift, whereas that of freeze-stored seedlings of source OK was three-fourths and two-thirds that of cold-stored seedlings in the January and February lifts, respectively. The RGC of freeze-stored seedlings of either source averaged 46 cm. Seedlings of inland source OK were 24 percent shorter than those of coastal source MA, however,

Table 46—Significance of seed source, lifting date, and freeze storage effects on top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir from Humboldt Nursery¹

Source of variation	Degrees freedom	Variance (mean square) for...				
		Budburst (pct)	Shoot length (cm)	Root length (cm)	Roots elongated	
					≥1.5 cm	<1.5 cm
Seed source, S	1	2.19	3.01	4059	376.2	61.0
Lifting date, D	2	42.14**	21.52**	1659	266.8	584.3
Storage type, T	1	29.50**	17.68**	10438 **	1370.3**	4369.7 **
SD	2	3.53		118	2.9	40.4
ST	1	27.85**	5.46*	3674	533.6	270.6
DT	2	10.84	3.86	1045	131.2	578.2
SDT	2	3.95		1299	105.4	78.9
Error	22	3.25	1.26	1163	144.0	264.4

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings of coastal and inland seed sources were lifted monthly in winter, stored at -1° or $+1^{\circ}\text{C}$ (30° or 34°F), and tested May 2; see Assessing Planting Stock Quality, Standard Testing Procedures, and *table 47*.

averaging 25 against 33 cm, and therefore had the better balance between RGC and foliar surface.

Storage type significantly affected leader growth on the coastal site and survival on the inland site, where all survivors were heavily browsed by deer (*tables 48, 49*). Freeze storage of coastal source MA reduced height and leader length by 8 and 26 percent, respectively, after 2 years. Survivals of freeze-stored and cold-stored seedlings of inland source OK averaged 57 against 74 percent the first

year, and based on the intact blocks remaining, 64 against 79 percent the second year. Freeze damage increased with earlier lifting, as the 2-year mortality of freeze-stored seedlings was 33, 10, and 1 percent higher than that of cold-stored seedlings from the December, January, and February lifts, respectively.

Immediate freeze storage apparently reduces TGC and RGC more in coastal seedlings, yet increases mortality more on inland sites. Large reductions in RGC may cause little mortality on mesic sites,

whereas small reductions may cause high mortality on xeric sites. Freeze storage reduced the RGC of coastal seedlings by 56 percent (*table 47*), yet first-year survival averaged 95 percent (*table 49*). By contrast, freeze storage reduced the RGC of inland seedlings by only 25 percent, but that increased mortality by 17 percent. Freeze-stored seedlings survived on the coastal site because they had RGC higher than critical, whereas many died on the inland site because summer drought and evaporative stress there placed a much higher premium on RGC. Critical RGC can be many times higher on warm, dry sites than on cool, moist sites (see *fig. 34*, and Seed Source Assessments-Douglas-fir, *table 7*).

Reduced leader growth of freeze-stored seedlings on the coastal site suggested that RGC was high enough to secure survival but not vigorous top growth. Weak root elongation can limit uptake of water and nutrients, impair photosynthesis, and retard bud formation and the buildup of stored reserves, and thereby reduce shoot growth the following spring.

Use of immediate freeze storage at Humboldt Nursery would likely reduce the survival and growth potentials of Douglas-fir planting stock, even for late lifts within the source lifting windows. To prevent accidental freezing of seedlings lifted for cold storage and spring planting, the nursery should

- Adhere rigidly to the recommended temperature of 1° C (34° F) in the precooler (see Precooler Storage)
- Use alarm systems to insure that a temperature of 0-1° C (32-34° F) is maintained in the center of every packed bag

Table 47—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir after freeze or cold storage at Humboldt Nursery¹

Seed source ² (testing date) and storage type	TGC and RGC, by lifting date			Mean ³
	Dec 27	Jan 24	Feb 22	
Oregon Coast Range, N				
MA 062.10 83 (May 2)				
TGC budburst, <i>pct</i>				
Cold	69.3	88.3	96.7	84.8 a
Freeze	29.3	29.0	80.3	46.2 b
shoot length, <i>cm</i>				
Cold	2.8	4.0	4.8	3.9 a
Freeze	.5	.6	3.5	1.5 b
RGC root length, <i>cm</i>				
Cold	81.8	139.9	93.8	105.2 a
Freeze	40.4	37.5	61.8	46.6 b
roots ≥1.5 <i>cm</i>				
Cold	30.2	50.8	38.1	39.7 a
Freeze	13.9	14.9	25.5	18.1 b
roots <1.5 <i>cm</i>				
Cold	46.3	68.5	59.0	57.9 a
Freeze	22.2	18.0	44.5	28.2 b
Klamath Mtns, E				
OK 321.40 83 (May 2)				
TGC budburst, <i>pct</i>				
Cold	33.0	89.7	90.7	71.1
Freeze	58.7	64.3	88.7	70.6
shoot length, <i>cm</i>				
Cold	1.4	4.5	5.2	3.7
Freeze	2.0	2.2	4.9	3.0
RGC root length, <i>cm</i>				
Cold	37.2	68.1	76.0	60.4 a
Freeze	36.8	52.2	47.4	45.5 b
roots ≥1.5 <i>cm</i>				
Cold	17.2	28.7	27.3	24.4 a
Freeze	15.4	22.2	20.6	19.4 b
roots <1.5 <i>cm</i>				
Cold	41.8	57.2	48.7	49.2 a
Freeze	21.5	30.8	41.7	31.3 b

¹ Seedlings were stored at -1° or +1° C (30° or 34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 46*.

³ Means followed by unlike letters differ significantly (*p* = 0.05).

Finally, freeze-storing stock at -1° C (30° F) to -2° C (28° F) may improve survival on planting sites where winter snowpacks melt late. Freeze storage is safe if the seedlings to be frozen are first conditioned at 1° C, for some yet-to-be determined period. Once that threshold period is known, the nursery can tap the advantages of freeze storage without risking freeze damage (Racey 1988). High survivals in

recent tests of 2-0 Shasta red fir on the Illinois Valley Ranger District, Siskiyou National Forest, southwest Oregon, proved that 1 month of cold storage at 1° C is sufficient to permit successful freeze storage. One month is probably more than enough to insure safe freeze storage of other true firs and of Douglas-fir as well.

Precooler Storage

Years ago in Humboldt Nursery, before the annual harvest exceeded 10 million, lifting was paced to maintain a steady, manageable supply of seedlings to the packing belt. The normal pace was such that most seedlings could be graded, packed, and stored the same day they were lifted, and if packing fell behind, lifting was halted. These sensible procedures were a luxury that vanished as wildfire planting and regeneration cutting increased and seedling orders soared. When heavy or prolonged rainstorms came through, lifting and packing were precluded until soil conditions again permitted safe lifting.

Faced with harvesting up to 18 million seedlings annually, Humboldt had to take advantage of every day that soil and weather conditions permitted lifting. When conditions were good, backlogs developed because even experienced packing crews could not properly separate, grade, bundle, root-prune, and pack seedlings as fast as trained lifting crews could safely pull and box them (see *fig. 7N-Q*).

To keep newly lifted seedlings from heating during the day or freezing solid at night, often the fate of those stacked in the shade outdoors, Humboldt had to hold them in premium cold storage. That stop-gap arrangement worked, but complicated seedling handling and traffic patterns and strained the already limited cold storage facilities. To expand storage capacity and secure precision temperature control, new facilities were built, including a pair of large coolers to store seedlings at 1° C (34° F) temporarily, under wet burlap in standard field totes (see *fig. 7R-T*).

Table 48—Significance of lifting date and freeze storage effects on survival and growth in field performance tests of 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date) and source of variation ³	Variance (mean square) for...			
	Survival (pct)	Height (cm)	Leader (cm)	Diam (mm)
Oregon Coast Range, N				
MA 062.10 83 (Apr 1)				
1-yr Storage, T	0.000	1.98	4.06	—
Lifting date, D	2.217*	2.34	11.73 *	—
Block, B	.474	14.63	12.24	—
TD	.150	15.62	.44	—
BT	.296	22.08	4.16	—
BD	.568	18.14	2.49	—
BTD	.502	22.01	3.77	—
2-yr Storage, T	2.817	265.44	289.96 *	0.561
Lifting date, D	2.600	188.48	128.84 *	7.690*
Block, B	1.343	191.12	45.16	3.020
TD	.467	51.27	45.16	2.386
BT	.557	64.96	41.51	2.088
BD	.804	69.45	26.54	1.688
BTD	.707	47.73	14.76	1.417
Klamath Mtns, E				
OK 321.40 83 (May 3)				
1-yr Storage, T	40.017**	1.09	0.504	—
Lifting date, D	4.850	31.70	2.130	—
Block, B	25.557	13.25	3.410	—
TD	9.217	16.38	.366	—
BT	.794	9.40	.458	—
BD	3.091	15.97	1.337	—
BTD	2.828	18.06	.519	—
2-yr Storage, T	22.881 **	0.19	0.57	0.309
Lifting date, D	7.238	1.99	4.55	.235
Block, B	2.000	58.20	24.64	2.722
TD	9.238*	7.14	11.54	1.374
BT	1.603	26.49	3.86	1.524
BD	2.488	24.51	6.65	1.442
BTD	1.877	25.78	3.27	.900

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings were lifted monthly in winter, stored at -1° or +1° C (30° or 34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 49*.

³ Degrees freedom were 1, 2, 9, 2, 9, 18, and 18 for T, D, B, TD, BT, BD, and BTD, respectively.

Table 49—Survival and growth in field performance tests of 2-0 Douglas-fir held in freeze or cold storage at Humboldt Nursery¹

Seed source ² (planting date) and storage type	Performance, by lifting date			Mean ³
	Dec 27	Jan 24	Feb 22	
Oregon Coast Range, N				
MA 062.10 83 (Apr 1)				
1-yr survival, <i>pct</i>				
Cold	92	94	100	95.3
Freeze	93	95	98	95.3
height, <i>cm</i>				
Cold	42.6	40.4	42.5	41.8
Freeze	42.0	42.8	41.7	42.2
leader, <i>cm</i>				
Cold	8.7	8.3	10.0	9.0
Freeze	8.4	7.9	9.2	8.5
2-yr survival, <i>pct</i>				
Cold	90	94	100	94.7
Freeze	89	89	93	90.3
height, <i>cm</i>				
Cold	52.9	52.9	60.9	55.6 a
Freeze	50.9	50.1	53.1	51.4 b
leader, <i>cm</i>				
Cold	13.5	16.0	20.9	16.8 a
Freeze	12.5	10.6	14.2	12.4 b
diam, <i>mm</i>				
Cold	7.6	7.9	8.4	8.3
Freeze	8.0	7.8	8.4	8.1
Klamath Mtns, E				
OK 321.40 83 (May 3)				
1-yr survival, <i>pct</i>				
Cold	76	74	71	73.7 a
Freeze	44	65	63	57.3 b
height, <i>cm</i>				
Cold	30.4	30.0	30.8	30.4
Freeze	31.7	28.2	32.1	30.7
leader, <i>cm</i>				
Cold	5.7	5.4	5.2	5.4
Freeze	5.7	4.9	5.1	5.2
2-yr survival, <i>pct</i>				
Cold	81.4	75.7	80.0	79.0 a
Freeze	48.6	65.7	78.6	64.3 b
height, <i>cm</i>				
Cold	35.9	36.1	34.1	35.4
Freeze	35.0	35.0	35.6	35.2
leader, <i>cm</i>				
Cold	7.0	7.9	5.6	6.8
Freeze	5.6	6.8	7.5	6.6
diam, <i>mm</i>				
Cold	8.4	9.2	8.4	8.7
Freeze	8.7	8.3	8.5	8.5

¹ Seedlings were stored at -1° or +1° C (30° or 34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 48*.

³ Means followed by unlike letters differ significantly ($p = 0.05$).

Almost immediately, Humboldt wanted to know how long Douglas-fir could be safely held in the precoolers. To find out, 2-0 seedlings of coastal source GQ 301.15 and inland source HA 312.40 from the western and southern Klamath Mountains, respectively, were precooled varying times, processed normally, and evaluated in field performance tests. Seedlings were dug on December 27, 1984 and transferred to the precooler under wet burlap in field totes. Seedlings in the totes were sampled immediately and after 1, 3, 6, and 15 days of precooling, then graded, root-pruned, packed, and stored at 1° C for spring planting in the seed zone of origin (see Assessing Planting Stock Quality, Standard Testing Procedures).

The test layouts consisted of five randomized complete blocks of five row plots, each containing 10 seedlings that had been in the precooler for 0, 1, 3, 6, or 15 days. First-year survival and growth were measured in autumn, and precooler effects were assessed using variance analysis program BMD P8V with effects fixed and blocks random (Jennrich and Sampson 1985).

Precooler time had no significant effect on either survival or growth (*table 50*). Survivals averaged 96 percent for coastal source GQ and 93 percent for inland source HA, in the western and southern Klamath Mountains, respectively. Leader growth was uniformly normal in the test of source GQ, but deer ate most of the new growth in that of source HA.

High survivals demonstrated that Humboldt Nursery can confidently hold seedlings in the precoolers for at least 15 days, the longest time tested, and probably for much longer. In reality, seedlings need never be held that long, because even the largest lots are usually packed within 4 days of lifting. Lifting crews routinely keep the precoolers full, so that winter rains seldom disrupt packing. When fully loaded, the precoolers hold enough seedlings to work all four of the packing belts (see *fig. 7V*) for at least 3 to 7 days, depending on planting stock size and type, that is, 1-0, 2-0, 1-1, or 2-1 (see the last chapter, Moving into the '90's).

Table 50—Survival and growth in field performance tests to determine safe time in the precooler for 2-0 Douglas-fir at Humboldt Nursery¹

Seed source ² (planting date)		Performance, by hours in precooler					LSD ³
		0	24	72	144	360	
Klamath Mtns, W							
GQ	301.15 85 (Apr 15)						
1-yr	survival, <i>pct</i>	100	98	98	88	98	11.9
	height, <i>cm</i>	30.2	30.5	31.3	29.3	30.3	2.55
	leader, <i>cm</i>	5.2	5.2	5.2	4.5	5.4	1.13
	diam, <i>mm</i>	5.9	5.6	6.2	5.7	5.9	.52
Klamath Mtns, S							
HA	312.40 85 (May5) ⁴						
1-yr	survival, <i>pct</i>	92	92	94	90	98	10.0
	height, <i>cm</i>	19.8	20.1	19.2	20.7	19.9	3.51
	leader, <i>cm</i>	.7	1.0	.4	.4	.6	.82
	diam, <i>mm</i>	5.4	5.6	5.3	5.5	5.9	1.04

¹ Seedlings lifted on December 27 were held varying times in the precooler at 1° C (34° F), then processed normally, stored at 1° C, and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*.

³ Least significant difference ($p = 0.05$)

⁴ Deer ate 83 percent of the leaders.

EVALUATING FALL AND WINTER PLANTING

Most planting in the Pacific Slope forests is done in spring, after frozen soils thaw or winter snowpacks melt. On coastal slopes of the North Coast Range and Oregon Coast Range, by contrast, winters are milder, and planting units at middle elevations are normally open and free of snow. Consequently, many units are planted in late autumn and winter, as well as in spring.

Knowingly or not, foresters who undertake fall or winter plantings with Humboldt Nursery stock assume that sites dominated by Pacific Ocean air can be planted successfully in fall and winter, and that the seedlings used are physiologically in tune with climate on the site. In past years, neither assumption was questioned, and plantings either succeeded or failed for reasons that were seldom known or recognized.

To determine safe times to plant Douglas-fir in coastal regions, field performance tests were installed on cleared planting sites in northwest California and southwest Oregon. High survivals showed that coastal site planting windows are open in October or November to May, provided that maritime influence prevails and that wise use is made of both freshly lifted seedlings and seedlings lifted and cold stored at the right time.

Site planting windows were determined using seedlings of source GQ 301.30 from the western Klamath Mountains of California and source CH 082.25 from the southern Oregon Coast Range. Seedlings were lifted monthly, processed normally, stored at 1° C (34° F), and planted on cleared sites within 3 days of lifting (fresh) and in late spring after extended cold storage (see Assessing Planting Stock Quality, Standard Testing Procedures).

Seedlings of California source GQ were planted monthly in October-April, 1976-77 and 1977-78. The tests were installed side by side on an upland site located at 1 700 ft (518 m) of elevation and 9 miles (14.4 km) from the Pacific Coast (see *table 1*

in Appendix B, and Appendix D, Planting Site Descriptions). The test layouts consisted of 10 randomized complete blocks of split plots, with lifting date split for planting date. Seedlings were planted 2 ft (0.6 m) apart in parallel rows of 10. Lifting date plots held one row of fresh seedlings planted 2 days after lifting, and one row of stored seedlings planted April 25, 1977 or May 1, 1978.

Seedlings of Oregon source CH were planted monthly in October–April, 1978–79. The test was installed on an upland site located at 2250 ft (686 m) of elevation and 16 miles (25.6 km) from the Pacific Coast (see *table 1* in Appendix B, and Appendix D, Planting Site Descriptions). The test layout was the same as that for the California tests, except that lifting date was split for time in cold storage. Lifting date plots held one row of fresh seedlings planted 2 days after lifting in October–March, from five rows to none of seedlings planted monthly after cold storage, and one row of stored seedlings planted April 23,

1979. Lifting and planting date effects on survival and growth were assessed using variance analysis program BMD P8V and a split-plot design with effects fixed and blocks random (Jennrich and Sampson 1985).

First-year survivals showed that planting windows in coastal regions of northwest California–southwest Oregon are open up to 6 months (*table 51*). By using combinations of fresh and stored seedlings, upland sites were successfully planted in late autumn to late spring. In the contiguous California tests, fresh seedlings were safely planted in October–March, and stored seedlings from December–March lifts, as late as May 1. The Oregon test also defined a wide planting window. Fresh seedlings were safely planted in November–March, and stored seedlings from January–March lifts, as late as April 23.

Survivals in the Oregon test showed that the duration of safe cold storage is markedly reduced when seedlings are lifted before the seed source

Table 51—Survival and growth infield performance tests to determine coastal site planting windows for 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date)		Performance, by nursery lifting date						LSD ³
1976-77		Oct 4	Nov 8	Dec 13	Jan 10	Feb 7	Mar 7	
Klamath Mtns, W								
GQ	301.30 (lift + 2) ⁴							
	1-yr survival, <i>pct</i>	95	99	97	97	99	99	4.6
	2-yr survival, <i>pct</i>	88	89	89	86	90	83	13.3
	height, <i>cm</i>	27.6	28.9	29.7	29.7	29.2	24.4	3.29
	leader, <i>cm</i>	6.6	4.6	6.8	4.7	4.3	3.5	1.20
	diam, <i>mm</i>	6.6	6.6	6.6	6.2	6.6	5.2	.76
	4-yr survival, <i>pct</i>	87	88	87	86	89	81	13.8
	height, <i>cm</i>	39.1	38.4	44.1	38.1	37.8	31.4	4.65
	leader, <i>cm</i>	7.6	6.1	9.4	5.9	6.1	5.1	1.68
	diam, <i>mm</i>	9.1	8.7	9.8	7.8	8.2	6.5	1.20
GQ	301.30 77 (Apr 25) ⁴							
	1-yr survival, <i>pct</i>	22	88	98	98	97	98	7.4
	2-yr survival, <i>pct</i>	18	64	90	80	85	73	11.4
	height, <i>cm</i>	—	22.0	24.2	22.1	24.2	22.4	2.93
	leader, <i>cm</i>	—	3.7	3.7	3.1	3.0	3.1	.94
	diam, <i>mm</i>	—	5.6	6.6	5.5	5.8	5.7	.77
	4-yr survival, <i>pct</i>	21	63	87	77	87	69	12.5
	height, <i>cm</i>	—	31.9	36.4	31.0	34.0	31.3	4.92
	leader, <i>cm</i>	—	7.5	7.2	6.5	6.6	6.2	1.84
	diam, <i>mm</i>	—	6.8	7.9	6.5	7.0	6.7	.88

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin, on sites dominated by Pacific Ocean air; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10, table 52*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Planted on infertile soil; see Appendix D for planting site description.

Table 51—Survival and growth infield performance tests to determine coastal site planting windows for 2-0 Douglas-fir from Humboldt Nursery-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date						LSD ³
1977-78	Oct 17	Nov 21	Dec 19	Jan 16	Feb 13	Mar 13	
Klamath Mtns, W							
GQ 301.30 (lift + 2)⁴							
1-yr survival, pct	96	99	100	97	99	100	3.1
height, cm	27.9	24.6	21.9	20.6	24.6	24.0	2.54
leader, cm	6.0	6.4	6.8	7.8	7.7	6.9	.81
diam, mm	5.3	4.6	4.7	4.6	4.9	5.2	.48
3-yr survival, pct	95	97	96	97	97	100	4.7
height, cm	30.9	29.0	25.5	25.1	27.2	30.4	3.06
leader, cm	2.7	3.3	3.1	3.1	2.5	4.4	1.2
diam, mm	6.2	5.9	5.3	5.3	5.8	6.6	.84
GQ 301.30 78 (May 1)⁴							
1-yr survival, pct	3	83	96	98	99	97	7.4
height, cm	—	18.9	19.6	19.7	21.1	20.7	3.05
leader, cm	—	5.3	6.4	7.5	7.4	6.3	.68
diam, mm	—	5.0	5.0	4.9	5.2	5.1	.52
3-yr survival, pct	3	82	90	95	93	91	8.1
height, cm	—	21.7	22.6	22.7	23.7	24.4	3.37
leader, cm	—	2.3	2.8	2.3	2.2	2.8	.94
diam, mm	—	4.7	4.5	4.9	5.1	5.1	.63
1978-79	Oct 15	Nov 13	Dec 11	Jan 8	Feb 5	Mar 5	
Oregon Coast Range, S							
CH 082.25 (lift + 2)							
1-yr survival, pct	0	90	97	92	93	87	10.4
height, cm	—	33.5	34.3	35.8	35.4	32.8	3.03
leader, cm	—	6.3	7.7	6.7	6.8	6.8	1.22
diam, mm	—	7.0	6.7	6.8	6.4	6.3	.79
2-yr survival, pct	0	90	96	90	91	85	10.5
height, cm	—	52.8	55.3	51.4	54.3	47.3	6.39
leader, cm	—	20.4	22.1	19.1	19.9	16.5	4.41
diam, mm	—	11.7	11.7	11.8	11.7	11.0	1.20
CH 082.25 79 (Apr 23)							
1-yr survival, pct	0	52	84	93	89	93	9.5
height, cm	—	26.6	33.6	32.6	30.0	33.1	2.77
leader, cm	—	4.9	6.2	6.4	5.5	6.4	1.18
diam, mm	—	5.1	6.0	6.4	5.1	5.9	.72
2-yr survival, pct	0	50	81	93	87	92	10.6
height, cm	—	43.7	49.4	51.8	43.8	50.4	7.18
leader, cm	—	18.8	17.2	20.2	14.9	18.3	5.60
diam, mm	—	10.3	11.4	11.8	10.1	10.9	1.04

¹ Seedlings were stored at 1 ° C (34° F) and planted in the seed zone of origin, on sites dominated by Pacific Ocean air; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, *table 52*, and Seed Source Assessments—Douglas-fir, *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Planted on infertile soil; see Appendix D for planting site description.

Table 52—Survival and growth in a field performance test to determine coastal site planting windows for 2-0 Douglas-fir held for varying times in cold storage at Humboldt Nursery¹

Seed source ² and nursery lifting date	Performance, by site planting date ³					
	Nov 15	Dec 13	Jan 10	Feb 7	Mar 7	Apr 23
Oregon Coast Range, S						
CH 082.25 79						
1-yr survival, <i>pct</i>						
Nov 13	90	91	69	80	54	52
Dec 11		97	94	85	93	84
Jan 8			92	85	93	93
Feb 5				92	87	89
Mar 5					87	93
height, <i>cm</i>						
Nov 13	33.5	31.1	29.2	30.6	28.5	26.6
Dec 11		34.3	33.0	30.3	34.1	33.6
Jan 8			35.8	32.4	36.3	32.7
Feb 5				35.4	31.8	30.0
Mar 5					32.8	33.1
leader, <i>cm</i>						
Nov 13	6.3	7.2	6.3	6.4	5.8	4.9
Dec 11		7.7	6.9	6.0	7.4	6.2
Jan 8			6.7	6.4	7.4	6.4
Feb 5				6.8	5.3	5.5
Mar 5					6.8	6.4
diam, <i>mm</i>						
Nov 13	7.0	6.4	6.1	6.2	5.5	5.1
Dec 11		6.7	6.5	6.0	6.5	6.0
Jan 8			6.8	6.0	6.8	6.4
Feb 5				6.4	6.1	5.1
Mar 5					6.3	5.9
2-yr survival, <i>pct</i>						
Nov 13	90	90	68	80	54	50
Dec 11		96	94	85	92	81
Jan 8			90	84	91	93
Feb 5				91	86	87
Mar 5					85	92
height, <i>cm</i>						
Nov 13	52.8	48.0	45.5	48.2	46.0	43.7
Dec 11		55.3	53.3	46.4	54.0	49.4
Jan 8			51.4	47.8	56.3	51.8
Feb 5				54.3	46.0	43.8
Mar 5					47.3	50.4
leader, <i>cm</i>						
Nov 13	20.4	19.1	17.4	19.1	18.3	18.8
Dec 11		22.1	21.0	17.4	20.9	17.2
Jan 8			19.1	16.6	21.8	20.2
Feb 5				19.9	16.1	14.9
Mar 5					16.5	18.3
diam, <i>mm</i>						
Nov 13	11.7	11.1	11.1	10.8	10.1	10.3
Dec 11		11.7	11.9	10.7	11.9	11.4
Jan 8			11.8	11.5	12.4	11.8
Feb 5				11.7	10.8	10.1
Mar 5					11.0	10.9

lifting window opens (table 52). Seedlings in November lifts survived well after 1 month of storage, but not after 2 months, and those in December lifts survived well after 3 months, but not 4 months. Seedlings lifted in January, within the source lifting window, survived well after 3.5 months of storage. Gains in storability with later lifting should be expected for narrow-window sources like CH 082.25, but not for wide-window sources like GQ 301.30 (see fig. 19, and Seed Source Assessments—Douglas-fir, tables 3, 6).

Planting windows defined by first-year survival were confirmed by 2-year survival and growth (tables 51, 52). Testing in the maritime regions of southwest Oregon and northwest California shows that Humboldt Douglas-fir may be safely planted in late autumn to late spring. Survivals of 90 percent and higher are achieved by using fresh stock in autumn, either fresh or stored stock in winter, and stored stock in spring. The key to success of fall and winter planting on coastal sites is that marine influence prevails. Success of fall-winter plantings on more inland sites will depend on distance from the Pacific Coast and location in river drainages that channel Pacific Ocean air.

¹ Seedlings were stored at 1° C (34° F) and planted in the seed zone of origin, on a site dominated by Pacific Ocean air; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 51.



Douglas-fir plantation at age 18, 2 years after thinning: View of Jones Ridge unit 2 from Ship Mountain Road, and closeup of vigorous released trees



SEED SOURCE ASSESSMENTS--OTHER CONIFERS

Although the seedling testing program focused chiefly on Douglas-fir, survival and growth potentials of eight other conifers, termed "minor" at Humboldt Nursery because orders for them are few and small compared with Douglas-fir, were assessed as well. Four widespread true firs—Shasta red, white, noble, and grand—and three associates of Douglas-fir in coastal forests—Sitka spruce, western hemlock, and western redcedar—were sampled when representative seed sources were available in the nursery. Shasta red fir from the eastern Klamath Mountains and northern California Cascades and white fir from the eastern Klamath Mountains were assessed for growth capacity and field performance in 1975-79. Noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar from the northern Oregon Coast Range were similarly assessed in 1982-86. Incense-cedar from the eastern Klamath Mountains was assessed for growth capacity in the 1982-83 lifting season, but was not tested for field performance. Seedlings were grown under Humboldt's traditional cultural regime (see Reforestation and the Nursery, Standard Cultural Practices).

Minor conifers at Humboldt are major ones to foresters who plant them often. In response to client concerns, seedlings of requested sources were run through standard tests of growth capacity and field performance following the sampling scheme shown in *fig. 8*. Seedling top and root growth capacity (TGC, RGC) were evaluated just after lifting and after cold storage, and stored seedlings were evaluated for survival and growth on cleared planting sites in the seed zones of origin (see Assessing Planting Stock Quality, Standard Testing Procedures).

Our aim for the minor conifers was to answer the same questions posed for Douglas-fir, namely:

- What are the seasonal patterns of seedling TGC and RGC from autumn to spring in the nursery?
- To what extent are TGC and RGC at lifting altered by seedling cold storage to spring planting time?
- When can seedlings in the nursery be safely lifted for cold storage and spring planting, that is, when do the seed source lifting windows open and close?
- How is first-year survival on the planting site related to TGC and RGC after seedling cold storage?
- Does nursery lifting date affect seedling growth on the planting site more or less than it affects first-year survival?

Minor conifers showed results similar to those for Douglas-fir, and permitted us to develop comparable management guides. Seedling TGC and RGC traced distinct seasonal patterns in the nursery and changed markedly in cold storage. First-year survivals defined wide and narrow seed source lifting windows, and depended directly on RGC after storage. Critical RGC depended on seed source and planting site conditions. Critical RGC was low in tests that were installed and managed properly, and was inflated in those where seedlings were planted offsite, with J and L roots, or too early or too late, or that were left unprotected against tough plant competition or hungry mammals. Safe lifting and cold storage schedules for the true firs and Sitka spruce, western hemlock, and western redcedar were formulated by applying narrowed versions of known source lifting windows to untested sources from the same or adjacent seed zones.

Nursery experience with the minor conifers repeatedly indicated needs for improved seedling cultural regimes, but few sowing requests were large enough to permit studies of cultural alternatives. Studies to improve true fir regimes are underway. Efforts to assess Brewer spruce, Engelmann spruce, coast redwood, Port-Orford-cedar, various pines such as western white, sugar, Jeffrey, ponderosa, and lodgepole, and possibly other species, will depend on clientele priorities and sowing requests.

This chapter summarizes the knowledge gained on Humboldt's minor conifers. Results are presented by species and are organized primarily in a reference format. Seed source differences are pointed out, and conclusions are drawn, where warranted.

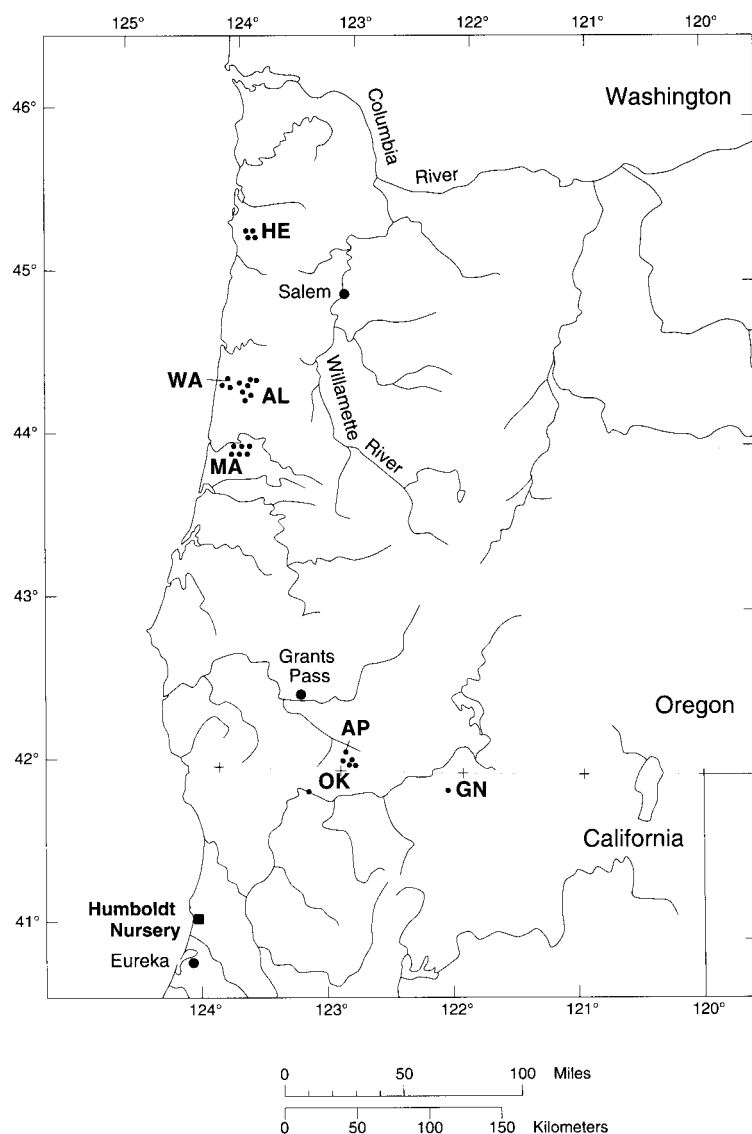


Figure 22—Seed sources used to determine lifting windows of minor conifers in Humboldt Nursery, and to evaluate seasonal patterns in top and root growth capacity (TGC, RGC), changes in TGC and RGC during seedling cold storage, and critical RGC for first-year survival. Seedlings of typical sources of Shasta red fir in the Klamath Mountains and California Cascades, white fir and incense-cedar in the Klamath Mountains, and noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar in the Oregon Coast Range were lifted monthly in autumn to spring, graded, root-pruned, and stored at 1 ° C (34° F) until spring planting time. Seedling TGC and RGC were evaluated in greenhouse tests just after lifting and after cold storage (see *fig. 9*). Survival and growth were evaluated in field performance tests on cleared planting sites in the seed zones of origin (see Appendix D Planting Site Descriptions).

Seed source¹

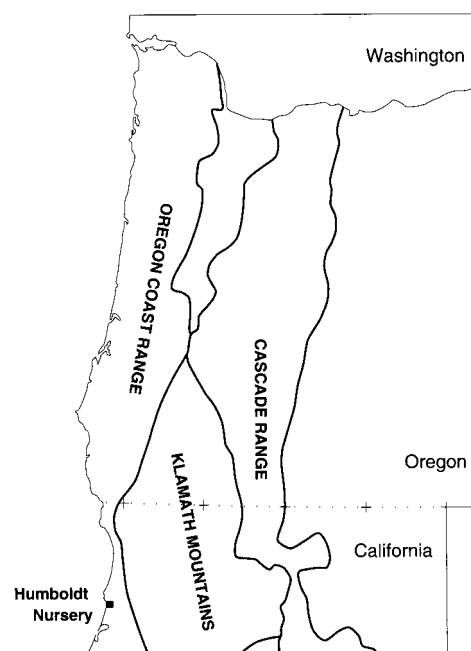
Oregon Coast Range, N

Siuslaw NF
Noble fir
Alsea RD
AL 252.40 83
Grand fir
Mapleton RD
MA 062.20 83
Sitka spruce
Hebo RD
HE 053.10 83
Waldport RD
WA 061.10 83
WA 061.10 84
WA 061.05 84
Alsea RD
AL 061.05 83
Mapleton RD
MA 062.10 83
MA 062.10 84
MA 062.05 84
Western hemlock
Hebo RD
HE 053.20 83
HE 053.15 84
Alsea RD
AL 061.15 84
AL 061.10 83
AL 252.25 85
Mapleton RD
MA 062.10 83

Oregon Coast Range, N

Siuslaw NF
Western redcedar
Hebo RD
HE 053.10 84
Alsea RD
AL 061.10 83
AL 061.10 84
Mapleton RD
MA 062.10 84
Klamath Mtns, E
Klamath NF
Shasta red fir
Oak Knoll RD
OK 321.60 76
OK 321.60 77
OK 321.60 78
White fir
Oak Knoll RD
OK 321.60 77
OK 321.60 78
Rogue River NF
Incense-cedar
Applegate RD
AP 511.40 83†
California Cascades
Klamath NF
Shasta red fir
Goosenest RD
GN 741.65 77

¹ Seed sources are listed by physiographic region and management unit of origin, National Forest (NF) and Ranger District (RD). The entries show tree seed zone (USDA Forest Service 1969, 1973), elevation (x100 ft), and test year. The symbol † indicates a source that was not outplanted.



SEED SOURCES ASSESSED

Seed sources used to assess minor conifers were typical of those sown in Humboldt Nursery (*fig. 22*). Shasta red fir was assessed for two sources from the Klamath Region, one from the northern California Cascades and one from the eastern Klamath Mountains. White fir and incense-cedar were assessed for sources from the eastern Klamath Mountains. Our findings apply to specific areas of the Klamath and Rogue River National Forests, and should be extrapolated with care to other regions.

Five species—noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar—were assessed for seed sources from the Siuslaw National Forest, which extends from latitude 43.7° to 45.3° N in the Oregon Coast Range. Noble fir was assessed for the source on Marys Peak, on the Alsea Ranger District, and grand fir, for a source from the Mapleton Ranger District. Sitka spruce, western hemlock, and western redcedar were assessed for three to six sources along a latitudinal transect of the Hebo, Waldport, Alsea, and Mapleton Ranger Districts. Sitka spruce and western hemlock were also assessed for sources from upper and lower elevations. Forest and climate types in the Pacific Coast Ranges suggest that our findings could be extrapolated north to the Olympic National Forest in southwest Washington and south to the Siskiyou National Forest in southwest Oregon.

Assessments of Shasta red fir were begun in 1975. Those of white fir were begun in 1976, after 10 percent of the seedlings in the red fir sowings were found to be white fir. Improved cone collection procedures now prevent such mixing, which was not unusual at the time, since white fir accounted for 10 to 40 percent of certain red fir lots in the Placerville Nursery. The Humboldt seedlings were separated just after lifting and tested for growth capacity before and after cold storage for the 1976-77 and 1977-78 lifting seasons. Field performance tests of Shasta red fir were installed in spring for 3 years, and those of white fir for 2 years, to evaluate stability of the seed source lifting windows.

Attention was shifted to the minor conifers in the Oregon Coast Range in 1982, after most of the work on 2-0 Douglas-fir had been completed (see Seed Source Assessments—Douglas-fir). Growth capacity and field performance tests were carried out on noble fir and grand fir for the 1982-83 lifting season, and on Sitka spruce, western hemlock, and western redcedar for the 1982-83 to 1984-85 seasons. Two sources of Sitka spruce and one of western redcedar

were repeated to determine stability of the source lifting windows. Growth capacity tests of incense-cedar from the Klamath Mountains were run for the 1982-83 season.

SEASONAL PATTERNS OF GROWTH CAPACITY

Seed source and lifting date significantly affected top and root growth capacity (TGC, RGC) of the minor conifers just after lifting through the winter season (*table 9*). Lifting date effects on TGC and RGC were analyzed for each source separately (see *table 4* in Appendix B). To illustrate the seasonal patterns and compare species and sources, TGC was graphed as the percentage of seedlings showing budburst or shoot extension (*fig. 23*), and RGC, as a percentage of the greatest new root length, cm per seedling, for the source (*fig. 24*).

TGC in Autumn-Winter

The true firs, Sitka spruce, and western hemlock, species that form dormant buds, show the same type of seasonal pattern in TGC as Douglas-fir. When graphed as budburst, TGC traced a sigmoid curve in autumn to spring (*fig. 23*). When graphed as shoot extension ≥ 1 cm (not shown), TGC traced an exponential curve from early winter or midwinter to late winter or spring (see *table 4* in Appendix B). The curves show that the chilling needed to release seedling dormancy was completed by midwinter or late winter, depending on seed source and lifting season. By contrast, western redcedar and incense-cedar, species that do not form buds, showed constant readiness for shoot growth, with TGC typically high in autumn and winter. Seasonal changes in TGC are described in the following summary, with the true firs grouped in natural pairs.

Shasta red fir and white fir—Red fir from sources OK 321.60 and GN 741.65 in the Klamath Mountains and California Cascades, and white fir from source OK 321.60 in the Klamath Mountains, increased TGC from less than 10 percent in November to 100 percent in February.

Noble fir and grand fir—Noble fir from source AL 252.40, on Marys Peak in the Oregon Coast Range, increased TGC from 7 percent in November to 100 percent in February, whereas grand fir from source MA 062.10, in the south end of the Siuslaw National Forest, increased TGC from 47 percent in November to 93 percent in February.

Table 9—Significance of seed source and lifting date effects on top and root growth capacity (TGC, RGC) of minor conifers tested just after lifting and after cold storage at Humboldt Nursery¹

Winter season, seed source, ² and source of variation	Degrees freedom	Variance (mean square) for...				
		Bud burst (pct)	Shoot length (cm)	Root length (cm)	Roots elongated	
					>1.5 cm	<1.5 cm
At lifting						
1976-77						
Shasta red fir						
OK 321.60, GN 741.65						
Seed source, S	1	0.008	—	3230	612	634
Lifting date, D	4	1.068 **	—	2702	467	512
SD	4	.027	—	2666	474	690
Error	20	.040	—	1028	241	365
1982-83						
Noble fir, grand fir						
AL 252.40, MA 062.20						
Seed source, S	1	0.042	0.150	11072	1438	3130
Lifting date, D	3	.580 **	3.935 **	6065	1329	5421
SD	3	.086 *	.018	4659	1014	240
Error	16	.018	.142	2706	609	2520
Sitka spruce						
HE 053.10, WA 061.10, AL 061.05, MA 062.10						
Seed source, S	3	0.230 **	0.623 **	8286**	1423 **	2214
Lifting date, D	4	2.542 **	12.422 **	2490	290	5714 **
SD	12	.081 **	.218 **	1983	210	897
Error	40	.010	.096	1281	216	1405
1983-84						
Sitka spruce						
WA 061.10, MA 062.10						
Seed source, S	1	0.154 **	3.434 *	58420**	5363 **	1829
Lifting date, D	4	1.045 **	23.032 **	9517*	1451 **	5415 *
SD	4	.126 **	1.949 *	7755*	1072 *	3420
Error	19	.015	.548	2147	310	1342
Western hemlock						
HE 053.20, AL 061.10, MA 062.10						
Seed source, S	2	0.038 **	0.714	2882	497	11766 **
Lifting date, D	4	1.272 **	25.687 **	86424**	15756 **	15899 **
SD	8	.006	.552	15224*	2762 *	3438 *
Error	30	.009	.483	5867	1070	1212
Western redcedar						
HE 053.10, AL 061.10, MA 062.10						
Seed source, S	2	—	—	58774	8919	6638
Lifting date, D	4	—	—	154087**	19704 **	5822 *
SD	8	—	—	5282	880	495
Error	29	—	—	25641	3829	2119
1984-85						
Western hemlock						
HE 053.15, AL 061.15, AL 252.25						
Seed source, S	2	0.459 **	2.844 **	109793**	25359 **	45882 **
Lifting date, D	4	.763 **	7.465 **	51086**	10542 **	8381 **
SD	8	.066 *	.761 **	6777	1506	2990
Error	30	.028	.149	10286	2060	1347

*, ** Significant at p <0.05, p <0.01.

¹ Seedlings were lifted monthly in autumn to spring and stored at 1 ° C (34° F) until spring planting time; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 22, and tables 4, 5 in Appendix B.

Table 9—Significance of seed source and lifting date effects on TGC and RGC of minor conifers tested just after lifting and after cold storage at Humboldt Nursery-continued ¹

Winter season, seed source ² , and source of variation	Degrees freedom	Variance (mean square) for...				
		Budburst (pct)	Shoot length (cm)	Root length (cm)	Roots elongated	
					≥1.5 cm	<1.5 cm
After storage						
1976-77						
Shasta red fir						
OK 321.60, GN 741.65						
Seed source, S	1	0.003	4.485 **	4685 **	1082 **	422
Lifting date, D	4	.003	.282	1336 **	310 *	602 **
SD	4	.003	.219	296	53	68
Error	20	.000	.372	227	72	105
1982-83						
Noble fir, grand fir						
AL 252.40, MA 062.20						
Seed source, S	1	3.920	1.193	57184 **	14514 **	17281 **
Lifting date, D	3	7.888 *	.853	7048	890	2367
SD	3	1.844	1.259	1978	253	1161
Error	16	1.921	.560	6069	712	802
Sitka spruce						
HE 053.10, MA 062.20						
Seed source, S	1	54.405 **	14.491 **	1613	244	74
Lifting date, D	4	14.490 **	.742 **	9892 *	1776 *	3077 **
SD	4	4.377 **	.950 **	1674	267	560
Error	20	.312	.050	2287	419	599
Sitka spruce						
WA 061.10, AL 061.05						
Seed source, S	1	2.760	3.571 **	1831	146	616
Lifting date, D	4	8.992 **	2.046 **	1088	56	269
SD	4	.809	.454	985	174	1764 **
Error	20	.898	.131	2746	538	525
1983-84						
Sitka spruce						
WA 061.10, MA 062.10						
Seed source, S	1	0.300 **	15.987 **	523	112	1178
Lifting date, D	4	.377 **	9.262 **	49962 **	6362 **	8871 **
SD	4	.110	.170	7542	911	2193
Error	20	.016	1.165	7840	963	1379
Western hemlock						
HE 053.20, MA 062.10						
Seed source, S	1	1.541 **	28.227 **	363726 **	63738 **	82268 **
Lifting date, D	4	.495 **	3.507 **	64217 **	12348 **	15021 **
SD	4	.211 **	2.490 **	70267 **	12710 **	11786 **
Error	20	.025	.485	13147	2581	2475
Western redcedar						
HE 053.10, MA 062.10						
Seed source, S	1	—	—	1442	3	4
Lifting date, D	4	—	—	183081 **	30975 **	18559 **
SD	4	—	—	24034	4205	1318
Error	20	—	—	30718	5972	2466
1984-85						
Western hemlock						
HE 053.15, AL 061.15						
Seed source, S	1	0.858 **	8.960 **	170340 **	41758 **	75975 **
Lifting date, D	4	.443 **	1.744 *	130624 **	24541 **	18614 **
SD	4	.058	.634	13758	2016	2070
Error	19	.039	.501	18582	3305	1805

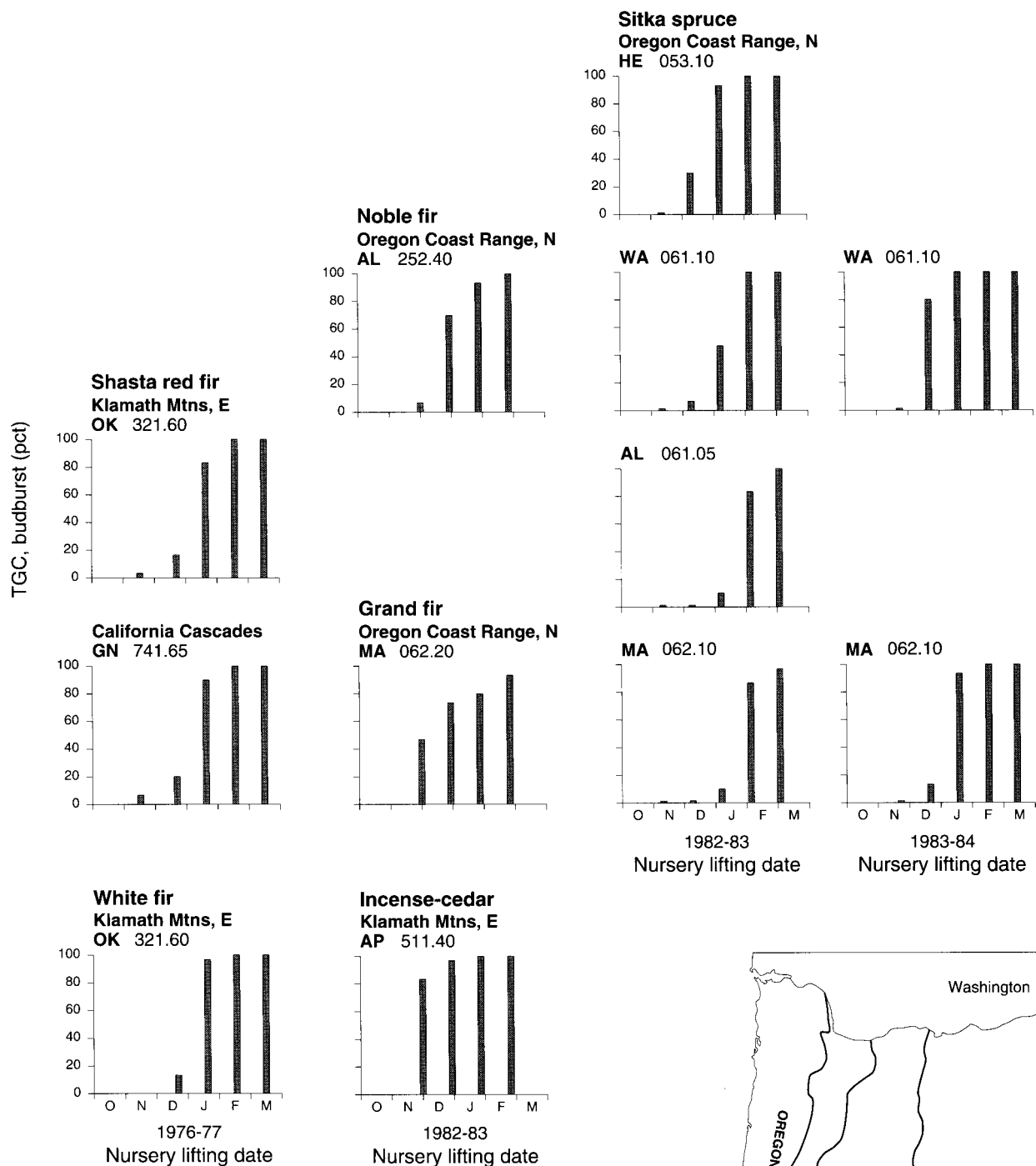
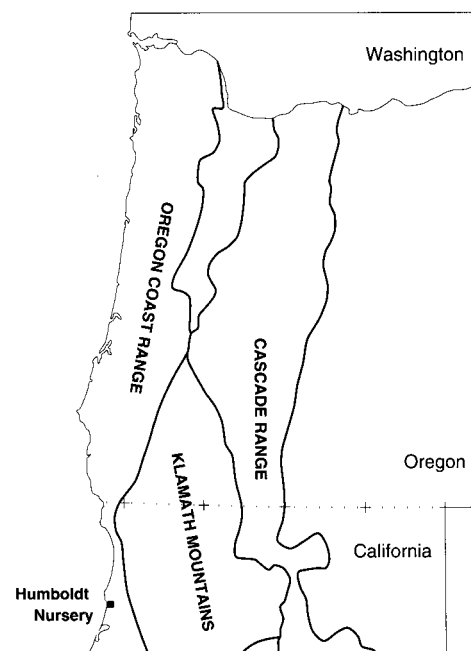
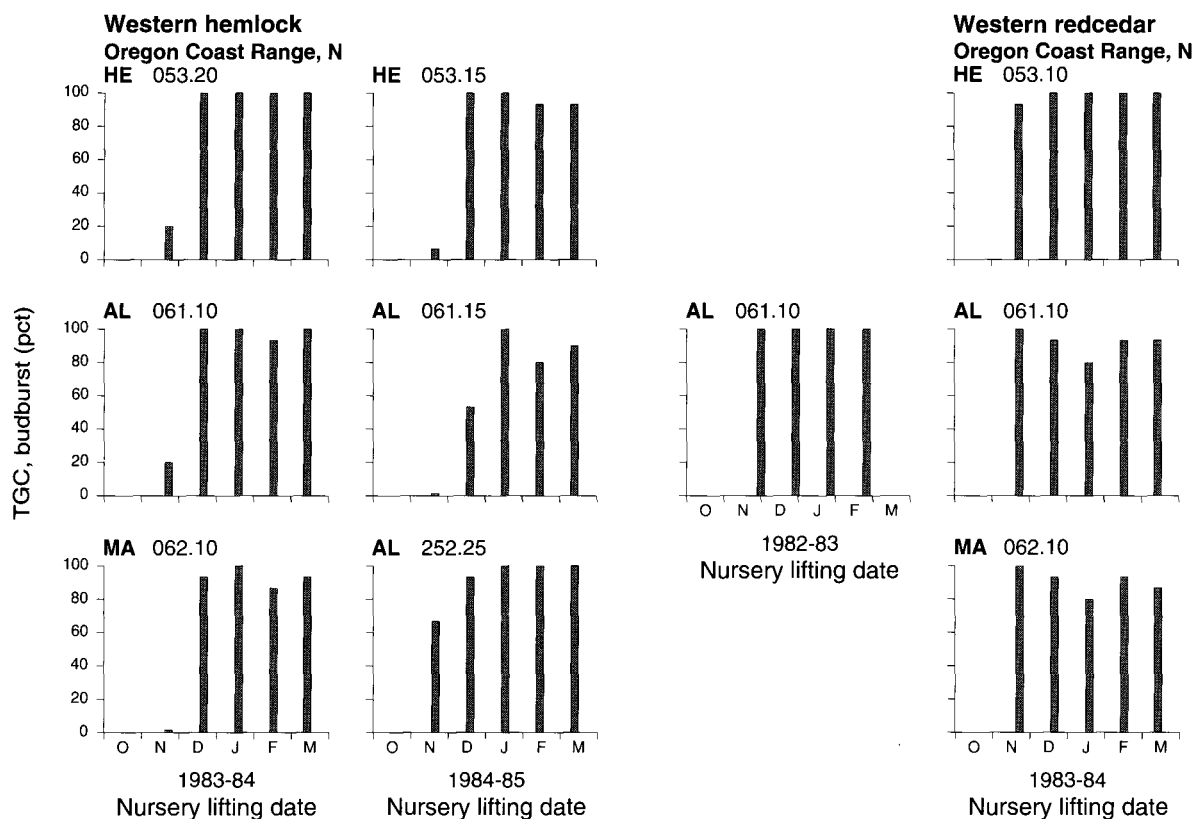


Figure 23—Seasonal patterns in top growth capacity (TGC) of minor conifers in Humboldt Nursery. Seedling TGC is graphed as the percentage of seedlings showing budburst or shoot extension ($n = 30$). Seedlings were lifted monthly in autumn to spring and tested just after lifting. The sigmoid patterns in TGC of Shasta red fir, white fir, noble fir, grand fir, Sitka spruce, and western hemlock show that the chilling needed to release dormancy and promote budburst is complete in early winter to midwinter. The plateau patterns in western redcedar and incense-cedar, which do not form buds, show high TGC in autumn and winter. Within species, the graphs are arrayed by nursery year, forest region, and seed source latitude.





Sitka spruce—Sitka spruce from the Oregon Coast Range increased in TGC from zero in November to 100 percent by March. In the 1982-83 lifting season, northern source HE 053.10 and midrange source WA 061.10 increased TGC faster than midrange source AL 061.05 and southern source MA 062.10. Overall, TGC ranged from zero to 30 percent in December, 10 to 93 percent in January, and 83 to 100 percent in February. In the 1983-84 season, midrange source WA 061.10 had TGC at 100 percent in January, whereas southern source MA 062.10 had TGC at 100 percent in February.

Western hemlock—Western hemlock of coastal sources in the Oregon Coast Range had TGC at zero to 20 percent in November, whereas inland source AL 252.25 had TGC at 67 percent. Seedling TGC reached 93 to 100 percent in December, except 53 percent in coastal source AL 061.15. In January-March, sources HE 053.20 and AL 252.25 maintained TGC at 100 percent, whereas lower-elevation sources HE 053.15, AL 061.15, AL 061.10, and MA 062.10 tended to decrease in TGC.

Western redcedar—Western redcedar from midrange source AL 061.10 in the Oregon Coast Range had TGC at 100 percent throughout the 1982-83 lifting season. In the 1983-84 season, northern source HE 053.10 had TGC at 93 to 100

percent in November-March, whereas midrange source AL 061.10 and southern source MA 062.10 had TGC varying from 100 percent in November to 80 percent in January to 93 percent in February.

Incense-cedar—Incense-cedar from source AP 511.40 in the Klamath Mountains increased TGC from 83 percent in November to 97 or 100 percent in December-February.

RGC in Autumn-Winter

Seasonal patterns of RGC in the minor conifers are of two distinct types. Depending on seed source the minor conifers show either a single-peak or a high-plateau pattern, whereas Douglas-fir shows the two-peak type in addition to the single-peak and high-plateau types. Graphed as a percentage of the highest new root length for the source, RGC traced either a single-peak pattern or a high-plateau that ranged from 1 to 4 months wide (*fig. 24*). Peak or highest RGC reached 1.7 m in Shasta red fir and 1.3 m in white fir, 1.3 m in noble fir and 2.3 m in grand fir, 3 m in Sitka spruce, 4.7 m in western hemlock, 6.1 m in western redcedar, and 4 m in incense-cedar (see *table 4* in Appendix B). Seasonal patterns in RGC are described in the following summary, with the true firs grouped in natural pairs.

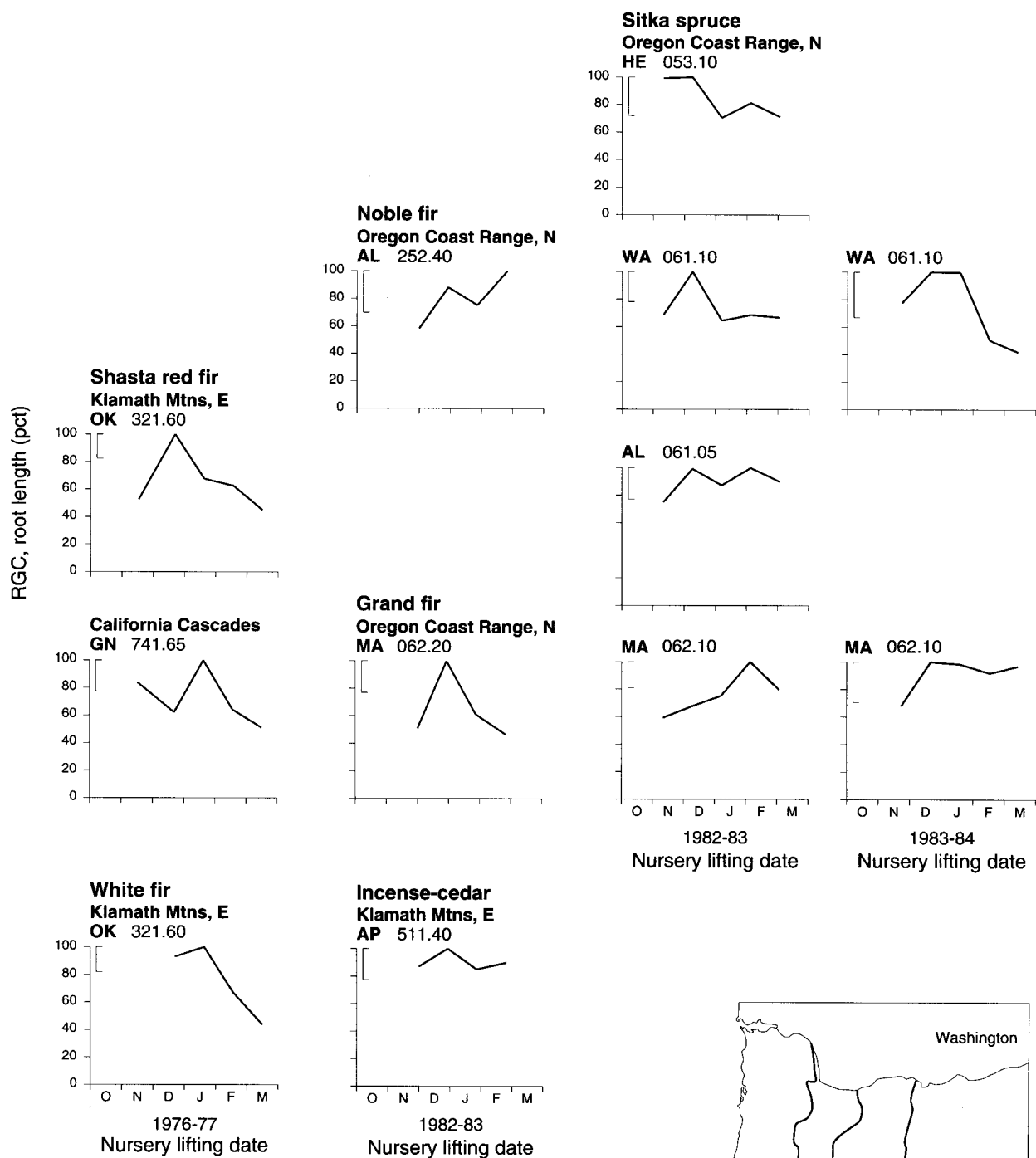
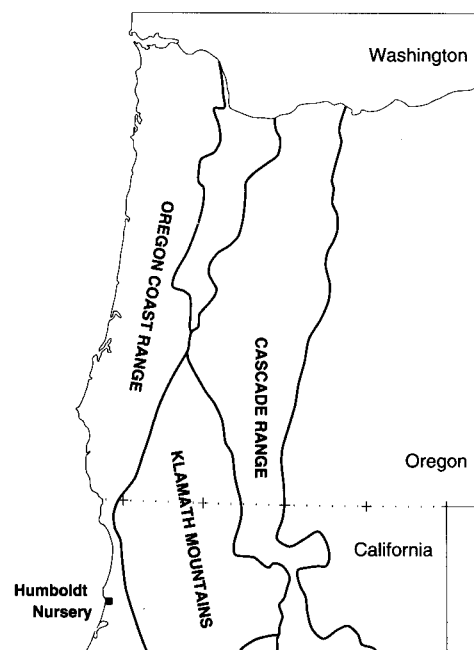
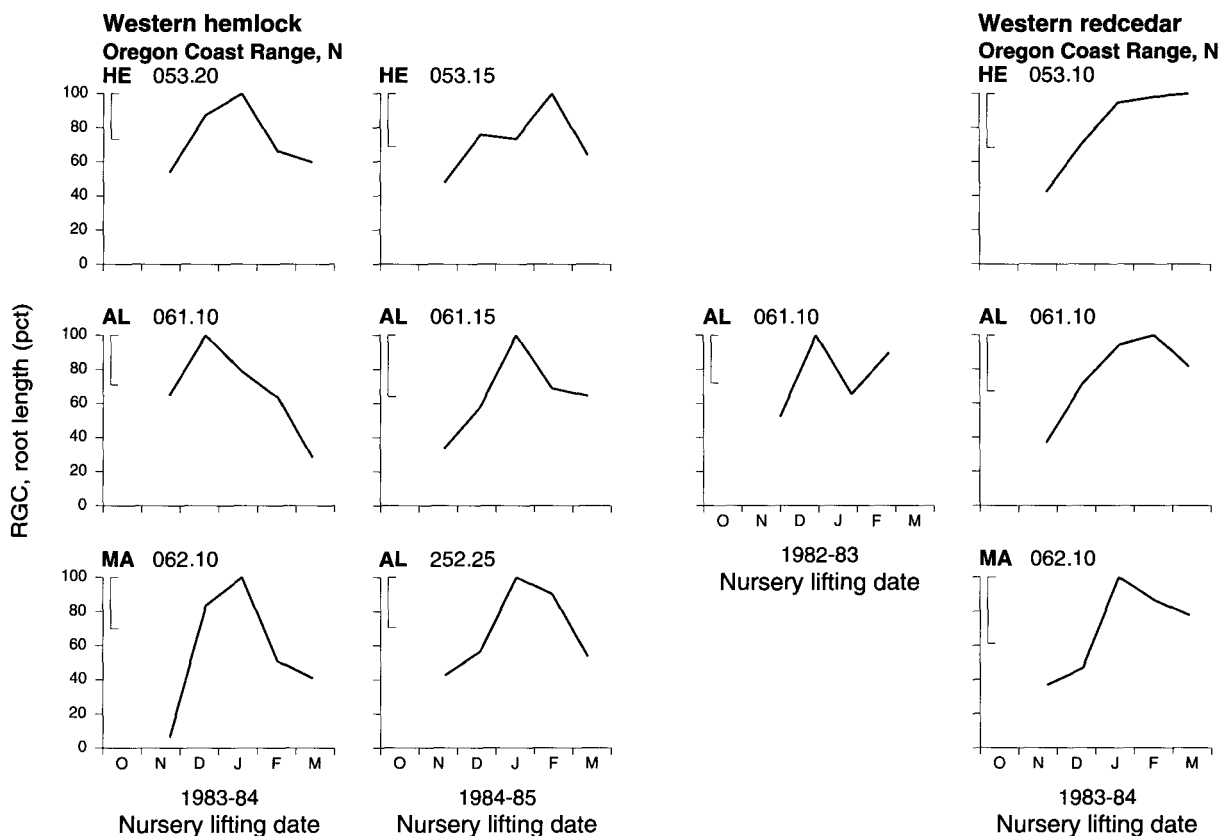


Figure 24—Seasonal patterns in root growth capacity (RGC) of minor conifers in Humboldt Nursery. Seedling RGC is graphed as a percentage of the highest RGC, cm per seedling, determined for the seed source ($n = 30$). Seedlings were lifted monthly in autumn to spring and tested just after lifting. The seasonal patterns in RGC are of three distinct types: single-peak, two-peak, and high-plateau. Within species, the graphs are arrayed by nursery year, forest region, and source latitude. Brackets indicate least significant difference ($p = 0.05$).





Shasta red fir and white fir—Red fir from sources OK 321.60 and GN 741.65 in the Klamath Mountains and California Cascades showed single-peak patterns, with peak RGC in December and January, respectively. By contrast, white fir from source OK 321.60 in the Klamath Mountains showed a narrow plateau pattern, with RGC high in December-January.

Noble fir and grand fir—Noble fir from source AL 252.40, Marys Peak in the Oregon Coast Range, showed a high-plateau pattern, with RGC high in December-February, whereas grand fir from source MA 062.20, the south end of the Siuslaw National Forest, showed a single-peak pattern with peak RGC in December.

Sitka spruce—Sitka spruce from northern and lower-elevation midrange sources HE 053.10 and AL 061.05 in the Oregon Coast Range showed wide plateau patterns, with RGC high in November-March. Upper-elevation midrange and southern sources WA 061.10 and MA 062.10 showed single-peak patterns in the 1982-83 lifting season, with peak RGC in December and February, respectively. The same sources showed high-plateau patterns in the 1983-84 season, with RGC high in November-January and December-March.

Western hemlock—Western hemlock from northern, midrange, and southern sources HE 053.20, AL 061.10, and MA 062.10 in the Oregon Coast Range all showed a narrow plateau pattern in the 1983-84 lifting season, with RGC high in December-January. By contrast, northern source HE 053.15 showed a wider plateau pattern in the 1984-85 season, with RGC high in December-February, whereas midrange coastal and inland sources AL 061.15 and AL 252.25 showed a narrow plateau pattern, with RGC high in January-February.

Western redcedar—Western redcedar from midrange source AL 061.10 in the Oregon Coast Range showed a high-plateau pattern in the 1982-83 lifting season, with RGC high in December-February. Northern source HE 053.10 and repeated midrange source AL 061.10 showed wide plateau patterns in the 1983-84 season, with RGC high in December-March, whereas southern source MA 062.10 showed a narrower plateau pattern, with RGC high in January-March.

Incense-cedar—Incense-cedar from source AP 511.40 in the Klamath Mountains showed a wide plateau pattern, with RGC high in November-March.

COLD STORAGE CHANGES OF TGC AND RGC

Seed source and lifting date significantly affected top and root growth capacity (TGC, RGC) of the minor conifers after cold storage, at spring planting time (*table 9*). Seedlings tested after storage showed either an increase, no change, or a decrease in the capacity for budburst or shoot extension and root elongation, compared to those tested just after lifting (see *tables 4, 5* in Appendix B).

Changes in TGC and RGC during seedling cold storage were assessed by r^2 for TGC and RGC before and after storage (*table 10*). For the true firs—Shasta red, white, noble, and grand—and Sitka spruce and western hemlock, TGC was expressed as the percentage of seedlings showing budburst, and for western redcedar and incense-cedar, those showing shoot extension. Seedling RGC was expressed as new root length, cm per seedling. Most sources showed huge changes, and r^2 was mostly smaller for

RGC than for TGC, indicating greater changes in RGC than in TGC.

Depending on seed source, TGC at lifting explained zero to 99 percent of the variation in TGC after storage; r^2 was 0.00 and 0.30 for Shasta red fir, 0.26 to 0.99 for Sitka spruce, 0.35 to 0.97 for western hemlock, 0.33 to 0.99 for western redcedar, and 0.00, 0.41, 0.88, and 0.93 for white fir, noble fir, grand fir, and incense-cedar, respectively. Also depending on source, RGC at lifting explained zero to 89 percent of the variation in RGC after storage; r^2 was 0.00 and 0.32 for Shasta red fir, 0.02 to 0.67 for Sitka spruce, 0.13 to 0.36 for western hemlock, 0.18 to 0.89 for western redcedar, and 0.00, 0.03, 0.49, and 0.70 for white fir, noble fir, grand fir, and incense-cedar.

Cold storage changes in each species were illustrated by graphing TGC and RGC at lifting and after storage. Seedling TGC was graphed and compared as the percentage of seedlings showing budburst or shoot extension (*fig. 25*), and RGC, as a percentage of the greatest new root length, cm per seedling, found for the source, first at lifting and then after storage (*fig. 26*).



Shasta red fir seedlings in their second growing season in Humboldt Nursery, looking west in A Block

TGC at Planting Time

Seedlings lifted for cold storage in late autumn or early winter showed spectacular gains in TGC after storage, at spring planting time (*fig. 25*). Overwinter storage completed the chilling needed for rapid budburst and shoot extension in the true firs—Shasta red, white, noble, and grand—and Sitka spruce and western hemlock, species that form dormant buds (see *table 5 in Appendix B*). In all tests, TGC of the true firs and Sitka spruce increased in autumn to midwinter lifts and remained high in midwinter to spring lifts. By contrast, TGC of western hemlock increased or not in autumn lifts, remained high or

Table 10—Coefficients of determination, r^2 , for top and root growth capacity (TGC, RGC) of minor conifers tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ²	Post-storage testing date	r^2	
		TGC	RGC
Shasta red fir			
OK 321.60 77	May 31	0.00	0.32
GN 741.65 77	May 31	.30	.00
White fir			
OK 321.60 77	Jun 6	0.00	0.00
Noble fir			
AL 252.40 83	Apr 25	0.41	0.03
Grand fir			
MA 062.10 83	Apr 25	0.88	0.49
Sitka spruce			
HE 053.10 83	Apr 4	0.66	0.37
WA 061.10 83	Mar 28	.81	.02
WA 061.10 84	Apr 23	.99	.10
AL 061.05 83	Mar 28	.26	.67
MA 062.10 83	Apr 4	.71	.48
MA 062.10 84	Apr 23	.70	.62
Western Hemlock			
HE 053.20 84	Mar 26	0.97	0.13
HE 053.15 85	Mar 25	.87	.46
AL 061.15 85	Mar 25	.76	.86
MA 062.10 84	Mar 26	.35	.36
Western redcedar			
HE 053.10 84	Apr 9	0.99	0.18
AL 061.10 83	May 23	.33	.19
MA 062.10 84	Apr 9	.66	.89
Incense-cedar			
AP 511.40 83	May 31	0.93	.70

¹ Seedlings were lifted monthly in autumn to spring and stored at 1 ° C (34° F). Seedling TGC was expressed as budburst or shoot extension (pct), and RGC, as root elongation (cm); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*, and *tables 4,5 in Appendix B*.

dropped to zero in early-winter lifts, and remained high or fell in midwinter to spring lifts, depending on seed source. That of western redcedar remained high or dropped to zero in autumn lifts and remained high or decreased slightly in early-winter to spring lifts, depending on source. That of incense-cedar decreased slightly in storage, but was still 90 percent or higher in the early-winter to spring lifts.

RGC at Planting Time

Seedlings of most of the minor conifers showed major changes in RGC after cold storage (*fig. 26*). Lifts that yielded high RGC after storage, at spring planting time, and lifts that showed relative gains or losses in RGC after storage, are noted in the following summary, with the true firs grouped in natural pairs.

Shasta red fir and white fir—Red fir from source OK 321.60 in the Klamath Mountains showed high RGC in the November-March lifts in the 1975-76 lifting season (not shown), and in the December-February lifts in the 1976-77 season, with gains in the January-March lifts. Red fir from source GN 741.65 in the California Cascades showed high RGC in the December-March lifts, with loss in the November lift and gains in the February-March lifts. White fir from source OK 321.60 in the Klamath Mountains showed high RGC in the December-March lifts, with gains in the February-March lifts.

Noble fir and grand fir—Noble fir from source AL 252.40, Marys Peak in the Oregon Coast Range, showed high RGC in the December-March lifts, with gain in the November lift and loss in the February lift. Grand fir from source MA 062.20, the south end of the Siuslaw National Forest, showed high RGC in the December-March lifts, with gains in the January-February lifts.

Sitka spruce—Sitka spruce from northern source HE 053.10 in the Oregon Coast Range showed high RGC in the December-March lifts in the 1982-83 lifting season, with losses in the November-December lifts. Midrange sources WA 061.10 and AL 061.05 showed high RGC in the November-March lifts in the same season, with gains in the January-March lifts of source AL, and southern source MA 062.10 showed high RGC in the December-March lifts, with loss in the November lift. In the 1983-84 season, midrange source WA 061.10 showed high RGC in the December-March lifts, with losses in the November-December lifts and gains in the February-March lifts, and southern source MA 062.10 showed high RGC in the January-March lifts, with losses in the November-December lifts.

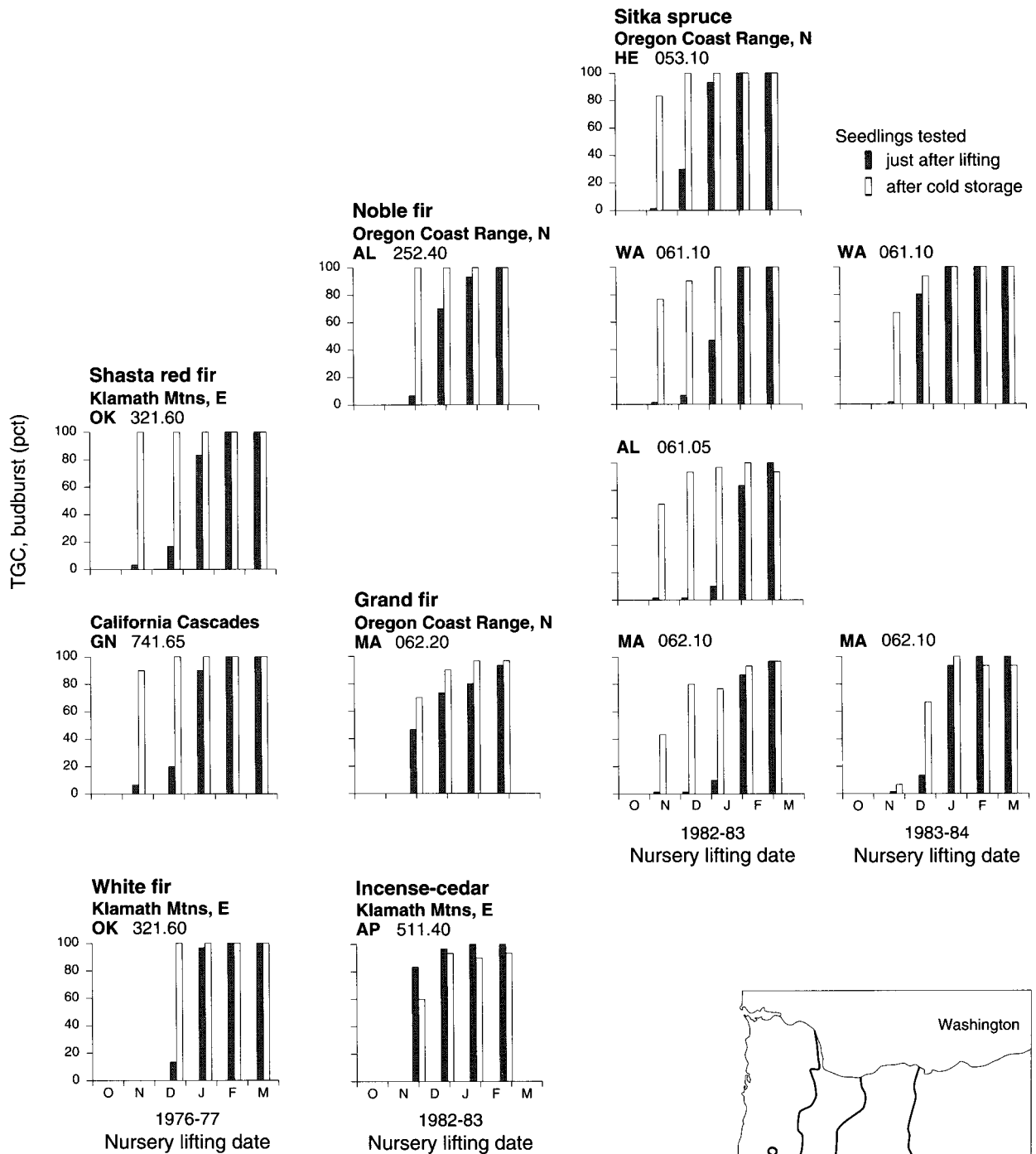
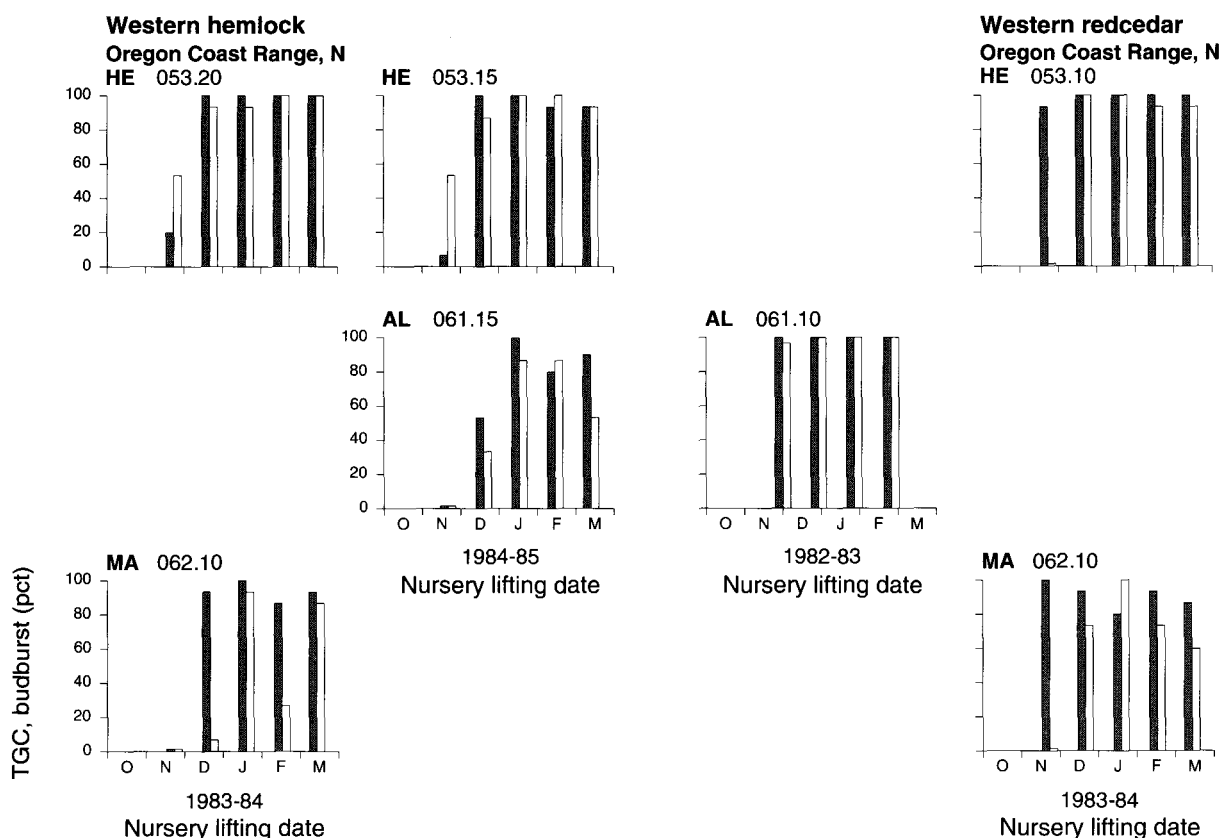


Figure 25—Cold storage effects on top growth capacity (TGC) of minor conifers at Humboldt Nursery. Seedling TGC is graphed as the percentage of seedlings showing budburst or shoot extension ($n = 30$). Seedlings were lifted monthly in autumn to spring, stored at 1°C (34°F), and tested at spring planting time. For Shasta red fir, white fir, noble fir, grand fir, Sitka spruce, and western hemlock, cold storage builds TGC in early-winter lifts and improves or maintains it in midwinter and later lifts. For western redcedar and incense-cedar, which do not form buds, cold storage maintains high TGC. Within species, the graphs are arrayed by nursery year, forest region, and seed source latitude.



Western hemlock—Western hemlock from northern sources HE 053.20 and HE 053.15 in the Oregon Coast Range showed high RGC in the December-March and January-March lifts, respectively, with losses in the November-December lifts. Midrange source AL 061.15 showed high RGC in the January-February lifts, with losses in the November-December and March lifts. Southern source MA 062.10 showed high RGC in the January lift only, with loss in the December lift.

Western redcedar—Western redcedar from northern source HE 053.10 in the Oregon Coast Range showed high RGC in the December-January lifts, with losses in the November and February-March lifts. Midrange source AL 061.10 showed high RGC in the December-March lifts, and southern source MA 062.10, high RGC in the January lift only, with losses in the November and February-March lifts.

Incense-cedar—Incense-cedar from source AP 511.40 in the Klamath Mountains showed highest RGC in the December lift, with losses in the November and January-February lifts.

Practical Implications

Findings for the minor conifers in Humboldt Nursery—Shasta red, white, noble, and grand firs, Sitka spruce, western hemlock, western redcedar, and incense-cedar—like those for Douglas-fir, demonstrate that results of growth capacity tests run just after lifting should not be used to predict planting stock quality after cold storage. Seedlings stored for spring planting mostly increase TGC and, depending on seed source and lifting date, either increase, maintain, or decrease RGC. Successful predictions of field survival might be possible where the seasonal patterns of TGC and RGC in the nursery and changes in TGC and RGC during storage are known. Unfortunately, too many sources require evaluation, and make this option impractical.

Growth capacity tests of the minor conifers after cold storage might be used to assess stock quality, provided that the tests are completed within 4 to 6 weeks of spring planting. Variation in RGC after storage is great, however, and indicates that the safe calendar period to lift and store seedlings for spring planting depends on the species and source. Reliable predictions of field performance for any particular conifer demand a specific knowledge of its seed source lifting windows and critical RGC for first-year survival on the planting sites.

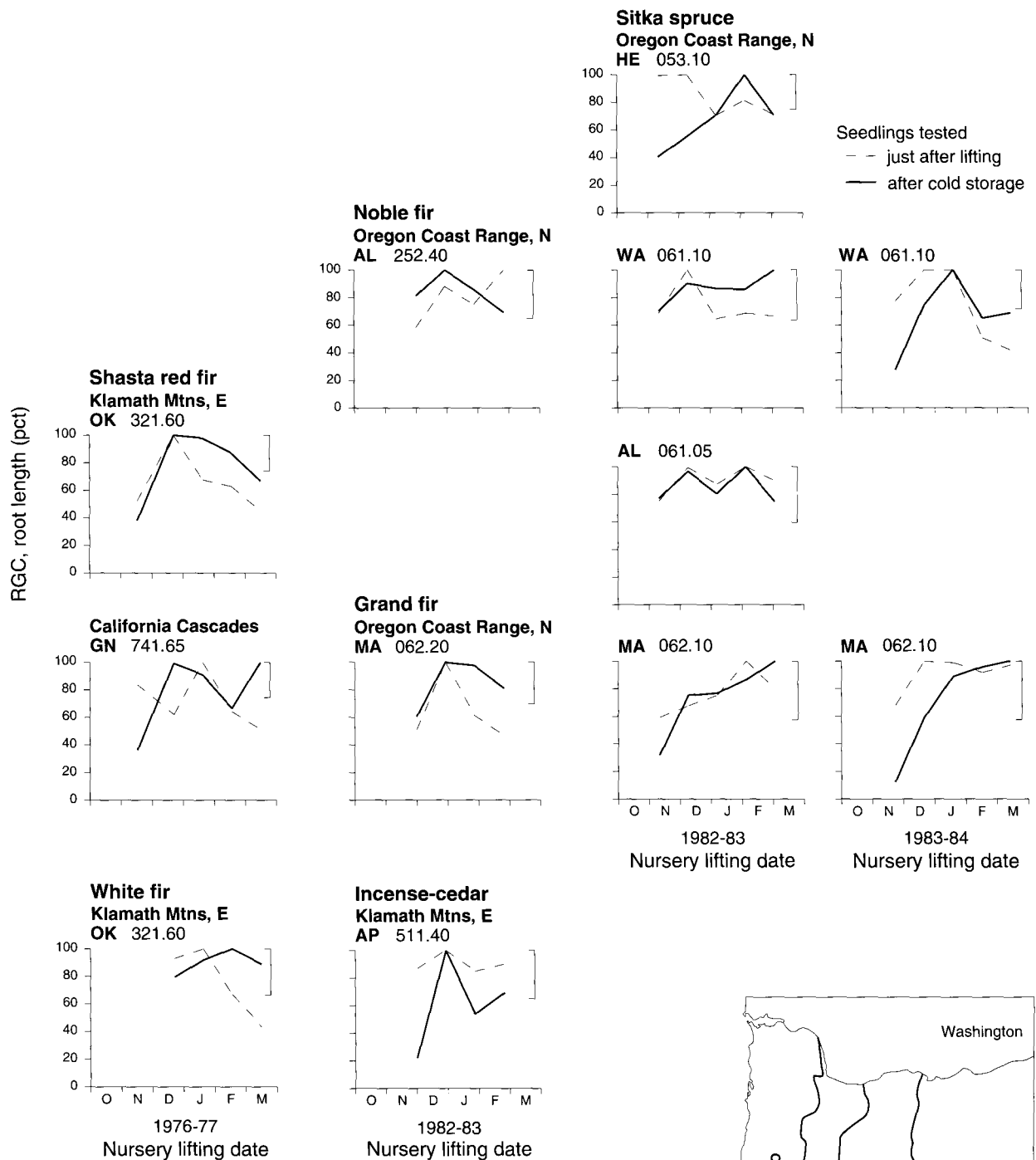
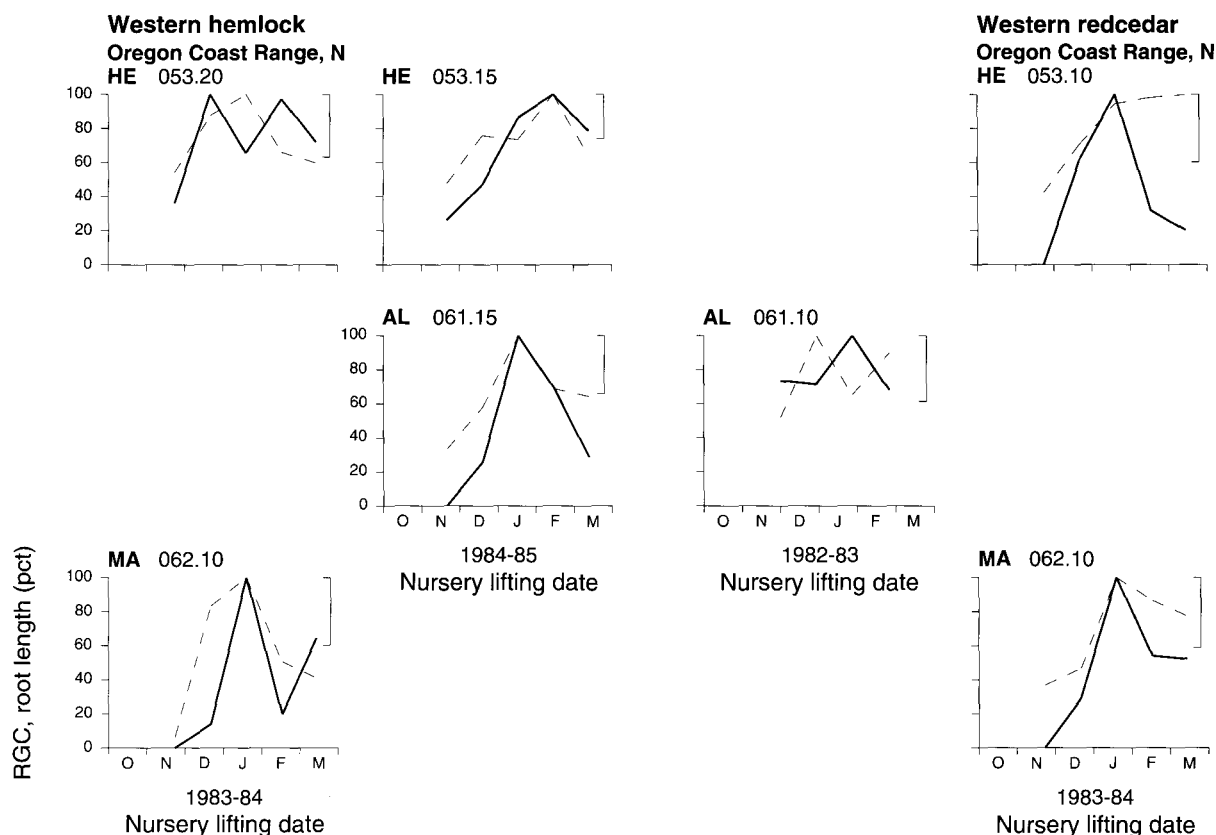


Figure 26—Cold storage effects on root growth capacity (RGC) of minor conifers at Humboldt Nursery. Seedling RGC is graphed as a percentage of the highest RGC, cm per seedling, determined for the seed source ($n = 30$). Seedlings were lifted monthly in autumn to spring, stored at 1°C (34°F), and tested at spring planting time. Cold storage decreases, increases, or maintains RGC, depending on seed source and lifting date. Within species, the graphs are arrayed by nursery year, forest region, and source latitude. Brackets indicate least significant difference ($p = 0.05$).



SEED SOURCE LIFTING WINDOWS

Seed source lifting windows, safe calendar periods to lift seedlings for cold storage and spring planting, were determined for seven of the minor conifers in Humboldt Nursery, that is, Shasta red, white, noble, and grand firs and Sitka spruce, western hemlock, and western cedar (*table 11, fig. 27*). Source lifting windows were determined in 26 field performance tests, and are described in the following summary, with the true firs grouped in natural pairs.

Shasta red fir and white fir—Red fir from source OK 321.60 in the Klamath Mountains showed a lifting window that was open 4 months, in late autumn to spring in the 1975-76 lifting season. First-year survival averaged 92 percent, and was 91 percent for seedlings that had been stored 7 months. In the 1976-77 and 1977-78 seasons, the window was open 3 months, in early winter to spring. First-year survival within the window averaged 63 and 74 percent in the respective tests, and gophers caused the high mortality in both.

Red fir from source GN 741.65 in the California Cascades also showed a window that was open 4 months, in late autumn to spring in the 1976-77 season. First-year survival averaged 96 percent, and was 91 percent for seedlings that had been stored 7 months.

White fir from source OK 321.60 in the Klamath Mountains showed a window that was open 3 months, in early winter to spring in the 1976-77 and 1977-78 seasons. First-year survival within the window averaged 68 and 88 percent in the respective tests, and gophers caused the high mortality in the 1977 test.

Noble fir and grand fir—Noble fir from source AL 252.40, Marys Peak in the Oregon Coast Range, showed a lifting window that was open 3 months, and grand fir from source MA 062.20, the south end of the Siuslaw National Forest, a window that was open 2 months. Both windows opened in late November, but that of noble fir closed in February and that of grand fir, in January. Within the windows, first-year survival averaged 91 percent for noble fir and 86 percent for grand fir.

Table 11—Seed source lifting windows for minor conifers in Humboldt Nursery¹

Seed source ²	Site planting date	Field survival, by nursery lifting date ³					LSD ⁴
		Nov	Dec	Jan	Feb	Mar	
----- <i>pct</i> -----							
Shasta red fir							
OK 321.60 76	May 25	91•	87•	98•	93•	92•	11.3
OK 321.60 77	May 17	43•	57•	62•	72•	60•	17.7
OK 321.60 78	Jun 2	48•	64•	78•	80•	47•	16.7
GN 741.65 77	Jun 13	91•	99•	100•	98•	94•	4.9
White fir							
OK 321.60 77	May 18		71•	69•	68•	62•	14.6
OK 321.60 78	Apr 12	84•	86•	92•	92•	64•	11.8
Noble fir							
AL 252.40 83	Apr 19	87•	99•	94•	86•		11.1
Grand fir							
MA 062.20 83	Apr 13	82•	97•	87•	79•		9.2
Sitka spruce							
HE 053.10 83	Mar 30	96•	97•	93•	99•	98•	4.5
WA 061.10 83	Mar 25	98•	100•	99•	100•	100•	2.0
WA 061.10 84	Apr 2	89•	98•	96•	98•	98•	6.4
WA 061.05 84	Apr 2	100•	95•	98•	97•	97•	5.1
AL 061.05 83	Apr 18	68•	69•	61•	77•	67•	11.5
MA 062.10 83	Apr 12	47•	70•	65•	75•	75•	15.0
MA 062.10 84	Mar 29	56•	92•	99•	97•	96•	8.1
MA 062.05 84	Mar 30	95•	93•	99•	96•	99•	4.2
Western hemlock							
HE 053.20 84	Apr 25	58•	92•	91•	96•	92•	15.3
HE 053.15 85	Apr 17	22•	60•	68•	70•	56•	12.1
AL 061.15 85	Apr 17	7•	56•	57•	45•	28•	16.9
AL 061.10 84	Apr 19	18•	49•	69•	69•	63•	18.2
AL 252.25 85	Apr 10	40•	47•	49•	50•	23•	17.7
MA 062.10 84	Apr 3	1•	26•	41•	15•	20•	13.6

Table 11—Seed source lifting windows for minor conifers in Humboldt Nursery-continued¹

Seed source ²	Site planting date	Field survival, by nursery lifting date ³					LSD ⁴
		Nov	Dec	Jan	Feb	Mar	
<i>pct</i>							
Western redcedar							
HE 053.10 84	Apr 25	32•	92•	98•	94•	93•	13.0
AL 061.10 83	May 6	66•	56•	59•	66•		22.8
AL 061.10 84	Apr 19	28•	86•	90•	94•	89•	10.4
MA 062.10 84	Apr 2	28•	84•	98•	94•	85•	12.1

¹ Seedlings were stored at 1 ° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 22.

³ Shaded bars indicate seed source lifting windows. The symbol • denotes nursery lifting date; the number is first-year survival.

⁴ Least significant difference (p = 0.05).

Sitka spruce—Sitka spruce from northern source HE 053.10 and midrange sources WA 061.10 and AL 061.05 in the Oregon Coast Range showed lifting windows that spanned more than 4 months, in late autumn to spring in the 1982-83 lifting season. In the same season, the window of southern source MA 062.10 was open more than 3 months, in early winter to spring.

In the 1983-84 season, the windows of the lower-elevation midrange and southern sources WA 061.05 and MA 062.05 spanned more than 4 months, in late autumn to spring, whereas those of the upper-elevation midrange and southern sources WA 061 .10 and MA 062.10 were open 3 to 3.5 months, in early winter to spring. The windows were stable for the repeated midrange and southern sources, WA 061.10 and MA 062.10, as the first safe lifting dates in the 1983-84 season were within 10 to 14 days of those in the 1982-83 season.

Western hemlock—Western hemlock of northern, midrange, and southern sources HE 053.20, AL 061.10, and MA 062.10 in the Oregon Coast Range showed lifting windows that were open more than 3 months, almost 3 months, and 1 month in the 1983-84 lifting season. First-year survivals within the respective source windows averaged 93, 63, and 40 percent.

In the 1984-85 season, the window of northern source HE 053.15 was open 3 months, in early winter to spring, whereas those of midrange coastal and inland sources AL 061.15 and AL 252.25 were open 2.5 months in winter and 3.5 months in late autumn to late winter. First-year survivals within the respective windows averaged 64, 53, and 47 percent.

Western redcedar—Western redcedar from midrange source AL 061.10 in the Oregon Coast Range showed a lifting window that was open 4 months, in late autumn to spring in the 1982-83 lifting season. The seedlings were planted offsite, inland in seed zone 252, and first-year survival averaged 62 percent.

In the 1983-84 season, the windows of northern and midrange sources HE 053.10 and AL 061.10 spanned more than 3 months, in early winter to spring, and the window of southern source MA 062.10, about 3 months. First-year survivals within the respective windows averaged 94, 90, and 90 percent. The window for repeated midrange source AL 061 .10 was reasonably stable, as the first safe lifting date in the 1983-84 season was within 18 days of that in the 1982-83 season.

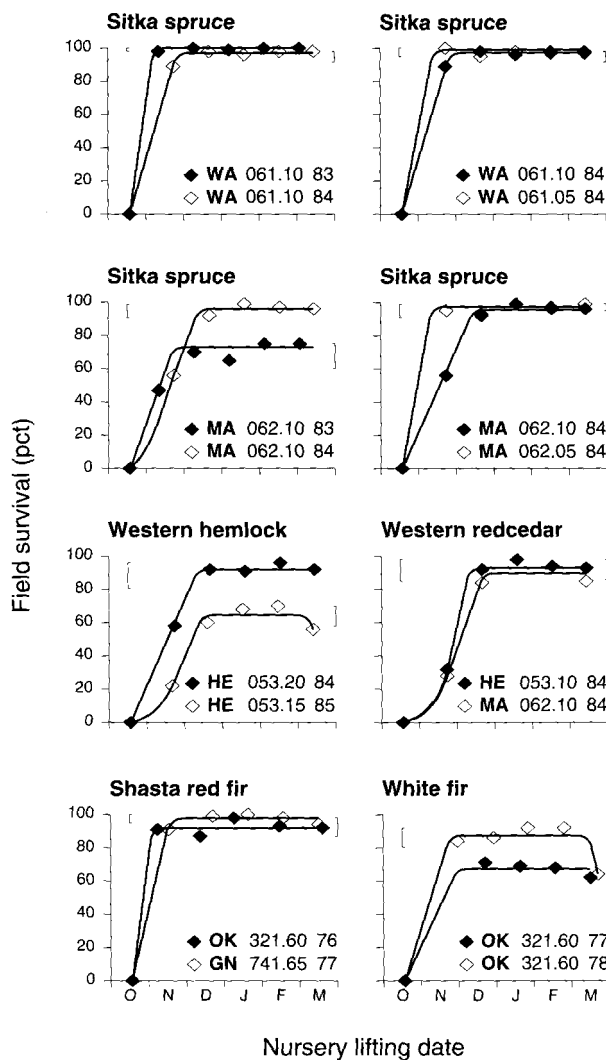


Figure 27—Seed source and lifting date effects on first-year survival of minor conifers from Humboldt Nursery. The survival patterns define lifting windows for Sitka spruce, western hemlock, and western redcedar in the Oregon Coast Range, Shasta red fir in the Klamath Mountains and California Cascades, and white fir in the Klamath Mountains. The patterns for Sitka spruce also show stability of the windows for sources from middle elevations (left) and wider windows for those from low elevations (right). The patterns for white fir show stability of the source window. Brackets indicate least significant difference ($p = 0.05$).

RGC, Site, and Survival

First-year survivals of the minor conifers were closely related to RGC after seedling cold storage, at spring planting time (*table 12, fig. 28*). Critical RGC on the planting site depended on species and seed source, site preparation and climate, and seedling protection. Critical RGC estimates in 20 field performance tests are described in the following summary, with the true firs grouped in natural pairs.

Shasta red fir and white fir—Critical RGC for red fir from source OK 321.60 in the Klamath Mountains ranged from 5 to 55 cm, and depended mostly on how soon competing plants and starving gophers invaded the planting site. Critical RGC for red fir from source GN 741.65 in the California Cascades was 5 cm. Here, the site was prepared by disking up slope and down, around the tree stumps and rock outcrops, and finally, along the contour. Cross-disking buried the dense stands of perennial grass and sedge and demolished the burrow systems of the resident gopher population (see Appendix D, Planting Site Descriptions).

Critical RGC for white fir from source OK 321.60 in the Klamath Mountains was also 5 cm. In this 1978 test, first-year survival within the lifting window averaged 88 percent. Grasses and gophers invaded the site the third year, after the seedlings were well established.

Noble fir and grand fir—Critical RGC for noble fir from source AL 252.40 and grand fir from source MA 062.20 in the Oregon Coast Range was 120 and 80 cm, respectively. The noble fir seedlings were planted offsite, at low elevation, and neither test was protected against competing vegetation.

Sitka spruce—Critical RGC in the 1983 tests of Sitka spruce in the Oregon Coast Range was 15 cm for northern source HE 053.10, 25 and 95 cm for midrange sources WA 061.10 and AL 061.05, and 90 cm for southern source MA 062.10, suggesting lower evapotranspirational stress at the higher latitudes and elevations. Critical RGC was just 1 cm in the 1984 tests of the repeated midrange and southern sources, WA 061.10 and MA 062.10, because competing vegetation was promptly controlled.

Western hemlock—Critical RGC in the 1984 tests of western hemlock in the Oregon Coast Range was 50 cm for northern source HE 053.20 and 415 cm for southern source MA 062.10. Critical RGC in the 1985 tests was 325 cm for northern source HE 053.15 and 280 cm for midrange source AL 061.15. Such excessive thresholds on northern, midrange, and southern sites suggest that western hemlock is especially sensitive to evaporative stress, compared to other minor conifers and Douglas-fir.

Western redcedar—Critical RGC in the 1983 test of western redcedar from midrange source AL 061.10 in the Oregon Coast Range was 200 cm. The seedlings were planted offsite, inland in seed zone 252, and competing vegetation was not controlled. By contrast, critical RGC in the 1984 tests of northern and southern sources HE 053.10 and MA 062.10 was only 1 cm. Site preparation was fully effective in both tests, and competing vegetation was not an immediate problem.

Table 12—Critical root growth capacity (RGC) in field performance tests of minor conifers from Humboldt Nursery¹

Seed source ²	Site planting date	RGC testing date	Critical RGC	Regression ³		
				b	r ²	
cm						
Shasta red fir						
OK 321.60 76	May 25	May 24	40	1.00	0.99	
OK 321.60 77	May 17	May 31	55	1.03	.84	
OK 321.60 78	Jun 2	Jul 5	5	.99	.88	
GN 741.65 77	Jun 13	May 31	5	1.03	1.00	
White fir						
OK 321.60 77	May 18	Jun 6	15	0.97	0.99	
Noble fir						
AL 252.40 83	Apr 19	Apr 25	120	1.01	1.00	
Grand fir						
MA 062.10 83	Apr 13	Apr 25	80	1.00	0.98	
Sitka spruce						
HE 053.10 83	Mar 30	Apr 4	15	0.99	1.00	
WA 061.10 83	Mar 25	Mar 28	25	.99	1.00	
WA 061.10 84	Apr 2	Apr 23	1	1.03	.99	
AL 061.05 83	Apr 18	Mar 28	90	1.00	.97	
MA 062.10 83	Mar 29	Apr 4	95	.99	.97	
MA 062.10 84	Apr 12	Apr 23	1	1.03	.92	
Western hemlock						
HE 053.20 84	Apr 25	Mar 26	50	1.02	1.00	
HE 053.15 85	Apr 17	Mar 25	325	.98	.94	
AL 061.15 85	Apr 17	Mar 25	280	1.01	.78	
MA 062.10 84	Apr 3	Mar 26	415	.96	.86	
Western redcedar						
HE 053.10 84	Apr 25	Apr 9	1	0.99	0.97	
AL 061.10 83	May 6	May 23	200	.95	.96	
MA 062.10 84	Apr 2	Apr 9	1	1.09	.97	

¹ Seedlings were lifted monthly in autumn to spring, stored at 1 ° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *figs. 22, 29; and table 11.*

³ $Y = bX$, where Y is first-year survival (pct) and X is percent of seedlings with RGC higher than critical; b is line slope and r^2 is coefficient of determination.

Lifting Windows and Tree Growth

To confirm seed source lifting windows of the minor conifers (*table 11*), we evaluated survival and growth for 2 and 3 years on the planting sites (see Assessing Planting Stock Quality, Standard Testing Procedures). Free-to-grow conditions prevailed in about half of the field performance tests, allowing us to evaluate early growth potential of Shasta red fir in the California Cascades, white fir in the Klamath

Mountains, and Sitka spruce, western hemlock, and western redcedar in the Oregon Coast Range.

The answer to the question "Is growth on the planting site greater for seedlings lifted near the middle of the source window?" is still **no**. The growth patterns associated with nursery lifting date were familiar ones (see Seed Source Assessments—Douglas-fir, *table 5 and fig. 18*). Growth on the planting site was often less when seedlings were lifted before the source window opened, and seldom differed between lifts within the window (*table 13, fig. 29*). Exceptions were noted in grand fir, western hemlock, and western redcedar.

Field performances are described in the following summary, with the true firs grouped in natural pairs.

Shasta red fir and white fir—Red fir was planted on typical sites in the eastern Klamath Mountains and northern California Cascades, and white fir, on typical sites in the eastern Klamath Mountains (see Appendix D, Planting Site Descriptions).

The Klamath tests of red fir source OK 321.60 were invaded by gophers, and consequent seedling losses within the lifting window were high. In the 1976 test, 3-year survival averaged 39 percent, down 53 percent from the first year. Seedling height averaged 19.9 cm, and leader length, 5.1 cm, to increase height by 34 percent. In the 1977 test, 2-year survival averaged 44 percent, down 19 percent from the first year. Seedling height averaged 17.9 cm, and leader length, 6.3 cm, to increase height by 54 percent. In the 1978 test, first-year survival averaged 74 percent. Seedling height averaged 12.7 cm, and leader length, 5 cm, to increase height by 65 percent.

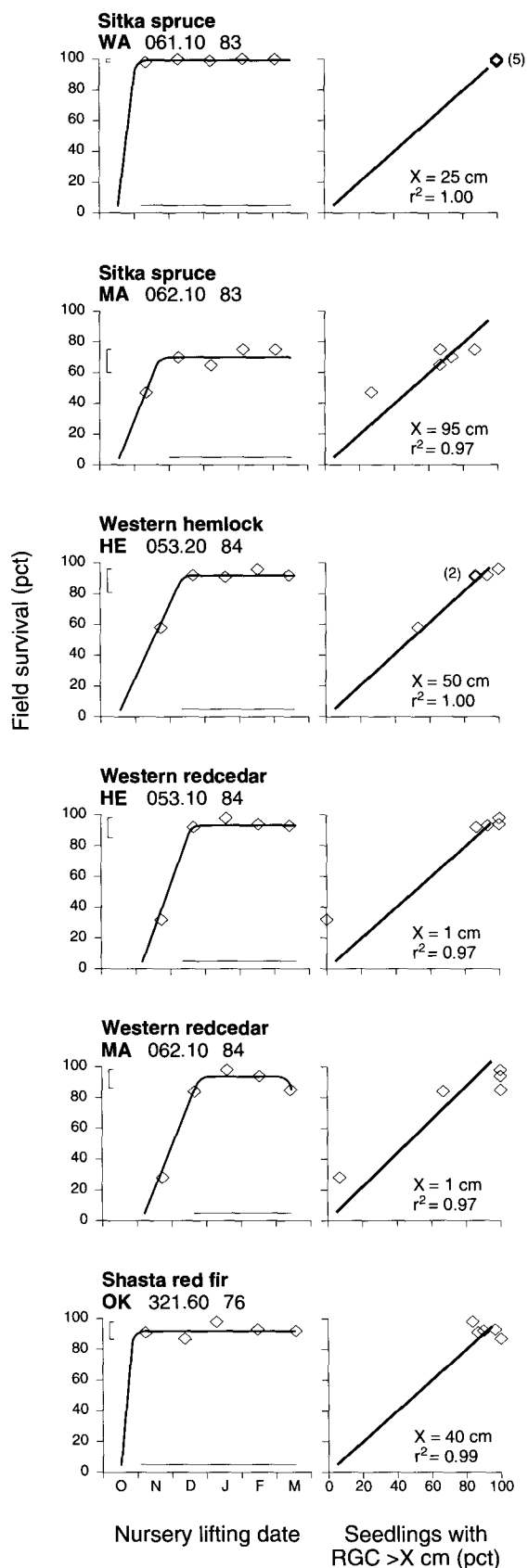


Figure 28—Critical root growth capacity (RGC) for first-year survival of minor conifers from Humboldt Nursery. Survivals and critical RGC (X) were determined in field performance tests of Shasta red fir in the Klamath Mountains and California Cascades and Sitka spruce, western hemlock, and western redcedar in the Oregon Coast Range. Critical RGC ranged up to 55 cm for Shasta red fir, 95 cm for Sitka spruce, 200 cm for western redcedar, and 415 cm for western hemlock, depending on seed source, planting site, root placement, and seedling protection (see *table 12*). The percentages of seedlings with RGC higher than critical explain most of the variation in survival. Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.

Table 13—Growth and survival in field performance tests of minor conifers from Humboldt Nursery¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	M	
Shasta red fir						
OK 321.60 76 (May 25)						
1-yr survival, <i>pct</i>	91	87	98	93	92	11.3
3-yr height, <i>cm</i>	19.9	18.9	20.7	19.6	21.2	3.77
leader, <i>cm</i>	5.2	5.6	5.0	5.0	4.7	1.29
survival, <i>pct</i>	46	47	49	48	45	25.3
OK 321.60 77 (May 17)						
1-yr survival, <i>pct</i>	43	57	62	72	60	17.7
2-yr height, <i>cm</i>	17.6	17.2	18.4	18.4	17.8	3.81
leader, <i>cm</i>	6.3	6.5	6.5	6.6	5.8	1.78
survival, <i>pct</i>	35	40	45	47	43	19.1
OK 321.60 78 (Jun 2)						
1-yr height, <i>cm</i>	12.1	13.2	13.9	12.3	12.2	1.77
leader, <i>cm</i>	4.9	5.3	5.5	5.1	4.3	1.58
survival, <i>pct</i>	48	64	78	80	47	16.7
GN 741.65 77 (Jun 13)						
1-yr survival, <i>pct</i>	91	99	100	98	94	4.9
2-yr height, <i>cm</i>	16.0	15.3	15.6	14.7	15.3	1.22
leader, <i>cm</i>	4.4	4.4	4.2	3.7	4.3	.82
survival, <i>pct</i>	84	94	97	92	87	8.6
5-yr height, <i>cm</i>	27.0	26.7	27.4	23.9	26.1	3.25
leader, <i>cm</i>	5.5	5.5	5.9	4.2	4.8	1.42
diam, <i>mm</i>	12.1	12.1	11.9	11.0	11.3	1.03
survival, <i>pct</i>	76	87	89	84	76	13.4
White fir						
OK 321.60 77 (May 18)						
1-yr survival, <i>pct</i>	-	71	69	68	62	14.6
2-yr height, <i>cm</i>	-	16.1	16.6	16.2	15.2	1.83
leader, <i>cm</i>	-	4.3	3.7	3.4	3.2	1.11
survival, <i>pct</i>	-	65	66	66	59	15.3
OK 321.60 78 (Apr 13)						
1-yr height, <i>cm</i>	13.9	15.0	16.3	15.1	13.0	1.76
leader, <i>cm</i>	5.5	5.6	6.4	5.4	4.0	.82
survival, <i>pct</i>	84	86	92	92	64	11.8
2-yr height, <i>cm</i>	19.5	19.8	22.4	20.3	16.4	2.52
leader, <i>cm</i>	6.3	5.6	6.6	6.0	5.0	1.16
survival, <i>pct</i>	77	79	86	84	61	12.4
OK 321.60 78 (Apr 13)						
3-yr height, <i>cm</i>	31.0	29.3	34.1	30.9	24.8	3.86
leader, <i>cm</i>	10.6	9.2	12.7	10.3	9.0	2.91
diam, <i>mm</i>	8.0	8.0	9.0	8.0	6.1	1.20
survival, <i>pct</i>	67	66	73	70	42	14.8
Noble fir						
AL 252.40 83 (Apr 19)						
1-yr height, <i>cm</i>	14.8	15.9	14.9	15.0		1.52
leader, <i>cm</i>	2.5	2.9	2.8	2.4		.52
diam, <i>mm</i>	5.1	5.3	5.2	5.2		.35
survival, <i>pct</i>	87	99	94	86		11.1

¹ Seedlings were stored at 1 °C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*, and *table 11*.

³ Least significant difference (p = 0.05).

Table 13—Growth and survival in field performance tests of minor conifers-continued¹

Seed source ² (planting date)		Performance, by nursery lifting date					LSD ³
		Nov	Dec	Jan	Feb	Mar	
Noble fir							
AL 252.40 83 (Apr 19)							
2-yr	height, <i>cm</i>	18.9	20.8	20.3	20.4		2.74
	leader, <i>cm</i>	4.4	5.8	6.2	5.4		1.78
	diam, <i>mm</i>	5.5	5.8	5.7	5.7		.72
	survival, <i>pct</i>	87	98	93	83		11.8
3-yr	height, <i>cm</i>	29.4	33.5	30.8	29.9		4.45
	leader, <i>cm</i>	10.8	12.7	11.9	10.9		2.19
	diam, <i>mm</i>	7.0	7.5	7.0	7.0		.67
	survival, <i>pct</i>	84	96	93	81		12.0
Grand fir							
MA 062.20 83 (Apr 13)							
1-yr	height, <i>cm</i>	31.0	30.5	30.6	30.0		2.20
	leader, <i>cm</i>	3.0	3.8	2.4	2.7		.45
	survival, <i>pct</i>	82	97	87	79		9.2
2-yr	height, <i>cm</i>	41.5	41.8	39.7	39.0		3.80
	leader, <i>cm</i>	11.4	14.0	10.9	11.1		2.90
	diam, <i>mm</i>	7.7	8.3	7.3	6.7		.80
	survival, <i>pct</i>	70	93	74	71		13.0
3-yr	height, <i>cm</i>	64.6	66.6	64.5	60.2		6.01
	leader, <i>cm</i>	23.0	25.2	24.6	21.3		3.49
	diam, <i>mm</i>	10.1	10.8	9.8	9.1		1.16
	survival, <i>pct</i>	67	90	72	69		12.9
Sitka spruce							
HE 053.10 83 (Mar 30)							
1-yr	height, <i>cm</i>	27.4	28.7	28.5	28.2	28.7	1.73
	diam, <i>mm</i>	3.9	4.0	3.7	3.9	3.9	.34
	survival, <i>pct</i>	96	97	93	99	98	4.5
2-yr	height, <i>cm</i>	47.0	49.2	47.2	48.8	49.2	3.71
	leader, <i>cm</i>	22.3	23.6	22.1	24.3	23.3	2.87
	diam, <i>mm</i>	5.8	6.0	6.1	6.0	6.1	.50
	survival, <i>pct</i>	95	98	94	99	98	4.3
3-yr	height, <i>cm</i>	67.4	69.7	68.2	68.8	69.4	5.00
	leader, <i>cm</i>	24.9	25.6	24.9	25.3	26.0	2.41
	diam, <i>mm</i>	9.3	9.9	10.2	9.6	9.9	.83
	survival, <i>pct</i>	95	97	94	98	97	5.0
WA 061.10 83 (Mar 25)							
1-yr	height, <i>cm</i>	33.3	33.1	32.3	35.4	36.4	2.85
	leader, <i>cm</i>	7.1	7.2	6.7	8.0	9.9	.92
	survival, <i>pct</i>	98	100	99	100	100	2.0
2-yr	height, <i>cm</i>	51.6	53.1	47.5	57.9	63.1	5.32
	leader, <i>cm</i>	22.3	22.6	18.6	26.2	30.4	4.36
	survival, <i>pct</i>	87	96	82	90	94	9.6
WA 061.10 84 (Apr 2)							
1-yr	height, <i>cm</i>	39.9	38.2	37.0	33.5	33.7	4.02
	leader, <i>cm</i>	8.4	8.4	9.2	7.5	7.6	1.30
	survival, <i>pct</i>	89	98	96	98	98	6.4
2-yr	height, <i>cm</i>	70.0	69.8	70.4	62.1	61.8	7.36
	leader, <i>cm</i>	30.3	32.7	36.2	29.7	29.2	4.37
	diam, <i>mm</i>	9.8	9.6	9.7	9.1	8.9	.78
	survival, <i>pct</i>	81	96	96	89	98	8.3

¹ Seedlings were stored at 1°C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*, and *table 11*.

³ Least significant difference ($p = 0.05$).

Table 13—Growth and survival in field performance tests of minor conifers-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Sitka spruce						
WA 061.05 84 (Apr 2)						
1-yr height, <i>cm</i>	38.5	37.4	38.4	39.1	38.5	5.83
leader, <i>cm</i>	9.6	10.4	12.7	9.4	10.2	2.06
survival, <i>pct</i>	100	95	98	97	97	5.1
2-yr height, <i>cm</i>	69.1	71.9	74.4	73.7	72.4	9.83
leader, <i>cm</i>	31.3	34.4	37.3	34.9	34.3	5.62
diam, <i>mm</i>	9.1	9.2	9.3	9.4	9.5	.99
survival, <i>pct</i>	98	92	96	95	94	5.5
AL 061.05 83 (Apr 18)						
1-yr height, <i>cm</i>	34.9	34.0	34.3	31.8	28.0	2.60
leader, <i>cm</i>	5.2	5.7	5.8	5.1	4.8	.88
diam, <i>mm</i>	4.7	4.7	4.6	4.4	4.1	.29
survival, <i>pct</i>	68	69	61	77	67	11.5
2-yr height, <i>cm</i>	39.1	42.1	40.4	39.6	34.4	4.57
leader, <i>cm</i>	7.0	10.2	7.8	8.6	7.5	3.13
diam, <i>mm</i>	5.4	5.5	5.2	5.2	4.5	.59
survival, <i>pct</i>	66	69	60	75	66	11.5
3-yr height, <i>cm</i>	53.3	54.5	54.1	53.0	48.0	7.62
leader, <i>cm</i>	14.1	15.0	15.0	15.7	14.8	3.24
diam, <i>mm</i>	6.6	7.0	6.6	6.5	5.8	.83
survival, <i>pct</i>	66	69	60	75	66	11.5
MA 062.10 83 (Apr 12)						
1-yr height, <i>cm</i>	30.3	31.0	30.9	32.0	33.8	3.84
leader, <i>cm</i>	6.3	7.0	6.2	7.4	7.4	2.12
survival, <i>pct</i>	48	70	65	75	75	15.0
2-yr height, <i>cm</i>	56.7	63.1	60.6	61.3	65.8	7.75
leader, <i>cm</i>	30.6	34.0	32.3	33.7	35.0	4.53
diam, <i>mm</i>	7.8	8.6	8.4	8.6	9.4	1.44
survival, <i>pct</i>	47	66	64	73	72	14.1
3-yr height, <i>cm</i>	106.1	119.9	114.6	117.3	125.6	13.0
leader, <i>cm</i>	50.8	56.7	53.8	56.6	58.6	7.68
diam, <i>mm</i>	14.5	16.1	15.5	16.1	17.5	2.71
survival, <i>pct</i>	47	66	64	73	69	14.1
MA 062.10 84 (Mar 29)						
1-yr height, <i>cm</i>	39.4	44.4	47.7	49.6	46.1	3.13
leader, <i>cm</i>	6.3	7.5	8.0	7.7	7.8	.89
diam, <i>mm</i>	4.6	5.0	5.3	5.6	5.2	.45
survival, <i>pct</i>	56	92	99	97	96	8.1
2-yr height, <i>cm</i>	55.9	59.9	69.1	66.2	67.0	6.58
leader, <i>cm</i>	14.8	15.3	19.1	16.5	20.0	4.98
diam, <i>mm</i>	6.8	7.5	8.4	8.3	7.9	1.07
survival, <i>pct</i>	36	65	67	70	64	16.6
MA 062.05 84 (Mar 30)						
1-yr height, <i>cm</i>	38.5	37.6	35.1	36.9	36.5	4.31
leader, <i>cm</i>	9.4	9.3	9.9	9.7	9.2	1.12
diam, <i>mm</i>	5.4	5.0	4.9	5.1	5.0	.56
survival, <i>pct</i>	95	93	99	96	99	4.2
2-yr height, <i>cm</i>	49.9	49.2	52.9	52.3	50.5	6.57
leader, <i>cm</i>	11.7	12.5	15.6	15.5	15.8	4.35
diam, <i>mm</i>	6.6	6.2	6.5	6.6	6.3	.96
survival, <i>pct</i>	74	69	84	74	72	14.4

Table 13— Growth and survival in field performance tests of minor conifers-continued ¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Western hemlock						
HE 053.20 84 (Apr 25)						
1-yr height, cm	33.5	45.4	42.1	46.8	46.9	4.45
leader, cm	11.9	15.8	15.8	15.7	14.8	2.19
diam, mm	2.9	4.2	3.7	4.2	4.2	.64
survival, pct	58	92	91	96	92	15.3
2-yr height, cm	58.5	68.8	70.3	68.9	66.0	7.65
leader, cm	33.2	36.5	38.7	38.8	35.6	4.91
diam, mm	6.0	8.0	7.3	7.7	7.2	1.08
survival, pct	57	85	80	89	84	15.6
3-yr height, cm	100.7	121.4	116.8	118.6	110.7	15.6
leader, cm	50.4	59.5	59.0	57.7	53.6	10.3
diam, mm	11.2	14.0	14.0	13.7	12.7	1.84
survival, pct	41	83	76	85	77	17.0
HE 053.15 85 (Apr 17)						
1-yr height, cm	27.6	33.6	40.8	37.7	37.9	5.61
leader, cm	5.0	6.4	8.9	7.5	5.4	2.03
diam, mm	2.8	3.7	4.6	4.6	4.0	.80
survival, pct	22	60	68	70	56	12.1
2-yr height, cm	53.9	63.7	83.7	79.8	67.8	12.1
leader, cm	29.0	38.3	47.6	45.2	33.8	7.38
diam, mm	6.1	7.8	10.5	9.4	7.5	1.76
survival, pct	21	56	67	69	54	12.9
AL 061.15 85 (Apr 17)						
1-yr height, cm	—	34.4	35.4	32.3	33.8	2.51
leader, cm	—	4.0	2.7	2.7	3.3	1.19
diam, mm	—	3.6	3.5	3.4	3.6	.34
survival, pct	7	56	57	45	28	16.9
2-yr height, cm	—	42.5	44.2	37.4	37.4	3.77
leader, cm	—	9.4	9.4	7.8	7.2	3.99
diam, mm	—	4.7	4.7	4.3	4.0	.70
survival, pct	7	56	57	45	28	16.9
AL 061.10 84 (Apr 19)						
1-yr height, cm	34.3	34.2	36.5	40.0	37.7	5.79
survival, pct	18	49	69	69	63	18.2
AL 252.25 85 (Apr 10)						
1-yr height, cm	28.6	32.5	36.0	34.2	29.0	4.10
leader, cm	3.1	5.6	5.8	5.9	2.5	1.62
diam, mm	3.4	3.6	4.0	4.1	3.2	.60
survival, pct	40	47	49	50	23	17.7
2-yr height, cm	32.7	35.8	37.7	38.5	29.6	6.95
leader, cm	8.3	7.5	8.4	8.0	5.4	4.66
diam, mm	4.7	5.7	5.6	6.0	4.3	1.22
survival, pct	40	47	49	50	23	17.7
MA 062.10 84 (Apr 3)						
1-yr height, cm	—	60.7	56.5	46.5	44.5	7.03
diam, mm	—	5.2	4.7	3.6	3.4	.84
survival, pct	1	26	41	15	20	13.6
2-yr height, cm	—	71.5	65.0	47.1	51.1	—
diam, mm	—	7.3	6.7	4.9	5.1	—
survival, pct	0	21	31	8	17	—

¹ Seedlings were stored at 1°C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*, and *table 11*.

³ Least significant difference ($p = 0.05$).

Table 13—Growth and survival in field performance tests of minor conifers-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Western redcedar						
HE 053.10 84 (Apr 25)						
1-yr height, cm	42.3	49.2	53.0	53.2	54.8	6.00
leader, cm	8.1	12.1	13.0	12.5	12.0	2.95
diam, mm	3.3	4.2	4.6	5.1	4.7	.93
survival, <i>pct</i>	32	92	98	94	93	13.0
2-yr height, cm	—	74.5	82.7	87.3	87.3	7.14
leader, cm	—	36.3	39.4	40.5	40.9	3.89
diam, mm	—	9.2	10.9	12.5	12.4	2.01
survival, <i>pct</i>	18	91	97	98	90	8.0
3-yr height, cm	1	16.8	130.5	133.3	137.5	12.8
leader, cm	—	40.2	45.1	45.7	49.6	4.85
diam, mm	—	17.5	20.7	23.1	23.2	3.23
survival, <i>pct</i>	18	90	97	97	89	8.6
AI 061.10 83 (May 6)						
1-yr height, cm	26.9	24.2	23.5	23.4		3.44
leader, cm	6.2	5.1	6.7	6.5		2.22
diam, mm	4.7	4.7	4.3	4.2		.59
survival, <i>pct</i>	66	56	59	66		22.8
2-yr height, cm	28.6	26.7	26.9	26.1		4.71
leader, cm	4.9	5.6	6.1	5.6		2.88
diam, mm	5.5	5.3	5.2	5.0		.76
survival, <i>pct</i>	65	52	44	54		26.4
3-yr height, cm	25.9	22.5	23.5	25.7		5.23
leader, cm	5.9	4.3	5.3	7.0		2.04
diam, mm	5.7	5.8	5.3	5.5		.66
survival, <i>pct</i>	63	50	42	53		26.0
AL 061.10 84 (Apr 19)						
1-yr height, cm	35.0	35.5	36.6	35.7	36.5	2.47
survival, <i>pct</i>	28	86	90	94	89	10.4
MA 062.10 84 (Apr 2)						
1-yr height, cm	38.8	40.8	49.1	49.6	46.4	4.29
diam, mm	3.9	3.6	4.7	4.9	4.5	.48
survival, <i>pct</i>	28	84	98	94	85	12.1
2-yr height, cm	—	50.7	59.6	59.9	54.6	4.43
leader, cm	—	10.0	10.5	10.4	7.8	2.39
diam, mm	—	5.8	7.0	7.0	6.1	.62
survival, <i>pct</i>	15	59	85	83	67	12.9

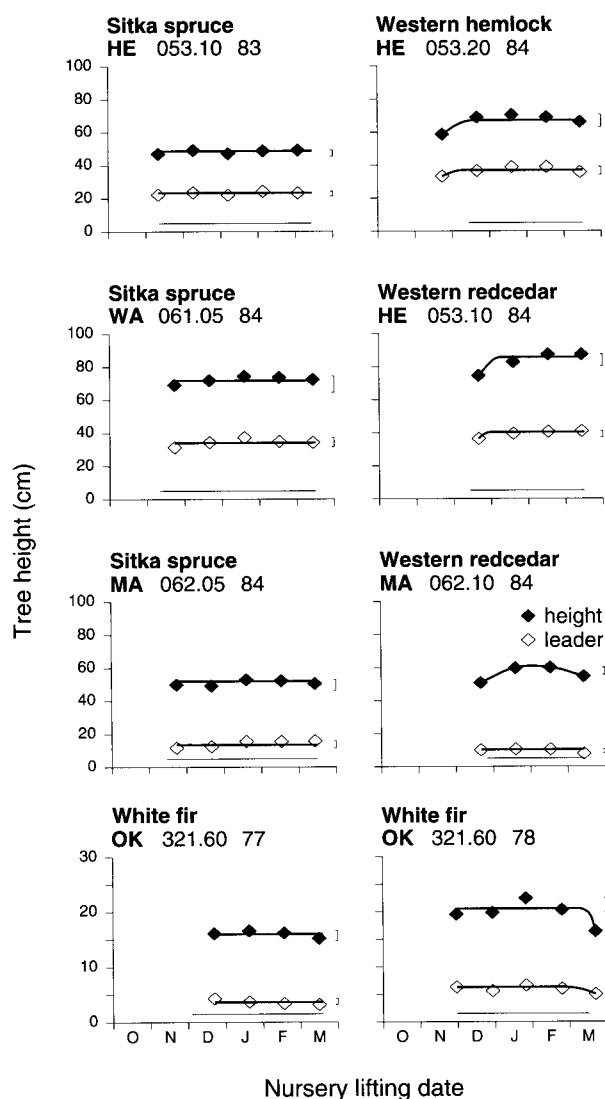


Figure 29—Seed source and lifting date effects on 2-year growth of minor conifers from Humboldt Nursery. The graphs show the growth patterns in field performance tests of Sitka spruce, western hemlock, and western redcedar in the Oregon Coast Range and white fir in the Klamath Mountains. Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.

The Cascades test of source GN 741.65 was free of gophers, grasses, and sedges for 2 years, and demonstrated the survival and growth potential of red fir planted on cleared sites in red fir forest. Survival averaged 91 percent after 2 years and 82 percent after 5 years, down just 5 and 14 percent, from the first year. After 2 years on the site, seedling height averaged 15.4 cm, and leader length, 4.2 cm, to increase height by 38 percent. After 5 years, stem height and basal diameter averaged 26.2 cm and 11.7 mm, and leader length, 5.2 cm, to increase height by 25 percent.

The Klamath tests of white fir source OK 321.60 were installed on sites that were 300 and 700 ft lower than the seed zone of origin. Gophers invaded the 1977 test, and 2-year survival averaged 64 percent. Seedling height averaged 16.0 cm, and leader length, 3.7 cm, to increase height by 30 percent. The 1978 test escaped the usual invasions of gophers and perennial grasses, and demonstrated the survival and growth potential of white fir planted on cleared sites in upper mixed conifer forest. Survival within the lifting window averaged 82 percent after 2 years and 69 percent after 3 years, down 6 and 19 percent, from the first year. After 2 years on the site, seedling height averaged 20.5 cm, and leader length, 6.1 cm, to increase height by 42 percent. After 3 years, stem height and diameter averaged 31.3 cm and 8.2 mm, and leader length, 10.7 cm, to increase height by 52 percent.

Noble fir and grand fir—Noble fir from source AL 252.40 in the Oregon Coast Range was planted on a site 2000 ft lower than the parent stands on Marys Peak. Summers were dry and herbaceous vegetation was dense, yet survival still averaged 88 percent after 3 years, down only 4 percent from the first year. Stem height and diameter averaged 31 cm and 7.1 mm, and leader length, 12 cm, to increase height by 63 percent.

Grand fir from source MA 062.20 in the Oregon Coast Range had to compete against a host of vigorous sprouters. Survival averaged 74 percent after 3 years, down 12 percent from the first year,

and suggested that the source lifting window was a bit narrower than the 2 months indicated by first-year survival (*table 11*). Stem height and diameter after 3 years averaged 64 cm and 10 mm, and leader length, 24 cm, to increase height by 60 percent.

Sitka spruce—Lifting windows for Sitka spruce from northern, midrange, and southern sources in the Oregon Coast Range were confirmed by 2-year survival and growth. Growth was spectacular, even where we mistakenly protected seedlings with vexar tubes. Neither elk nor deer browse Sitka spruce, and its rigid, sharp needles snag the tube mesh, forcing the leader to loop and thus permanently deform the stem.

The best 2-year growth was in the 1984 tests of midrange sources WA 061.10 and WA 061.05. Survival averaged 95 percent for the lower-elevation source and 92 percent for the upper-elevation source, down only 2 and 4 percent from the first year. Stem height and diameter averaged 72 cm and 9.3 mm for the lower source, and 67 cm and 9.4 mm for the upper source. Leader length averaged 34 and 32 cm, to increase heights by 90 and 91 percent.

The best 3-year growth was in the 1983 test of southern source MA 062.10. Survival within the lifting window averaged 68 percent, down 3 percent from the first year. Stem height and diameter averaged 1] 9 cm and 16.3 mm, and leader length, 56 cm, to increase height by 89 percent.

Western hemlock—Lifting windows for western hemlock from northern and midrange sources in the Oregon Coast Range were confirmed by 2-year survival and growth. Seedling mortality precluded confirmation of the lifting window for southern source MA 062.10.

Growth was excellent in the tests of northern sources. Within the lifting window of source HE 053.15, 2-year survival averaged 62 percent, down 2 percent from the first year. Stem height and diameter averaged 74 cm and 8.8 mm, and leader length, 41 cm, to increase height by 124 percent. Stem height and leader length were 24 and 29 percent greater for the lifts in mid- to late winter, the middle half of the

lifting window. Within the window of source HE 053.20, 2-year height and diameter averaged 68 cm and 7.6 mm, and leader length, 37 cm, to increase height by 1 19 percent. After 3 years, survival averaged 80 percent, down 13 percent from the first year. Stem height and diameter averaged 117 cm and 13.6 mm, and leader length, 57 cm, to increase height by 95 percent.

Seedlings of midrange source AL 252.25 were heavily browsed, and 2-year survival within the lifting window averaged only 46 percent. Stem height and diameter averaged 36 cm and 5.5 mm, and leader length, 8 cm, to increase height by 29 percent.

Western redcedar—Lifting windows for western redcedar from northern, midrange, and southern sources in the Oregon Coast Range were verified by 2-year survival and growth.

Growth was superior in the test of northern source HE 053.10. Within the lifting window, stem height and diameter averaged 83 cm and 11.2 mm after 2 years, and leader length, 39 cm, to increase height by 89 percent. After 3 years, survival still averaged 93 percent, down only 1 percent from the first year. Stem height and diameter averaged 130 cm and 21.1 mm, and leader length, 45 cm, to increase height by 53 percent. Leader length in the second and third years averaged 11 and 16 percent greater in the midwinter to spring lifts than in the earlier lifts, suggesting a later first safe lifting date than that indicated by first-year survival.

The 1983 test of midrange source AL 061 .10 was installed offsite, next to the noble fir test in seed zone 252. Browsing was severe, herbaceous vegetation swamped the site, and 3-year survival averaged 52 percent, down 10 percent from the first year. Stem height and diameter averaged 24 cm and 5.5 mm, and leader length practically zero.

Growth in the test of southern source MA 062.10 was modest. Survival within the lifting window averaged 74 percent after 2 years. Stem height and diameter averaged 58 cm and 6.7 mm, and leader length, 10 cm, to increase height by 21 percent.

NURSERY MANAGEMENT GUIDES

Safe lifting and cold storage schedules were developed for the true firs—Shasta red, white, noble, and grand—and Sitka spruce, western hemlock, and western redcedar in Humboldt Nursery. The schedules are based on survival and growth in field performance tests of known seed sources, and their use insures high survival and growth potential in seedlings destined for spring planting.

Survivals within the seed source lifting windows proved that any of the conifers tested can be safely stored for extended periods at 1°C (34° F). In the normal course of testing, Shasta red fir from the Klamath Mountains and California Cascades was successfully stored 7 months, repeatedly and in different nursery years (*table 11*). White fir from the Klamath Mountains was successfully stored 5 months, and noble fir and grand fir from the Oregon Coast Range, 4 months. Sitka spruce, western hemlock, and western redcedar from the Oregon Coast Range were all successfully stored 5 months.

Lifting and cold storage schedules for the minor conifers, like those for Douglas-fir, are keyed to seed source. Source lifting windows ranged from 6 weeks to more than 4 months wide, showing that seedlings can be safely lifted and stored for spring planting sometime in the period from early November to late March. Field performances proved that Shasta red fir, white fir, and Sitka spruce can be safely stored almost anytime in autumn to spring (*table 13*). By contrast, noble fir, grand fir, western hemlock, and western redcedar showed narrower lifting windows that opened at different times. Field performances of these species indicated that untested sources should be lifted and stored sometime in early to late winter, December 15 to February 15 (*table 11*).

To simplify planning of lifting schedules for the minor conifers, known source windows were divided into five types (*table 14*). To the extent possible, the types were defined to match those of Douglas-fir, as

follows: Type 1 windows are 4 months wide, and open before November 30 and close after March 10. Type 2 windows are more than 3 months wide, and open before December 10 and close after March 10. Type 3 windows are 3 months wide, and open before December 1 or 20 and close after March 1 or 10. Type 4 windows are 2 months wide, and open by December 10 or 20 and close after February 10 or March 1. Type 5 windows are less than 2 months wide, and open sometime before December 20 and close soon after January 20.

Sitka spruce consistently shows wide type 1 or 2 windows (see *tables 11, 14*), like most Douglas-fir from the Oregon Coast Range (see Seed Source Assessments—Douglas-fir, *table 3* and *fig. 19*). Other conifers from the Oregon Coast Range have narrower windows, which tend to decrease in width with decrease in source latitude. Northern sources of western hemlock and western redcedar, for example, are window type 3, whereas midrange sources are type 3 or 4, and southern sources, type 4 or 5. Noble fir from Marys Peak is type 4, and grand fir from the southern end of the Siuslaw National Forest is type 5.

Because two-thirds of the known source windows are 3 to 4 months wide, Humboldt Nursery can restrict lifting of the minor conifers to times when the nursery soil and weather conditions are favorable. Sources with wide windows, types 1 to 3, provide the nursery the flexibility needed to lift and store seedlings in late November-December and secure high survival and growth potentials at spring planting time.

Sources with narrow windows, types 4 and 5, and all untested sources should be scheduled for priority lifting in midwinter. Until testing proves otherwise, untested sources of noble fir, grand fir, western hemlock, and western redcedar should be lifted as window type 4, sometime in late December to early February. Wide-window sources should be scheduled earlier and later, before and after the priority sources, to take full advantage of Humboldt Nursery's extended lifting season.

Table 14—Types of seed source lifting windows for minor conifers in Humboldt Nursery¹

Seed source ²	Lifting window width	First-year field survival	Safe dates used in the nursery		Lifting Window type
			First	Last	
Shasta red fir	<i>days</i>	<i>pct</i>			
OK 321.60	87-128	63-92			
GN 741.65	120	97	Nov 30	Mar 10	1
White fir					
OK 321.60	104-107	68-87	Dec 10	Mar 10	2
Noble fir					
AL 252.40	82	92	Dec 10	Feb 10	4
Grand fir					
MA 062.20	55	89	Dec 10	Jan 20	5
Sitka spruce					
HE 053.10	127	97	Nov 30	Mar 10	1
WA 061.10	107-127	97-99	Dec 10	Mar 10	2
WA 061.05	127	97	Nov 30	Mar 10	1
AL 061.05	127	68	Nov 30	Mar 10	1
MA 062.10	92-107	71-96	Dec 20	Mar 10	3
MA 062.05	127	96	Nov 30	Mar 10	1
Western hemlock					
HE 053.20	95	93	Dec 20	Mar 10	3
HE 053.15	95	64	Dec 20	Mar 1	3
AL 061.15	71	53	Dec 10	Feb 10	4
AL 061.10	71	67	Dec 20	Mar 1	4
AL 252.25	96	47	Nov 30	Mar 1	3
MA 062.10	31	41	Dec 20	Jan 20	5
Western redcedar					
HE 053.10	95	94	Dec 20	Mar 10	3
AL 061.10	95- 99	62-90	Dec 20	Mar 10	3
MA 062.10	81	90	Dec 20	Mar 1	4

¹ See table 11, and Seed Source Assessments-Douglas-fir, tables 3, 6.

² See fig. 22.



Douglas-fir plantations at age 16, 2 years after thinning: View of Muzzleloader units D/E next to virgin stands on Muzzleloader Ridge, and below, view through Muzzleloader unit J toward Fox Ridge and Gordon Ridge



SEED SOURCE ASSESSMENTS— DOUGLAS-FIR

Survival and growth potentials of Douglas-fir planting stock produced in Humboldt Nursery were assessed for seed sources from coastal and inland regions of western Oregon and northern California. Seedlings of known sources were tested for top and root growth capacity (TGC, RGC) just after lifting and after cold storage, and for survival and growth on cleared planting sites in the seed zones of origin.

Seed source assessments aimed to answer five related questions:

- What are the seasonal patterns of seedling TGC and RGC from autumn to spring in the nursery?
- To what extent are TGC and RGC at lifting altered by seedling cold storage to spring planting time?
- When during the winter season can seedlings in the nursery be safely lifted for cold storage and spring planting?
- How is first-year survival on the planting site related to TGC and RGC after seedling cold storage?
- Does nursery lifting date affect seedling growth on the planting site more or less than it affects first-year survival?

Effects of seed source, nursery climate, and cold storage on seedling growth capacities were defined in 3 years. Effects of these same factors on field performance, which cooperators considered much more important, were clarified in 4 years.

Seedling TGC and RGC revealed distinct, innate seasonal patterns in the nursery, and depending on lifting date, changed markedly during cold storage. First-year field survivals defined seed source lifting windows, that is, safe calendar periods to lift seedlings for cold storage and spring planting. Seedlings that were lifted and stored within their source window and protected on the planting site were characterized by high survival and rapid growth, and demonstrated successful establishment. First-year survival was directly related to RGC after cold storage, and allowed us to determine critical RGC for a wide array of planting sites. Extended lifting and cold storage schedules for all Douglas-fir sources were developed by applying narrowed versions of the known source windows to untested sources from the same forest regions.

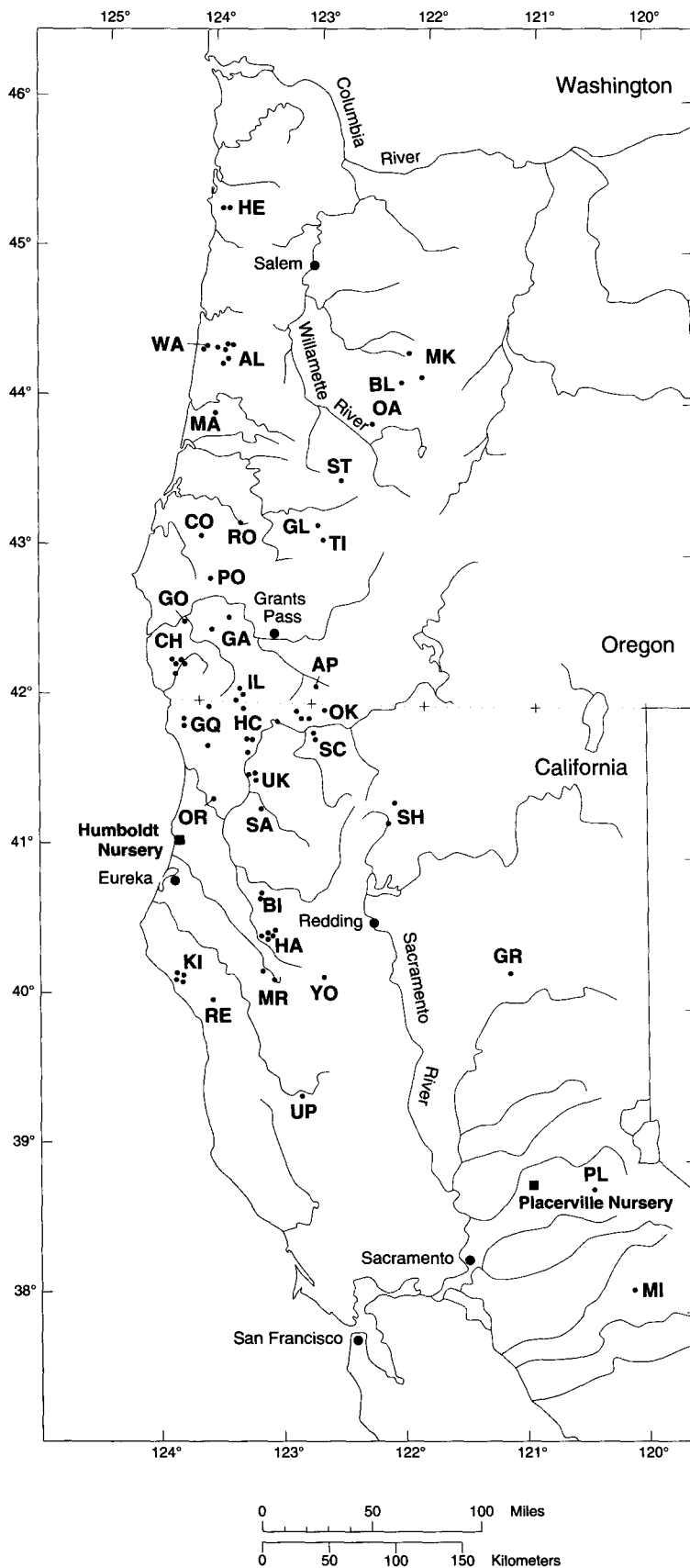
SEED SOURCES ASSESSED

Douglas-fir seed sources assessed for Humboldt Nursery were chosen at latitudes ranging from 38° N in central California to 46° N in northwest Oregon (*fig. 10*). The forests sampled run the length of the Oregon Coast and North Coast Ranges and extend through the Klamath Mountains into the Oregon Cascades, the California Cascades, and the Sierra Nevada (*fig. 3*). Sources tested for growth capacity and field performance ranged from about 150 ft (45 m) of elevation above sea level near the Pacific Ocean to 5000 ft (1525 m) inland (see *table 1* in Appendix B).

Assessments undertaken in the 1975-76 winter lifting season served as pilot trials. To launch our regional sampling scheme, we chose seed sources from coastal and inland areas in southwest Oregon and northwest California. Initial testing covered five sources through the lifting season, and two of those five after seedling cold storage.

Assessments undertaken in the 1976-77 lifting season covered 14 seed sources, 12 new sources that were chosen along environmental gradients on the Pacific Slope, and 2 sources that were repeated from the 1975-76 season to evaluate effects of variation in nursery climate. These sources formed the core of three coast-inland transects and two latitudinal transects of the physiographic regions served by Humboldt. The coast-inland transects were located across the middle of western Oregon, through the Klamath Mountains along the Oregon-California border, and across northern California. The latitudinal transects were located in opposing coastal and inland regions, one running north-south in the Oregon Coast-North Coast Range and the other in the Cascade Range-Sierra Nevada.

Assessments undertaken in the 1977-78 lifting season covered 13 seed sources, 9 new sources that were chosen along environmental gradients on the Pacific Slope, and 4 sources that were repeated from the 1975-76 and 1976-77 seasons to evaluate effects of variation in nursery climate. The new sources filled gaps in existing transects and formed a third latitudinal transect, one running north-south



Seed source¹

Oregon Coast Range, N

Siuslaw NF
Hebo RD
HE 053.20 83o
HE 053.10 79
Waldport RD
WA 061.20 83o
WA 061.10 77
Alsea RD
AL 252.15 80o
AL 252.10 77
AL 252.10 81u
AL 252.05 78
AL 061.20 83o
AL 061.05 79
Mapleton RD
MA 062.10 79p

Oregon Coast Range, S

Coos Bay RA
CO 072.10 84o
Siskiyou NF
Powers RD
PO 072.25 79
Gold Beach RD
GO 081.20 79p
Chetco RD
CH 082.25 76
CH 082.25 77
CH 082.25 78
CH 082.25 79f
CH 082.10 79

Klamath Mtns, N

Roseburg RA
RO 270.20 84o
Siskiyou NF
Galice RD
GA 511.30 79
GA 512.25 79
Illinois Valley RD
IL 512.40 79p
IL 512.35 78p
IL 512.13 79

Klamath Mtns, W

Six Rivers NF
Gasquet RD
GQ 301.30 77f
GQ 301.30 78f
GQ 301.30 79
Orleans RD
OR 302.30 79

Klamath Mtns, central

Klamath NF
Happy Camp RD
HC 301.50 79
HC 301.30 77
HC 301.30 78
HC 301.30 79
Ukonom RD
UK 301.20 79
UK 302.44 79
UK 311.40 79
Salmon River RD
SA 311.40 79

Klamath Mtns, E

Rogue River NF
Applegate RD
AP 511.40 79
Klamath NF
Oak Knoll RD
OK 321.40 77
OK 321.40 78
OK 321.40 79
OK 321.30 80o
OK 321.30 81u
Scott River RD
SC 322.40 78
SC 322.40 79

Klamath Mtns, S

Shasta-Trinity NF
Big Bar RD
BI 312.40 77
BI 312.30 78
Hayfork RD
HA 312.50 80u
HA 312.25 78
HA 312.25 79
HA 312.25 79o
HA 312.25 80u
Yolla Bolla RD
YO 371.45 78

N Coast Range, coastal

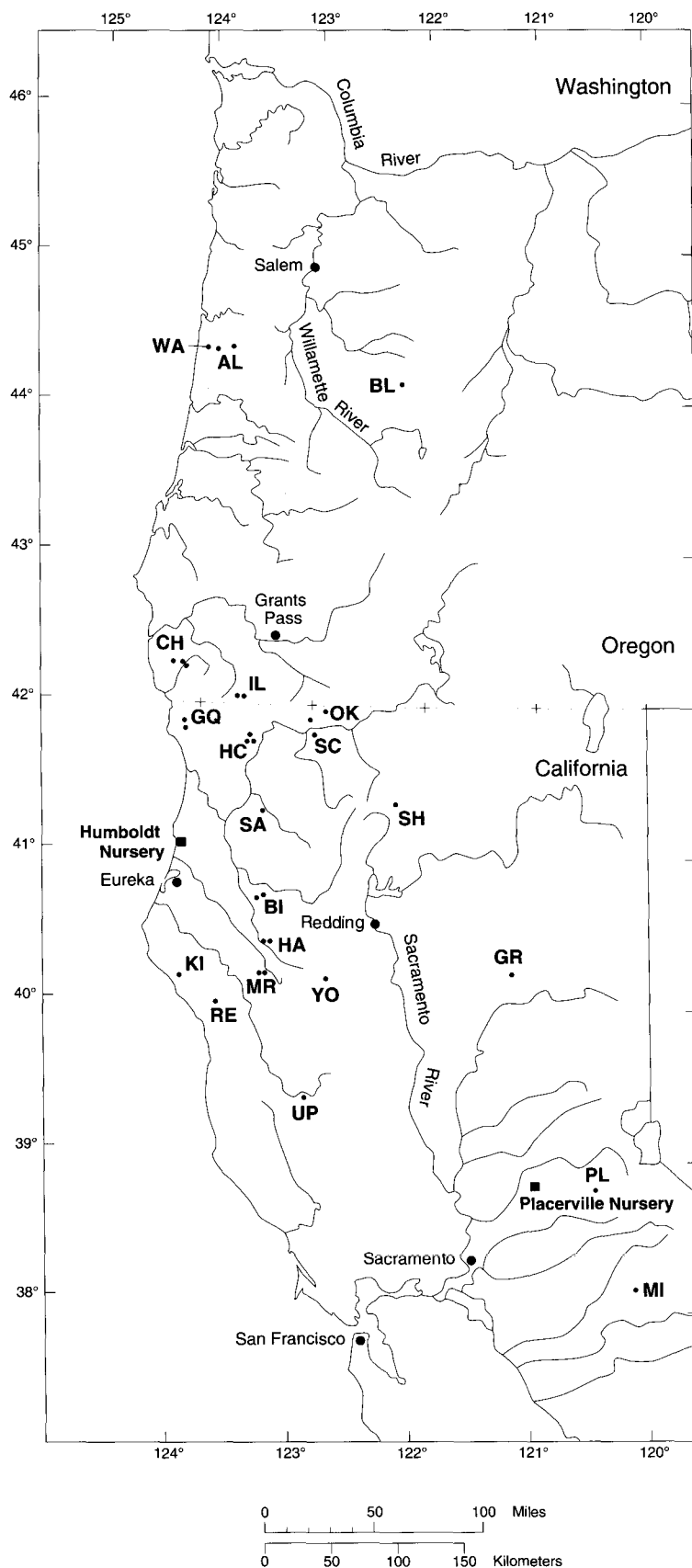
Six Rivers NF
Gasquet RD
GQ 091.20 81u
Ukiah RA
King Range
KI 390.25 77
KI 390.20 79
KI 390.20 80o
KI 390.20 84o
Red Mountain
RE 093.25 78

N Coast Range, inland

Six Rivers NF
Mad River RD
MR 303.45 79
MR 340.36 78
Mendocino NF
Upper Lake RD
UP 372.30 77

Oregon Cascades, W

Willamette NF
McKenzie RD
MK 472.45 79
MK 472.30 80o
Blue River RD
BL 472.30 77
Oakridge RD
OA 482.30 81u
Umpqua NF
Steamboat RD
ST 491.30 79
Glide RD
GL 491.30 79
Tiller RD
TI 492.30 79



Seed source¹

Oregon Coast Range, N

Siuslaw NF
Waldport RD
WA 061.10 77
Alsea RD
AL 252.10 77
AL 252.05 78

Oregon Coast Range, S

Siskiyou NF
Chetco RD
CH 082.25 76
CH 082.25 77
CH 082.25 78

Klamath Mtns, N

Siskiyou NF
Illinois Valley RD
IL 512.25 76‡
IL 512.35 78

Klamath Mtns, W

Six Rivers NF
Gasquet RD
GQ 301.30 77
GQ 301.30 78

Klamath Mtns, central

Klamath NF
Happy Camp RD
HC 301.30 76‡
HC 301.30 77
HC 301.30 78
Salmon River RD
SA 311.40 78‡

Klamath Mtns, E

Klamath NF
Oak Knoll RD
OK 321.40 77
OK 321.40 78
Scott River RD
SC 322.40 78

Klamath Mtns, S

Shasta-Trinity NF
Big Bar RD
BI 312.40 77
BI 312.30 78
Hayfork RD
HA 312.25 76‡
HA 312.25 78
Yolla Bolla RD
YO 371.45 78

N Coast Range, coastal

Ukiah RA
King Range
KI 390.25 77
Red Mountain
RE 093.25 78

N Coast Range, inland

Six Rivers NF
Mad River RD
MR 340.40 76‡
MR 340.36 78
Mendocino NF
Upper Lake RD
UP 372.30 77

Oregon Cascades, W

Willamette NF
Blue River RD
BL 472.30 77

California Cascades

Shasta-Trinity NF
Mt Shasta RD
SH 516.30 77

Sierra Nevada, N

Plumas NF
Greenville RD
GR 523.45 77

Sierra Nevada, W

Eldorado NF
Placerville RD
PL 526.40 77
Stanislaus NF
Mi-Wok RD
MI 531.40 77

¹ Seed sources are listed by physiographic region and management unit of origin, National Forest (NF) and Ranger District (RD) or Bureau of Land Management Resource Area (RA). The entries show tree seed zone (USDA Forest Service 1969, 1973), elevation (x100 ft), and test year. The symbol ‡ indicates a source that was not outplanted.

Figure 11—Douglas-fir seed sources used to evaluate seasonal patterns in top and root growth capacity (TGC, RGC) in Humboldt Nursery, changes in TGC and RGC during seedling cold storage, and critical RGC for first-year field survival. Seedlings of 25 sources from coastal and inland regions of western Oregon and northern California were lifted monthly in autumn to spring, graded, root-pruned, and stored at 1° C (34° F) until spring planting time. Seedling TGC and RGC were evaluated in greenhouse tests just after lifting and after cold storage (see fig. 9). Survival and growth were evaluated in field performance tests on cleared planting sites in the seed zones of origin (see Appendix D, Planting Site Descriptions).

Quality, Standard Testing Procedures). In the course of three lifting seasons, 25 sources were assessed for coastal and inland regions of western Oregon and northern California (*fig. 11*). A few sources were repeated to investigate stability of the seasonal patterns and related effects of annual variation in nursery climate.

Variance analyses indicated that seed source and lifting date significantly affected TGC and RGC in every lifting season, and that seed source affected the seasonal patterns in every test group (*table 1*). Seed source and lifting date markedly affected budburst, shoot extension, root elongation, and roots elongated. The best source in each group had RGC

two to four times greater than the poorest source, and there were major shifts in source ranking in successive lifts (see *table 2* in Appendix B).

To illustrate their nature and geographic variation, seasonal patterns were graphed for each source. To clarify the pattern types and facilitate source comparisons, TGC was charted as the percentage of seedlings showing budburst, and RGC, as a percentage of the greatest new root length, cm per seedling, found for the source (see later, *figs. 13, 14*).

Table 1—Significance of seed source and lifting date effects on top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery¹

Winter season ² and source of variation	Degrees freedom	Variance (mean square) for...			
		Shoot length (cm)	Root length (cm)	Roots elongated	
				≥1.5 cm	<1.5 cm
1975—76 I					
Seed source, S	4	—	7634 **	729.4 **	333
Lifting date, D	4	—	3794 **	666.3 **	17945 **
SD	16	—	3095 **	354.8 *	1561
Error	44	—	991	165.3	1226
1976—77 IIa					
Seed source, S	6	—	15016 **	1664.6 **	3170 **
Lifting date, D	4	—	8940 **	864.6 **	6915 **
SD	24	—	2719 **	330.6 **	798
Error	70	—	800	108.8	660
1976—77 IIb					
Seed source, S	3	—	8477 **	754.4 **	226
Lifting date, D	5	—	6683 **	800.9 **	6192 **
SD	15	—	3844 **	480.2 **	707
Error	48	—	917	115.0	757
1976—77 III					
Seed source, S	6	—	11982 **	1653.0 **	2776 **
Lifting date, D	4	—	15058 **	2075.5 **	5887 **
SD	24	—	2356	270.0	630
Error	70	—	1657	226.7	952
1977—78 IVa					
Seed source, S	6	6.62 **	806	121.8	792
Lifting date, D	4	317.38 **	12050 **	1665.2 **	7475 **
SD	24	2.43 **	810 *	103.8 *	338
Error	69	.48	412	58.8	284
1977—78 IVb					
Seed source, S	4	4.41 **	900 *	131.5 *	885 **
Lifting date, D	5	234.28 **	7005 **	1064.9 **	5224 **
SD	20	2.36 **	989 **	123.5 **	461 *
Error	59	.42	338	51.9	249
1977—78 V					
Seed source, S	6	8.95 **	14264 **	1805.0 **	6212 **
Lifting date, D	4	253.97 **	31147 **	4725.5 **	15255 **
SD	24	2.97 **	1915 **	282.1 **	769
Error	69	.39	855	126.7	648

*, ** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings were lifted monthly in autumn to spring; see Assessing Planting Stock Quality, Standard Testing Procedures.

² I, II, ...V denote groups of seed sources that were sampled on the same series of lifting dates; see *table 2* in Appendix B.

Autumn-Winter Climate

Nursery climate varied considerably from year to year. Air and soil temperatures were typically cool in the 1975-76 and 1976-77 lifting seasons, but were warmer than usual in the 1977-78 season (*fig. 12*). Seedling chilling, defined as cumulative time at air temperatures lower than 10° C (50° F), totaled 600 hours in autumn of the cool years and 400 hours in autumn of the warm year. Minimum daily soil temperatures at a depth of 8 cm (3 in) dropped below 10° C in October and remained low until April. Maximum daily soil temperatures at 8 cm dropped below 10° C in November, remained low in the cool winters but cycled above 10° C in the warm winter, and exceeded 10° C in March.

Seedling buds were dormant by November. Root growth in the nursery ceased in November and resumed in March. When winter soil temperatures

were below 10° C, visible root growth was rare and consisted mostly of a few new white root tips less than 2 mm (0.1 inch) long.

TGC in Autumn-Winter

Seasonal patterns of TGC were consistent and strongly expressed. Whether measured by budburst or shoot extension (see *table 2* in Appendix B), TGC always traced some form of sigmoid curve. In terms of budburst, TGC increased from zero in November to 100 percent by March (*fig. 13*). Initial rises in TGC were found in February in the 1975-76 lifting season, in January in the 1976-77 season, and in December in the 1977-78 season. In all seed sources and lifting seasons, the cumulative seedling chilling needed to permit uniform budburst and rapid shoot extension was fully met by late winter.

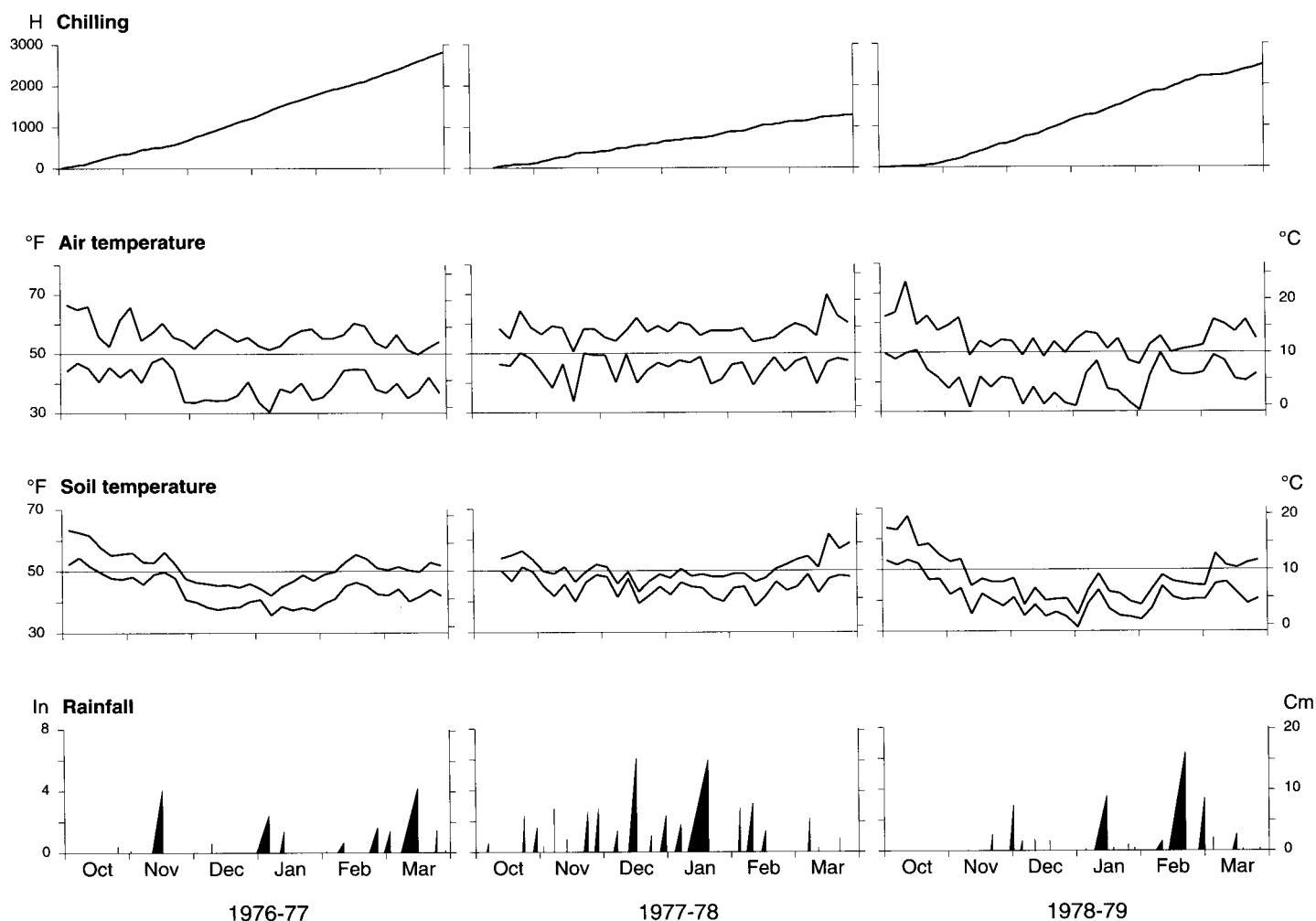


Figure 12—Autumn-winter weather patterns in Humboldt Nursery. Seedlings underwent substantially greater chilling in the winter seasons of 1975-76 (not shown), 1976-77, and 1978-79 than in 1977-78, when the weather was abnormally warm.

Because TGC is a measure of dormancy release, its seasonal rise is expected to trace a sigmoid curve. Within the pattern type, however, seed source differences were evident in both the onset of and rate of increase in TGC. In the 1975-76 lifting season, for example, compare sources IL and HA from the northern and southern Klamath Mountains, respectively. In the 1976-77 season, compare sources GQ and HC from the western and central Klamath Mountains, and sources SH and PL from the California Cascades and the western Sierra Nevada. In the 1977-78 season, compare sources AL and OK from the northern Oregon Coast Range and eastern Klamath Mountains, and sources SC and SA from the eastern and central Klamath Mountains.

Differences between years in the timing of the seasonal increase in TGC suggested that dormancy release was accomplished several weeks sooner in the warm winter of 1977-78 than in the cool winters of 1975-76 and 1976-77. Research has shown that fully chilled buds cannot expand until the roots send a hormonal signal, which they apparently do after the soil and roots have warmed to 5° C (41° F) and higher (Lavender and others 1973). Because the nursery soil at Humboldt was often warmer than 5° C during the 1977-78 season (*fig. 12*), the buds of seedlings lifted in midwinter had probably already received the signal, and were able to expand immediately rather than await hormone activation and translocation in the greenhouse.

RGC in Autumn-Winter

Contrasting seasonal patterns of RGC were found among seed sources in every test group. Pattern indications, however, sometimes varied with the root growth trait. Seasonal patterns were most distinctive when RGC was expressed as the new length of roots elongated ≥ 1.5 cm, per seedling. The number elongated ≥ 1.5 cm or > 2 mm showed the same pattern as root length, but the number elongated < 1.5 cm did not always trace the pattern shown by longer roots (see *table 2* in Appendix B).

Pattern types—Three distinct types of innate seasonal pattern of RGC were traced in each of the three lifting seasons (*fig. 14*).

The first, most common type showed a single peak in winter. Single-peak patterns characterized seed source HC from the central Klamath Mountains in all three lifting seasons; source BL from the Oregon Cascades, source OK from the eastern Klamath Mountains, and sources PL and MI from the western Sierra Nevada in the 1976-77 season; and sources AL and CH from the Oregon Coast Range, source SC from the eastern Klamath Mountains, sources BI and YO from the southern Klamath

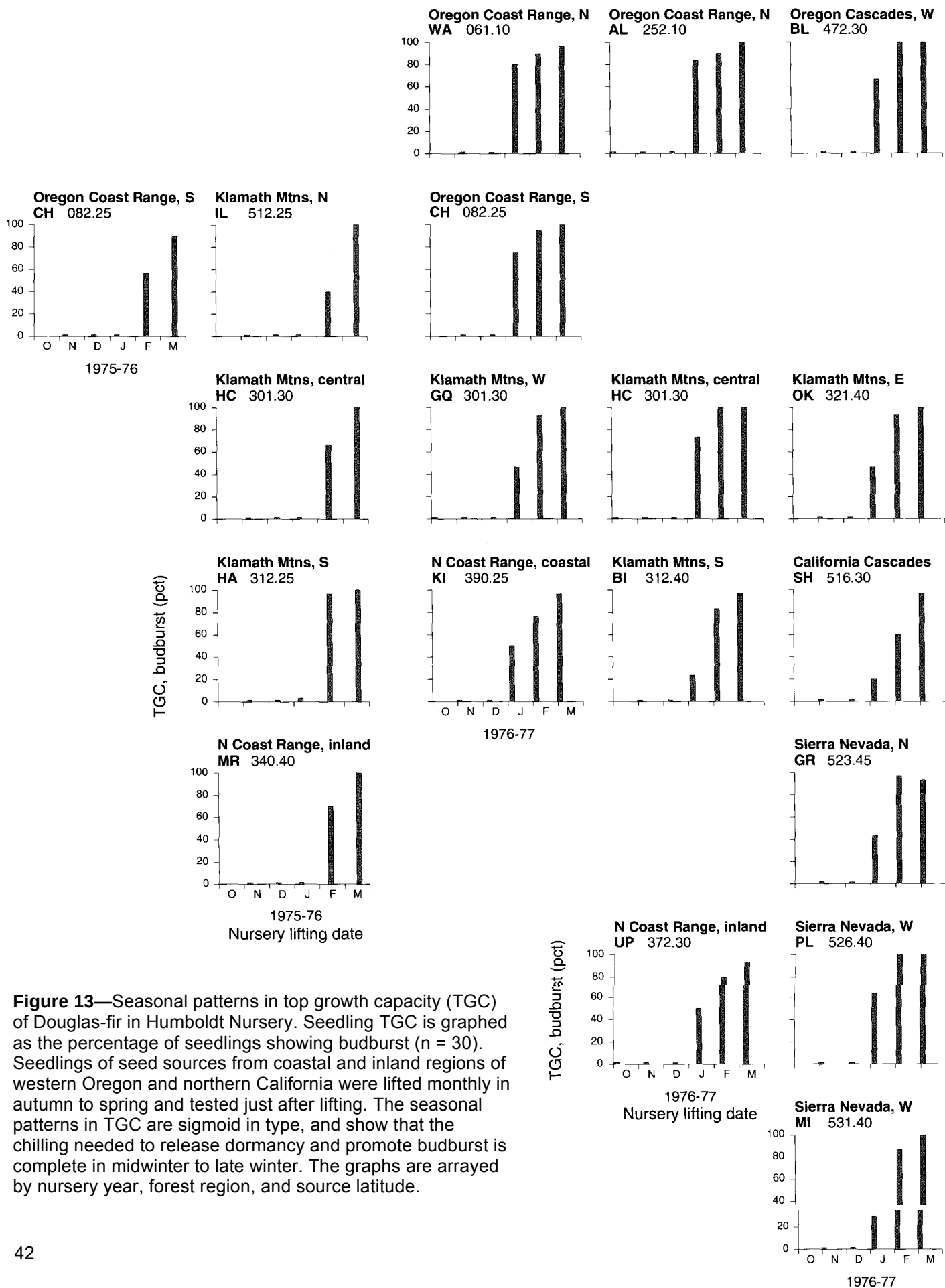
Mountains, and sources RE and MR from the North Coast Range in the 1977-78 season.

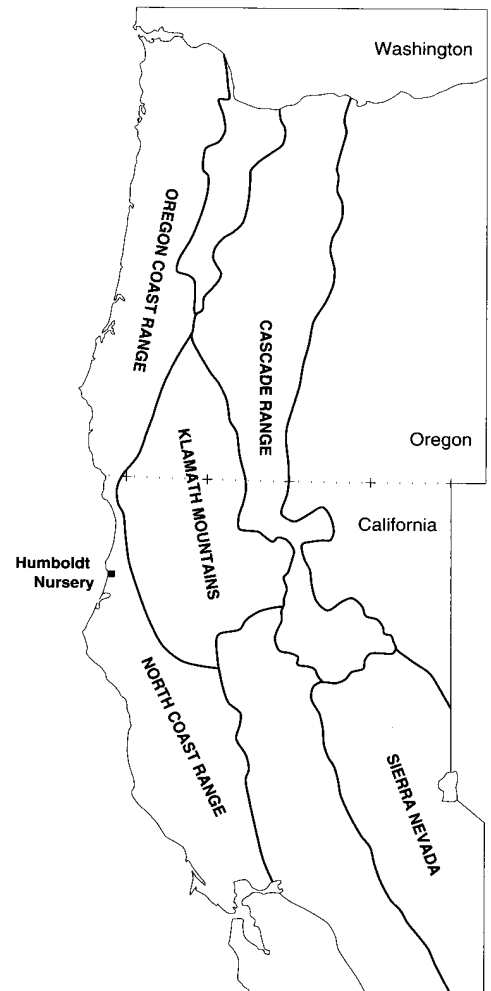
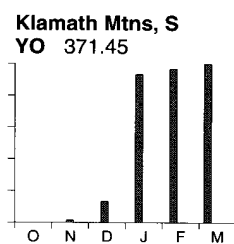
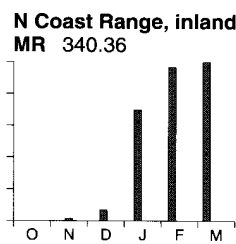
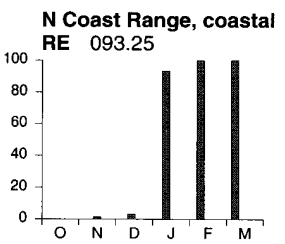
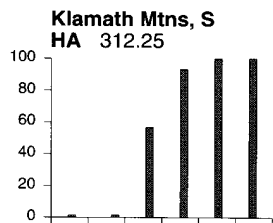
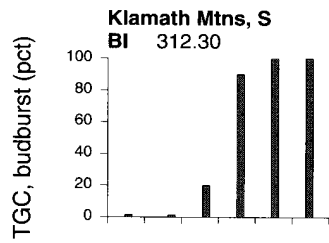
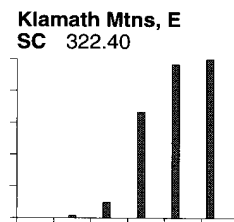
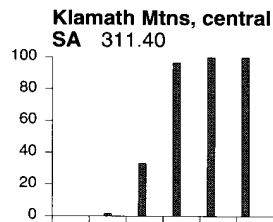
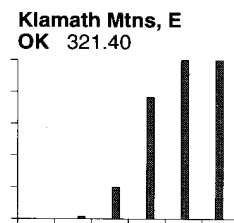
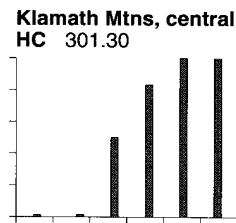
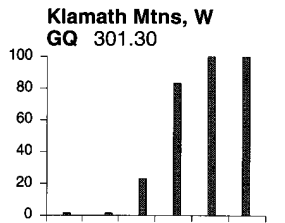
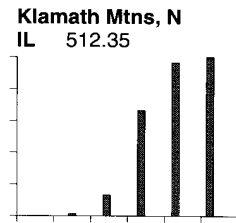
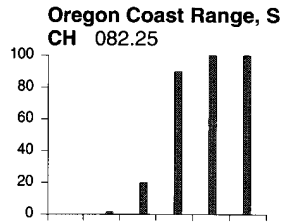
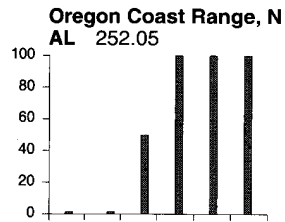
The second type showed a high plateau for 5 to 12 weeks, depending on seed source. High-plateau patterns characterized source IL from the northern Klamath Mountains in the 1975-76 lifting season; source BI from the southern Klamath Mountains and source UP from the inland North Coast Range in the 1976-77 season; and sources IL, SA, and OK from the northern, central, and eastern Klamath Mountains, respectively, in the 1977-78 season.

The third type showed two peaks separated by a significant depression. The peaks appeared in late autumn or early winter and in early winter, midwinter, or late winter, depending on seed source. Two-peak patterns characterized source MR from the inland North Coast Range in the 1975-76 lifting season; sources WA, AL, and CH from the Oregon Coast Range, source GQ from the western Klamath Mountains, source KI from the coastal North Coast Range, source SH from the California Cascades, and source GR from the northern Sierra Nevada in the 1976-77 season; and sources GQ and HA from the western and southern Klamath Mountains in the 1977-78 season.

Geographic variation—During the cold winter of 1976-77 (*fig. 12*), coastal seed sources showed two-peak patterns only (*fig. 14*). Two-peak patterns characterized sources WA and AL from the northern Oregon Coast Range, source CH from the southern Oregon Coast Range, source GQ from the western Klamath Mountains, and source KI from the North Coast Range. By contrast, inland seed sources showed all three pattern types, but often the same type for adjoining regions. Single-peak patterns characterized source BL from the Oregon Cascades, sources HC and OK from the central and eastern Klamath Mountains, and sources PL and MI from the western Sierra Nevada. High-plateau patterns characterized sources BI and UP from the southern Klamath Mountains and southern North Coast Range, and two-peak patterns characterized sources SH and GR from the California Cascades and northern Sierra Nevada.

Seed sources representing coast-inland transects in western Oregon and along the Oregon-California border showed two-peak patterns for sources near the coast and single-peak patterns for sources inland. Those showing two peaks were sources WA and AL from the northern Oregon Coast Range, and sources CH and GQ from the southern Oregon Coast Range and western Klamath Mountains. Those showing single peaks were source BL from the western Oregon Cascades and sources HC and OK from the central and eastern Klamath Mountains. Sources representing the coast-inland transect in northern

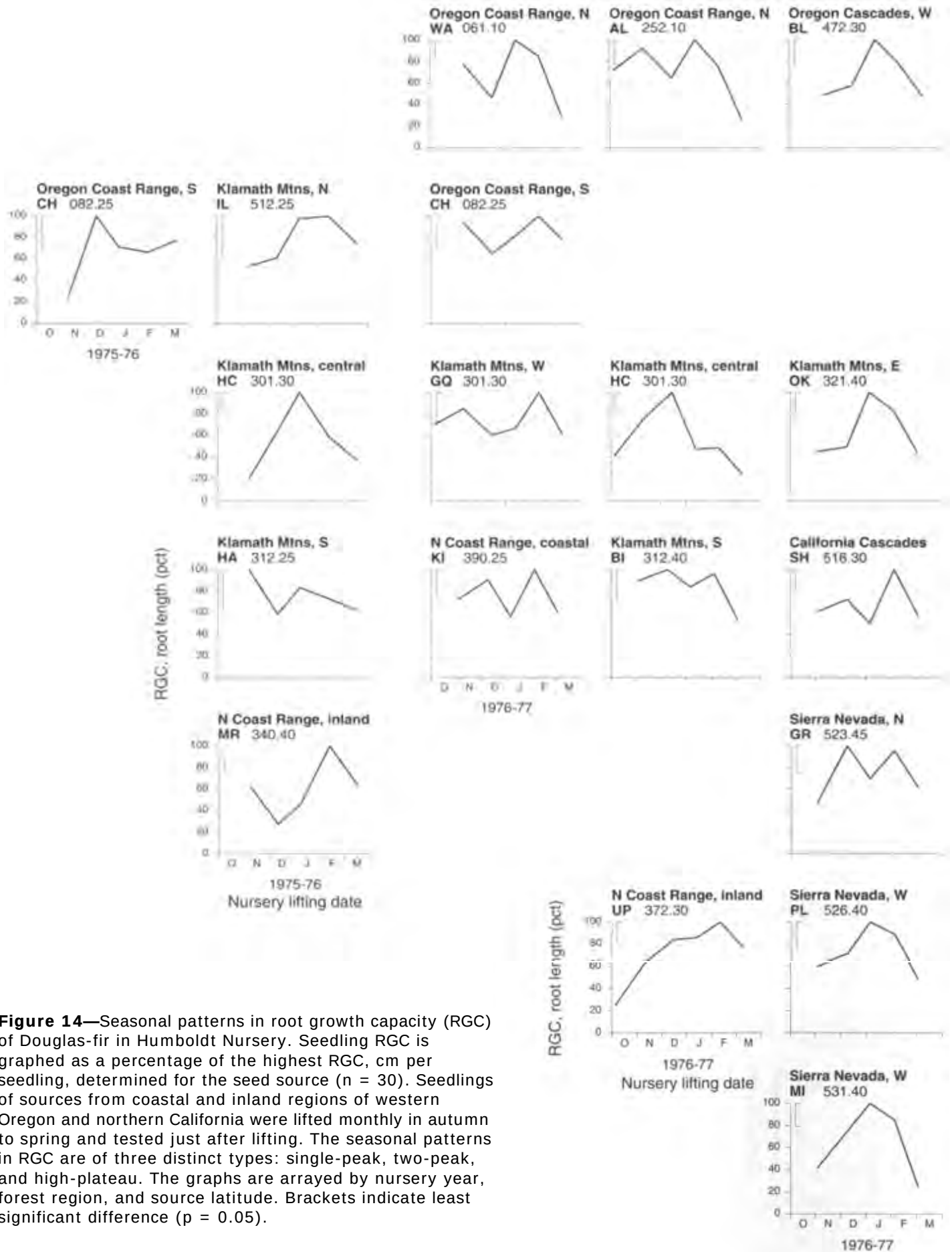


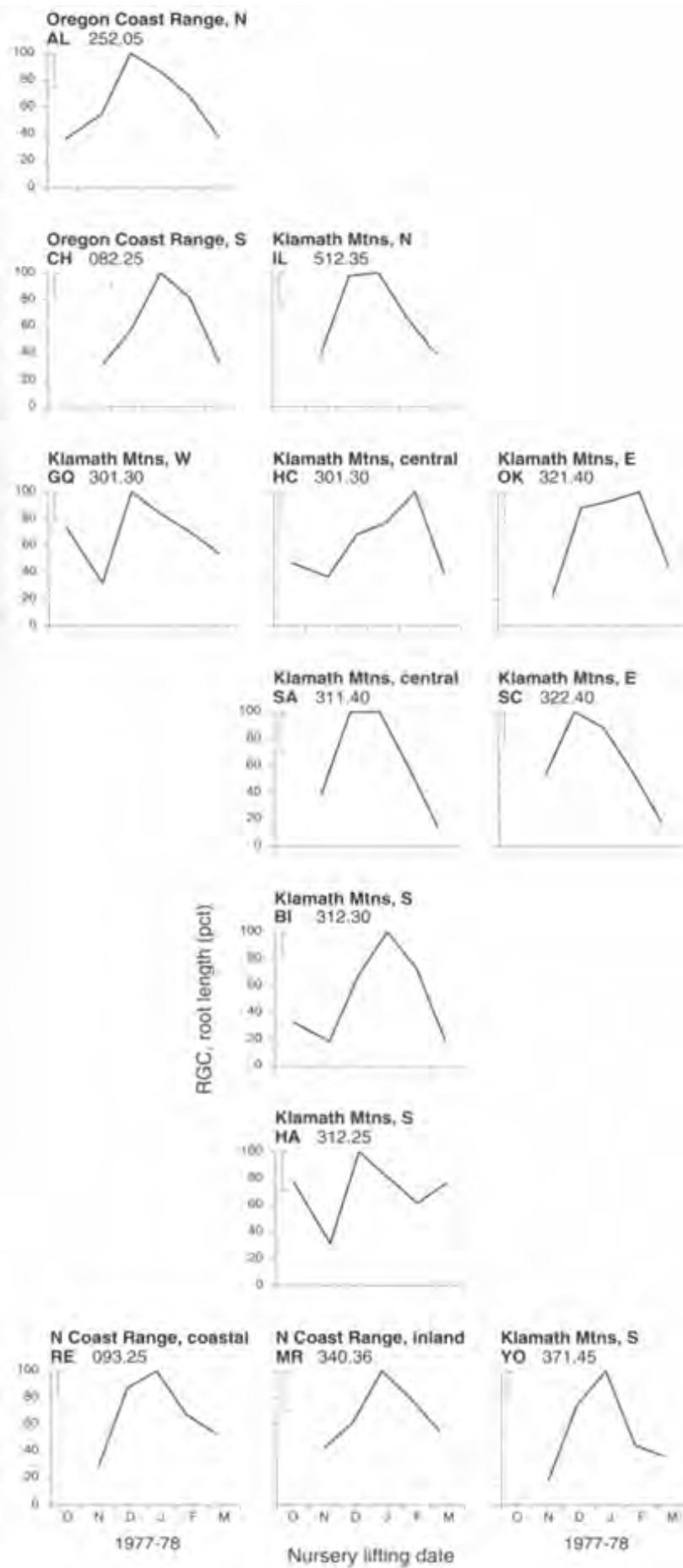


1977-78

Nursery lifting date

1977-78





California showed two-peak and high-plateau patterns, with two peaks for coastal source KI from the North Coast Range, high plateaus for inland sources BI and UP from the southern Klamath Mountains and North Coast Range, and two peaks again for sources SH and GR from the California Cascades and northern Sierra Nevada.

During the warm winter of 1977-78 (*fig. 12*), identical two-peak patterns were shown by coastal source GQ and inland source HA, from the western and southern Klamath Mountains, respectively (*fig. 14*). Single-peak patterns characterized sources AL and CH from the northern and southern Oregon Coast Range; coastal source RE and inland source MR from the North Coast Range; and sources HC, SC, BI and YO from the central, eastern, and southern Klamath Mountains. High-plateau patterns characterized sources IL, SA, and OK from the northern, central, and eastern Klamath Mountains. Taken together, the Klamath sources showed all three pattern types.

Pattern stability—Evaluations of repeated seed sources suggested that the seasonal patterns of RGC shift in time and type when autumn-winter climate in the nursery is warmer than normal. Source HC from the central Klamath Mountains always traced a single-peak pattern, but RGC peaked in January of the 1975-76 lifting season, in December of the 1976-77 season, and in February of the 1977-78 season (*fig. 14*). The source peak occurred 1 and 2 months earlier in the cold winters than in the warm one (*fig. 12*).

Source CH from the southern Oregon Coast Range tended to form two peaks in the 1975-76 lifting season and did form two in the 1976-77 season, but showed a single peak in the 1977-78 season. The progression suggests that the second peak depends on seedling chilling in autumn-winter in the nursery. Source GQ from the western Klamath Mountains seemed to form two peaks in both the cold 1976-77 and warm 1977-78 seasons. The October peak in 1977, however, likely reflected the normal autumn surge of root growth in the beds, so the second peak was probably the true one.

A pattern shift in source HA from the southern Klamath Mountains may also be explained. Unlike other inland sources, source HA had small seeds like coastal sources, tended to form two peaks in the 1975-76 lifting season, and with inland source MR from the North Coast Range, showed the same autumn peak and winter depression in the 1976-77 season as sources WA and AL from the northern Oregon Coast Range, source CH from the southern Oregon Coast Range, and source GQ from the western Klamath Mountains. Moreover, sources HA

and GQ showed the same pattern in the 1977-78 season. The coastal pattern tendencies seen in sources HA and MR suggest that maritime influence extends well inland along the Trinity and Mad Rivers drainages, respectively (*fig. 3*).

Source OK from the eastern Klamath Mountains had a single-peak pattern in the 1976-77 lifting season and a high-plateau pattern in the 1977-78 season (*fig. 14*). Of the five repeated sources, that is, source CH from the southern Oregon Coast Range and sources GQ, HC, OK, and HA from the western, central, eastern, and southern Klamath Mountains, respectively, source OK was the only one to change pattern type.

Practical Implications

Douglas-fir in Humboldt Nursery shows wide variation in the seasonal patterns of TGC and RGC. Yet seedlings of all seed sources attain high levels of TGC and RGC sometime during the lifting season, indicating that the nursery climate provides the physiological conditioning needed to produce planting stock with high survival and growth potentials. Testing seedlings just after lifting, however, may never become a useful way to assess planting stock quality, because any meaningful interpretation of results would have to depend on a specific knowledge of the seasonal patterns of seed sources in the nursery.

Seed source differences in the seasonal patterns of RGC largely confirm tree seed zones in western Oregon and northern California as useful divisions of genetic variation in Douglas-fir, as practical guides to the safe movement and use of planting stock (*figs. 3, 4*). Within certain zones, however, large differences were found between the patterns of seed lots from adjacent Ranger Districts. Pattern differences between sources from within zone 301 in the western and central Klamath Mountains and within zone 312 in the southern Klamath Mountains coincide with prominent topographic barriers that cut these zones in half. The north-south spine of the Western Siskiyou forms the common boundary of the Gasquet and Happy Camp Districts, separates the coastal and inland watersheds of the Klamath River, and effectively splits zone 301. In like manner, an east-west string of peaks and ridges forms the common boundary of the Big Bar and Hayfork Districts, divides watersheds of the Trinity River to the north from those of Hayfork River to the south, and effectively splits zone 312. Zones 301 and 312, and others like them, should be formally divided to warn of genetic change.

Table 2—Coefficients of determination, r^2 , for top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ²		Post-storage testing date	r ²		
			TGC	RGC	
Oregon Coast Range, N					
WA	061.10 77	Apr 15	0.35	0.03	
AL	252.10 77	Apr 21	.51	.06	
AL	252.05 78	Jun 28	.75	.01	
Oregon Coast Range, S					
CH	082.25 77	Mar 15	0.30	0.43	
CH	082.25 78	Apr 6	.19	.03	
Klamath Mtns, N					
IL	512.35 78	May 16	0.44	0.12	
Klamath Mtns, W					
GO	301.30 77	Apr 25	0.34	0.68	
GO	301.30 78	May 1	.51	.06	
Klamath Mtns, central					
HC	301.30 77	Mar 10	0.71	0.02	
HC	301.30 78	Apr 28	.80	.28	
SA	311.40 78	Jun 12	.92	.75	
Klamath Mtns, E					
OK	321.40 77	May 4	0.34	0.21	
OK	321.40 78	Apr 11	.00	.24	
SC	322.40 78	May 3	.21	.13	
Klamath Mtns, S					
BI	312.40 77	May 9	0.25	0.15	
BI	312.30 78	Jun 27	.68	.31	
HA	312.25 78	Apr 3	.92	.08	
YO	371.45 78	May 8	.47	.14	
N Coast Range, coastal					
KI	390.25 77	Apr 4	0.71	0.00	
RE	093.25 78	Apr 3	.69	.19	
N Coast Range, inland					
MR	340.36 78	May 1	0.68	0.22	
UP	372.30 77	Apr 4	.96	.86	
Oregon Cascades, W					
BL	472.30 77	May 2	0.35	0.09	
California Cascades					
SH	516.30 77	May 9	0.47	0.35	
Sierra Nevada, N					
GR	523.45 77	Apr 13	0.35	0.38	
Sierra Nevada, W					
PL	526.40 77	Apr 13	0.35	0.18	

¹Seedlings were lifted monthly in autumn to spring and stored at 1° C (34° F). TGC was expressed as budburst (pct), and RGC, as root elongation (cm); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*, and *tables 2, 3* in Appendix B.

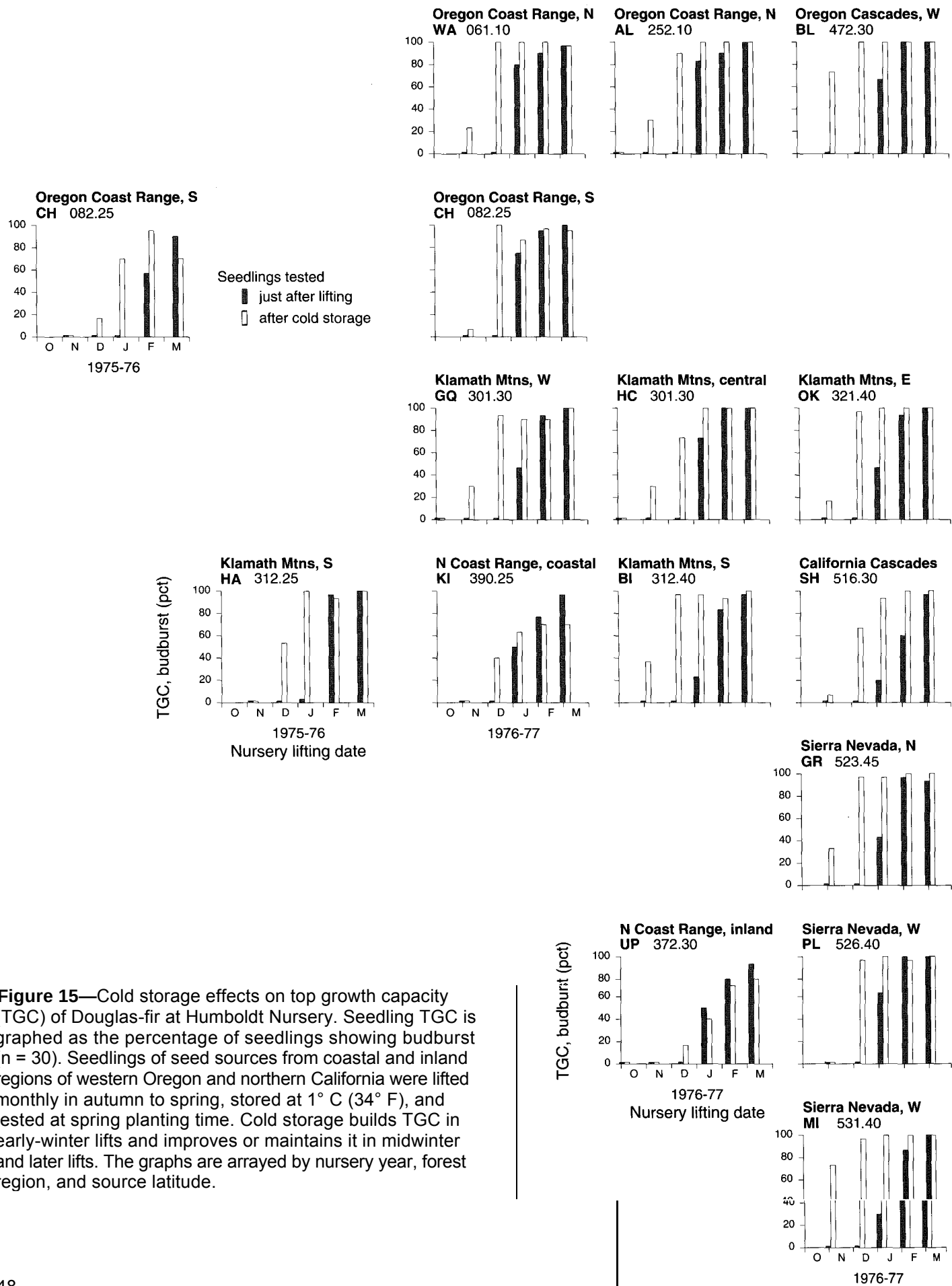
COLD STORAGE CHANGES OF TGC AND RGC

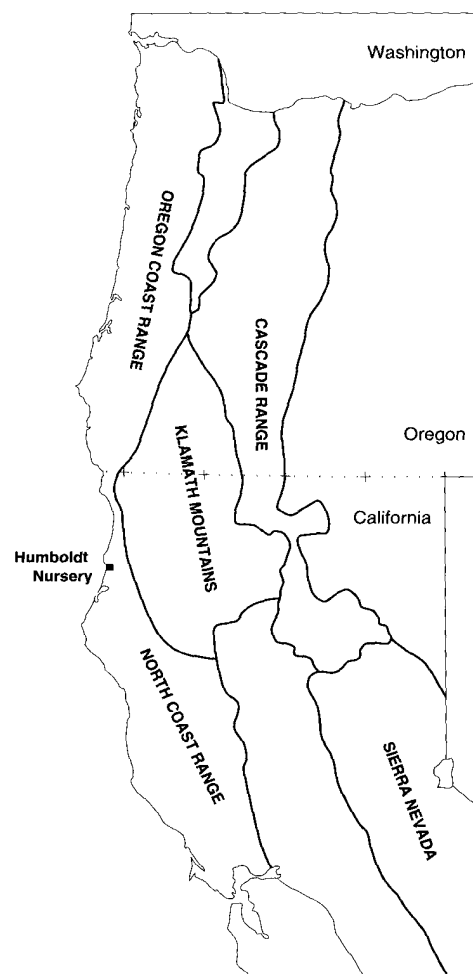
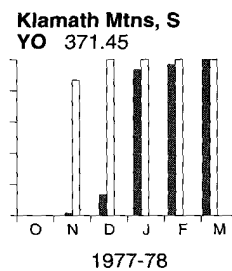
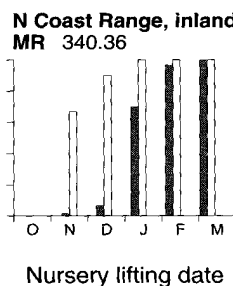
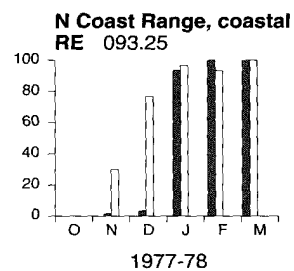
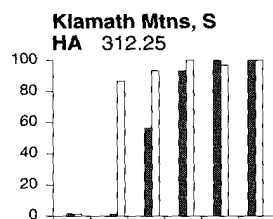
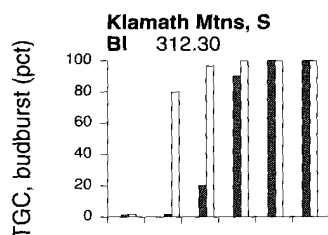
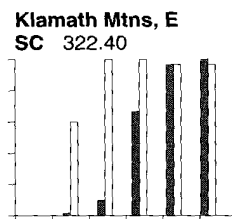
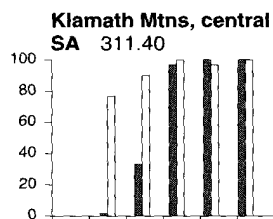
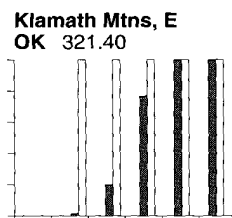
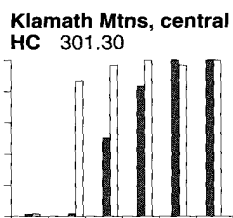
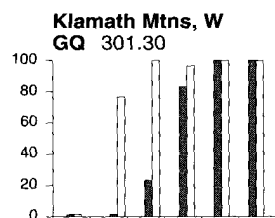
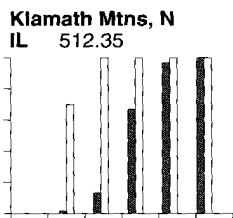
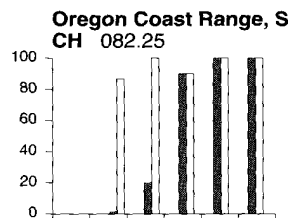
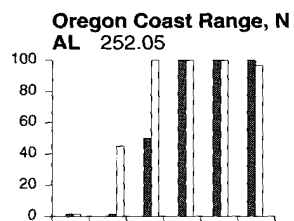
The second step taken to assess Douglas-fir in Humboldt Nursery was to evaluate seedling top and root growth capacity (TGC, RGC) of coastal and inland seed sources after cold storage. Research on the physiological quality of ponderosa pine seedlings had demonstrated beneficial effects of chilling at 5° C (41° F) and cold storage at 1° C (34° F). Cold storage at 1° C increases TGC in ponderosa pine—apparently by completing the chilling needed to promote rapid shoot extension—and either increases, maintains, or decreases RGC, depending on nursery lifting date (Krugman and Stone 1966, Stone and Jenkinson 1971).

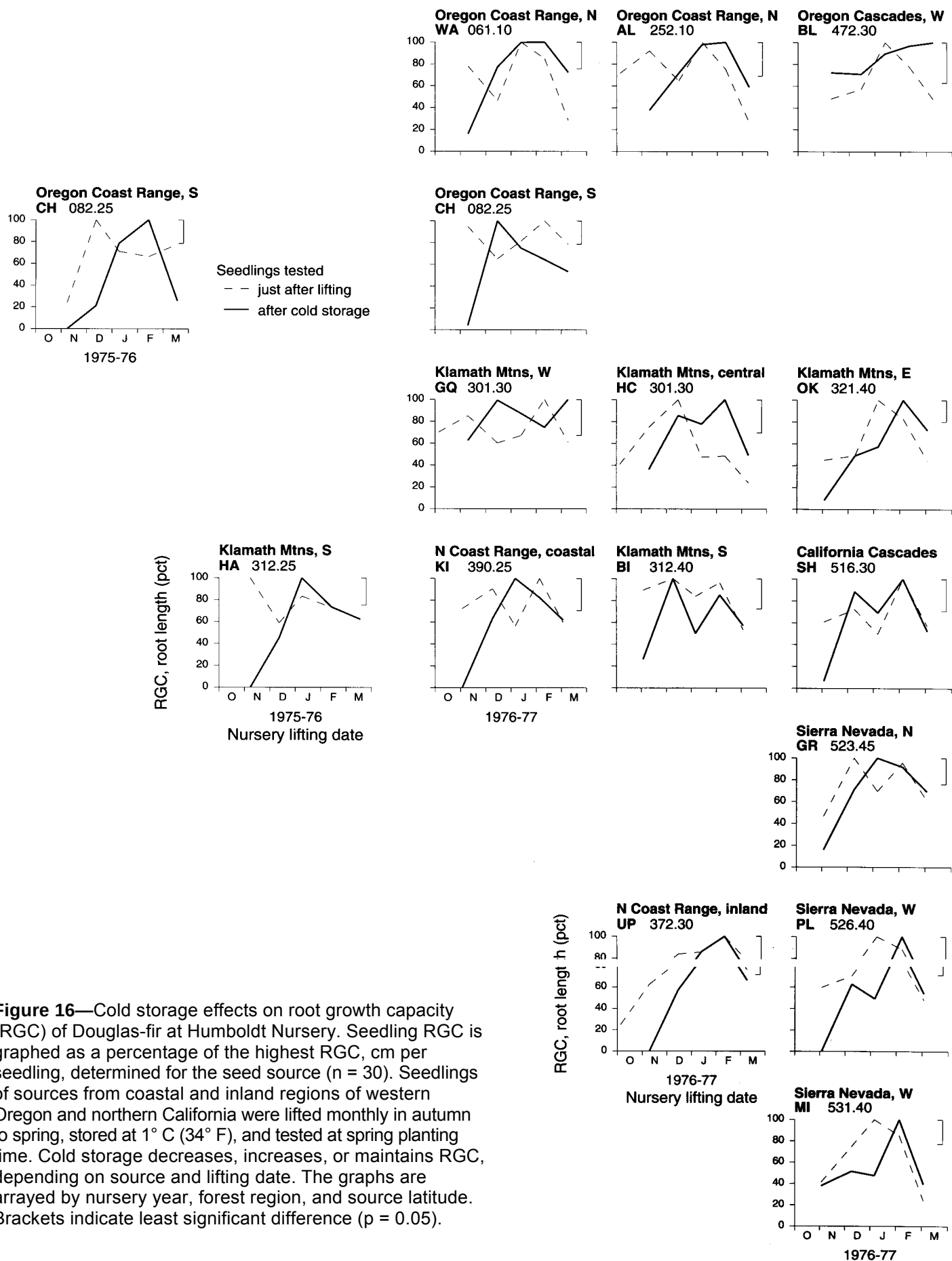
Whether Douglas-fir responds in the same way, and to what extent seed source affects response, was unknown. To find out, 23 sources from coastal and inland regions of western Oregon and northern California (*fig. 11*) were retested after cold storage, at spring planting time (see Assessing Planting Stock Quality, Standard Testing Procedures). Five of the 23 sources were repeated to assess effects of variation in nursery climate (*fig. 12*). Results were used to evaluate changes in TGC and RGC during cold storage, and to identify lifting periods that result in high TGC and RGC after storage (*fig. 15, 16*).

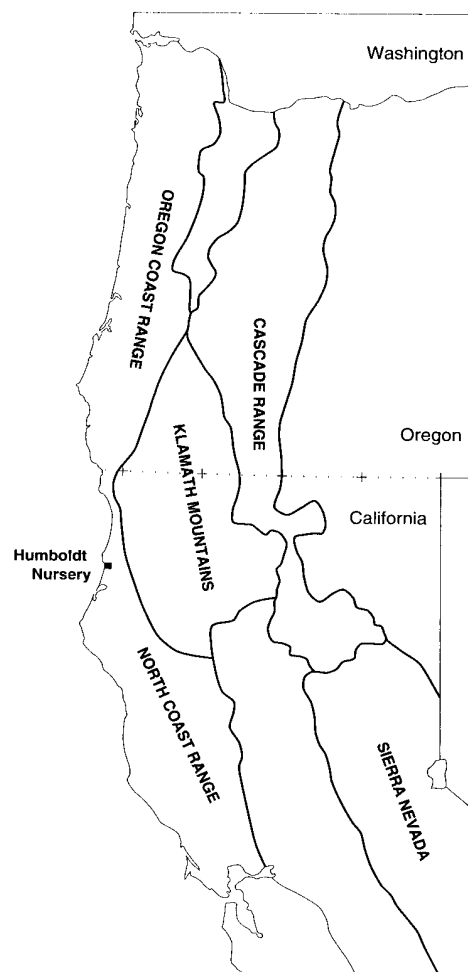
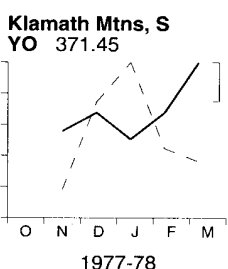
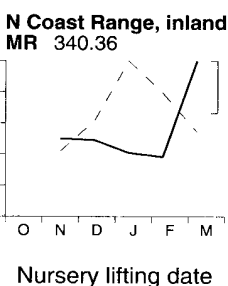
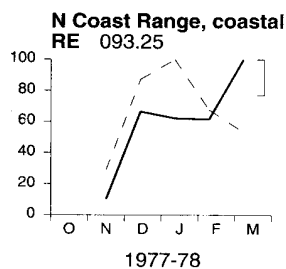
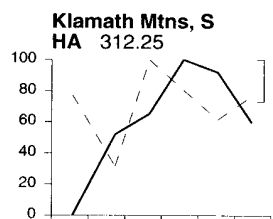
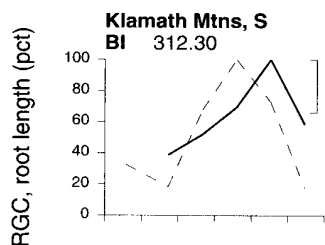
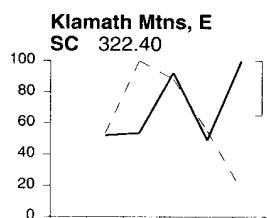
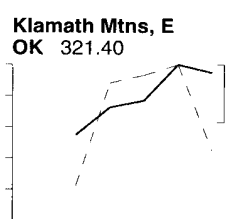
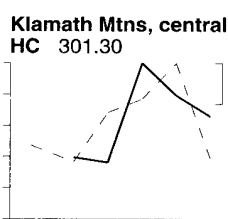
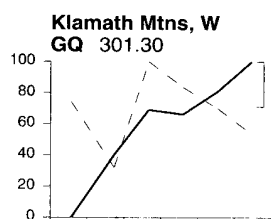
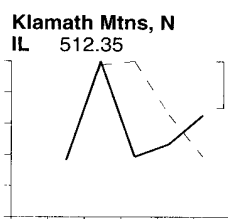
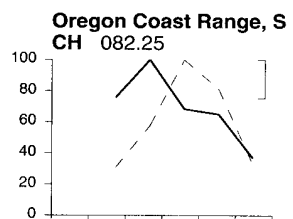
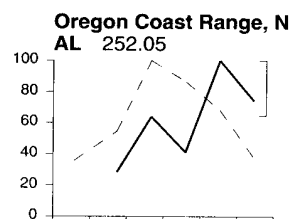
Post-storage testing dates ranged from March 10 to June 28, depending on the field performance tests. Field tests were installed on dates ranging from March 10 to June 19, with the median in April, and stored seedlings of most sources were evaluated for TGC and RGC in the greenhouse before the site planting windows closed (Jenkinson 1980). Variance analyses consistently indicated that nursery lifting date significantly affected TGC and RGC after cold storage. In every source, pronounced differences between lifts were evident in budburst, shoot extension, root elongation, and roots elongated (see *table 3* in Appendix B).

Changes in TGC and RGC during seedling cold storage were assessed by r^2 for TGC and RGC before and after storage (*table 2*). In 54 and 88 percent of the tests, TGC and RGC at lifting explained less than half of the variation in TGC and RGC after storage. For TGC expressed as budburst, percent, r^2 ranged from 0.00 to 0.96 and was less than 0.50 in 14 of 26 tests. For RGC expressed as root length, cm per seedling, r^2 ranged from 0.00 to 0.86 and was less than 0.50 in 23 of 26 tests.









Cold storage changes were illustrated by graphing TGC and RGC at lifting and after storage. Seedling TGC was expressed and compared as the percentage of seedlings showing budburst (*fig. 15*), and RGC, as a percentage of the greatest new root length, cm per seedling, found for the source, first at lifting and then after storage (*fig. 16*).

TGC at Planting Time

Cold storage to spring planting time resulted in spectacular increases in the TGC of seedlings that were lifted and stored in late autumn and early winter (*fig. 15*). For seedlings of every seed source, the chilling needed to permit rapid budburst and shoot extension (see *table 3* in Appendix B) was completed in the dark at 1° C (34° F). Cold storage maintained high TGC in late-winter lifts, with budburst typically at 100 percent. Reductions in TGC during storage were rare and not significant, including those suggested in source CH from the southern Oregon Coast Range in the 1975-76 lifting season and sources KI and UP from the North Coast Range in the 1976-77 season.

In budburst, TGC commonly increased from zero at lifting in December to 100 percent after cold storage. This response characterized 10 of the 14 sources assessed during the 1976-77 season, namely sources WA, AL, and CH from the northern and southern Oregon Coast Range, source BL from the Oregon Cascades, sources GQ, OK, and BI from the western, eastern, and southern Klamath Mountains, and sources GR, PL, and MI from the northern and western Sierra Nevada.

Storage effects were equally dramatic in the 13 sources assessed during the 1977-78 season. Seedling TGC increased from zero at lifting in November to 80 percent or higher after storage in source CH from the southern Oregon Coast Range and sources HC, OK, BI, HA, and YO from the central, eastern, and southern Klamath Mountains. In 12 sources, TGC increased from 10-50 percent at lifting in December to 90 percent or higher after storage. In source RE from the North Coast Range, TGC increased from 5 percent at lifting to 80 percent after storage.

RGC at Planting Time

Cursory inspections of RGC patterns at lifting and after cold storage to spring planting times show that storage variously affected every seed source (*fig. 16*). Whether stored seedlings increase, maintain, or

decrease RGC clearly depends on seed source and lifting date. Indicated safe calendar periods to lift seedlings for cold storage and spring planting ranged from 6 weeks to more than 4 months.

Overwinter cold storage from October or early November reduced RGC to zero in almost every source in the 1975-76 and 1976-77 lifting seasons. There were exceptions. Autumn lifting and storage did not reduce RGC in source BL from the western Oregon Cascades, source GQ from the western Klamath Mountains, or source MI from the western Sierra Nevada, at least not relatively.

Storage of later lifts either increased, maintained, or decreased RGC, yet still resulted in high RGC at planting time. High RGC after storage characterized seedlings of most sources lifted in December-March or some combination of those months and November. Seedlings stored during the 1975-76 season had highest RGC in the January lift of source CH from the southern Oregon Coast Range and source HA from the southern Klamath Mountains.

Seedlings stored during the 1976-77 season had highest RGC in the November-March lifts of source GQ from the western Klamath Mountains, the November-February lifts of source BL from the western Oregon Cascades, and the December-February lifts of sources WA and AL from the northern Oregon Coast Range, source KI from the North Coast Range, source HC from the central Klamath Mountains, source SH from the California Cascades, and source GR from the northern Sierra Nevada. By contrast, RGC was highest in the December lift of source CH from the southern Oregon Coast Range, the December and February lifts of source BI from the southern Klamath Mountains, and the February lift of source OK from the eastern Klamath Mountains, source UP from the North Coast Range, and sources PL and MI from the western Sierra Nevada.

Seedlings stored during the 1977-78 season had highest RGC in the February-March lifts of source AL from the northern Oregon Coast Range, source GQ from the western Klamath Mountains, sources RE and MR from the North Coast Range, and source YO from the southern Klamath Mountains. In the remainder, RGC was highest in the December lift of source CH from the southern Oregon Coast Range and source IL from the northern Klamath Mountains, the January-February lifts of sources HC, BI, and HA from the central and southern Klamath Mountains, and the December-March lifts of source OK and January and March lifts of source SC from the eastern Klamath Mountains.

Practical Implications

High levels of RGC after varying durations of seedling cold storage to spring planting times imply optimum calendar periods for lifting Douglas-fir in Humboldt Nursery. Initially, however, safe times to store seedlings for spring planting should be based on determinations of first-year survival on cleared planting sites in the seed zones of origin. Using RGC test results to select lifting dates is risky without specific knowledge of the relation between RGC after storage and survivals on sites typical of the seed sources. Once the critical RGCs for survival are known, post-storage RGC tests could be used to predict survival and determine lifting schedules for future seedling crops.

SEED SOURCE LIFTING WINDOWS

Field survival and growth are the definitive proof of planting stock quality, and most planting foresters will accept no less. Consequently, the third and most important step taken to assess Douglas-fir in Humboldt Nursery was to test the survival and growth of cold-stored seedlings on cleared planting sites in the seed zones of origin. Seed source lifting windows were derived from these field performance tests, and were immediately used to revise Humboldt's lifting and cold storage schedules. In terms of benefits to the nursery and clientele, source lifting windows arguably are the most significant achievement of the first 4 years of the testing program.

Lifting windows were determined for seed sources from throughout the coastal and inland regions of western Oregon and northern California. The results were used to develop nursery management guides that insure the physiological quality of Douglas-fir planting stock. The guides were applied by scheduling lifting and cold storage of all untested sources within the lifting windows of appropriate known sources. Beginning with the 1978-79 and 1979-80 lifting seasons, conservative first and last safe lifting dates were assigned to every source in the nursery. Assigned safe dates were based on safe dates previously determined for known sources from the same or nearby seed zones.

Any nursery that grows up to 20 million seedlings of a hundred or more seed sources must expect an annual blizzard of clientele requests to lift seedlings in midwinter. Humboldt Nursery knows this drill well. Guides available for Pacific Slope nurseries suggest that late-winter lifting is essential to secure

dormant planting stock and limit harmful cold storage (Cleary, Greaves, and Owston 1978, Hermann and others 1972). Strict applications of such guides abandon proven successful cold storage, disregard known source differences in storability, and promote stock quality problems. The logistics of grading, packing, and storing 20 million seedlings might be managed in 4 to 6 weeks, but to assume the endlessly fair weather needed to permit damage-free lifting would be ludicrous.

At Humboldt, winter rains are normal and often soak the beds for days at a time. Lifting when the soil is wet, heavy, and sticky, is disastrous. Pulling seedlings from muddy soil unavoidably rips deep wounds in taproots, snaps conductive tissues in the primary laterals, and strips the short, fine secondary roots. Damaged roots insure lethal water stress and guarantee plantation failures. Functional roots enable seedlings to reach available soil water and survive summer drought. Successful reforestation demands planting stock with intact roots and high growth capacity.

Wide seed source lifting windows permit the nursery to lift seedlings only when soil conditions make root damage unlikely. First-year survivals in field performance tests showed that 16 of the 56 sources assessed were safely lifted and stored anytime from mid-November to late March. Thus, 28 percent of the sources had lifting windows that were open for at least 4 months, more than enough to plan and establish an extended lifting schedule.

Field performance tests were designed to relate survival and growth to lifting date, to define safe, source-specific calendar periods to store seedlings for spring planting (see Assessing Planting Stock Quality, Standard Testing Procedures). Cooperators installed 58 field tests during the spring planting seasons of 1976-79, and by 1980, lifting windows were known for 46 seed sources. Later tests had other objectives, but still supplied the same kinds of data, and by 1985, lifting windows had been determined for 56 sources in 74 tests (*fig. 10*).

Field Survivals

Seed source lifting windows were defined by first-year field survivals (*table 3*). To determine the safe lifting period for any particular source, seedling survival Y , percent, was graphed against lifting date X , Julian. First and last safe dates were then read from the curve as X for $Y = \text{highest survival} - \text{LSD}$ ($p = 0.05$). Least significant difference was calculated by $\text{LSD} = q[\text{ems}/r]^{0.5}$, where ems is the error mean square from variance analysis (see Assessing Planting Stock Quality, Standard Testing Procedures).

Table 3—Seed source lifting windows for Douglas-fir in Humboldt Nursery¹

Seed source ²	Site planting date	Field survival, by nursery lifting date ³					LSD ⁴	
		Nov	Dec	Jan	Feb	Mar		
----- pct -----								
Oregon Coast Range, N								
HE 053.10 79	May 1	79•	99•	99•	97•	97•	7.9	
WA 061.10 77	Apr 15	35•	89•	94•	86•	96•	9.8	
AL 252.15 80o	Mar 31		72•	99•	99•	99•	9.8	
AL 252.10 77	Apr 21	60•	97•	97•	98•	100•	8.2	
AL 252.10 81	Apr 13	57•	95•	98•	96•	98•	5.6	
AL 252.05 78	Apr 13		88•	96•	99•	100•	7.5	
AL 061.05 79	Apr 10	82•	100•	98•	98•	98•	6.8	
MA 062.10 79	Apr 24	77•	87•	97•	93•	93•	9.1	
Oregon Coast Range, S								
CO 072.10 84o	Apr 10		61•	97•	95•	96•	5.8	
PO 072.25 79	Apr 26	42•	90•	97•	96•	96•	9.5	
GO 081.20 79	Apr 5	29•	64•	72•	67•	60•	15.4	
CH 082.25 76	Apr 23	0•	28•	73•	96•	84•	10.2	
CH 082.25 77	Mar 15	13•	55•	69•	82•	76•	12.6	
CH 082.25 78	Apr 6	70•	64•	67•	88•	89•	14.4	
CH 082.25 79	Apr 23	52•	84•	93•	89•	93•	9.5	
CH 082.10 79	Apr 23	42•	87•	95•	91•	83•	9.5	
Klamath Mtns, N`								
RO 270.20 84o	Mar 28		67•	92•	98•	97•	7.5	
GA 511.30 79	Apr 14	73•	82•	84•	81•	92•	13.8	
GA 512.25 79	Apr 14	74•	91•	92•	90•	88•	9.8	
IL 512.40 79	Apr 24		85•	73•	61•	71•	67•	17.7
IL 512.35 78	May 16	36•	59•	55•	61•	44•	16.3	
IL 512.13 79	May 8	16•	28•	53•	56•	51•	13.4	

¹Seedlings were stored at 1 ° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 10, and table 1 in Appendix B. The letter o denotes 1-0 planting stock.

³ Shaded bars indicate seed source lifting windows. The symbol • marks nursery lifting date; the number is first-year survival.

⁴Least significant difference ($p = 0.05$).

⁵ Test was installed on landslide (source GQ) or ultramafic soil (sources OK, SC).

Table 3—Seed source lifting windows for Douglas-fir in Humboldt Nursery-continued¹

Seed source ²	Site planting date	Field survival, by nursery lifting date ³					LSD ⁴
		Nov	Dec	Jan	Feb	Mar	
<i>pct</i>							
Klamath Mtns, W							
GQ 301.30 77	Apr 25	88*	98*	98*	97*	98*	4.6
GQ 301.30 78	May 1	83*	96*	98*	99*	97*	7.8
GQ 301.30 79 ⁵	Apr 6	7*	25*	75*	64*	48*	19.3
OR 302.30 79	Apr 4	67*	73*	81*	78*	88*	11.4
Klamath Mtns, central							
HC 301.50 79	May 23	88*	97*	98*	97*	100*	5.1
HC 301.30 77	Mar 10	38*	85*	95*	94*	93*	10.5
HC 301.30 78	Apr 28	64*	90*	95*	89*	91*	10.7
HC 301.30 79	Mar 20	59*	89*	93*	98*	91*	11.2
UK 301.20 79	Mar 23	54*	80*	90*	93*	92*	11.5
UK 302.44 79	Mar 24	87*	95*	98*	97*	96*	6.2
UK 311.40 79	Apr 9	30*	71*	90*	71*	74*	16.3
SA 311.40 79	Mar 25	87*	97*	96*	99*	100*	6.4
Klamath Mtns, E							
AP 511.40 79	Apr 26	69*	86*	90*	93*	90*	11.6
OK 321.40 77 ⁵	May 4	1*	39*	55*	71*	52*	19.0
OK 321.40 78	Apr 11	92*	88*	88*	95*	90*	7.4
OK 321.40 79	Apr 5	82*	98*	95*	97*	96*	7.5
OK 321.30 80o	Apr 3	58*	73*	88*	84*	79*	13.9
OK 321.30 81	Apr 4	54*	87*	78*	83*	83*	10.1
SC 322.40 78	May 3	44*	92*	90*	84*	91*	8.9
SC 322.40 79 ⁵	May 15	19*	64*	84*	81*	63*	13.5
Klamath Mtns, S							
BI 312.40 77	Mar 17	45*	78*	82*	69*	78*	13.3
BI 312.30 78	May 17	87*	85*	99*	94*	96*	8.0
HA 312.50 80	May 13	9*	42*	40*	49*	47*	13.9
HA 312.25 78	Apr 27	73*	87*	93*	86*	90*	9.8
HA 312.25 79	Apr 2	73*	96*	93*	94*	95*	10.0
HA 312.25 79o	Apr 2	64*	87*	93*	85*	94*	9.3
HA 312.25 80	May 6	12*	33*	32*	42*	30*	10.5
YO 371.45 78	May 2	67*	90*	84*	93*	95*	9.9

Table 3—Seed source lifting windows for Douglas-fir in Humboldt Nursery-continued¹

Seed source ²	Site planting date	Field survival, by nursery lifting date ³					LSD ⁴
		Nov	Dec	Jan	Feb	Mar	
<i>pct</i>							
N Coast Range, coastal							
GQ 091.20 81	Apr 8	70*	94*	92*	97*	97*	6.0
KI 390.25 77	Mar 18	5*	45*	67*	66*	81*	16.2
KI 390.20 79	Mar 30	79*	88*	85*	90*	87*	10.6
KI 390.20 80o	Apr 11	4*	81*	93*	94*	94*	9.5
KI 390.20 84o	Apr 12	35*	86*	97*	96*	95*	7.1
RE 093.25 78	Apr 6	20*	69*	82*	75*	86*	16.9
N Coast Range, inland							
MR 303.45 79	Apr 14	40*	55*	74*	75*	66*	13.6
MR 340.36 78	Apr 24	64*	74*	88*	92*	91*	13.0
UP 372.30 77	Mar 10	6*	45*	56*	48*	51*	11.2
Oregon Cascades, W							
MK 472.45 79	Jun 19	75*	79*	84*	75*	84*	10.5
MK 472.30 80o	May 19	48*	88*	86*	88*	88*	14.9
BL 472.30 77	Apr 8	64*	90*	80*	88*	76*	12.9
OA 482.30 81	Mar 27	37*	74*	69*	77*	80*	9.5
ST 491.30 79	Apr 17	87*	85*	90*	88*	92*	11.7
GL 491.30 79	Jun 5	60*	85*	92*	89*	87*	13.0
TI 492.30 79	Apr 16	97*	97*	98*	93*	100*	5.4
California Cascades							
SH 516.30 77	May 6	7*	41*	72*	71*	71*	14.1
SH 521.40 79o	May 22	78*	89*	88*	90*	91*	11.6
Sierra Nevada, N							
GR 523.45 77	Apr 25	1*	39*	67*	84*	73*	11.5
Sierra Nevada, W							
PL 526.40 77	Apr 1	0*	77*	92*	90*	74*	12.8
MI 531.40 77	Apr 15	70*	87*	90*	93*	73*	12.0

¹Seedlings were stored at 1 ° C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 1* in Appendix B. The letter o denotes 1-0 planting stock.

³ Shaded bars indicate seed source lifting windows. The symbol • marks nursery lifting date; the number is first-year survival.

⁴ Least significant difference ($p = 0.05$).

⁵ Test was installed on landslide (source GQ) or ultramafic soil (sources OK, SC).

The geographic variation and stability of source lifting windows were also defined. Associations between lifting window width and seed source latitude, longitude, and elevation were assessed by coefficients of multiple determination, R^2 . Window stability was evaluated by repeated sowings of seedlots from sources in the northern and southern Oregon Coast Range and the western, central, eastern, and southern Klamath Mountains. Hours of seedling chilling up to the first safe lifting dates were determined from the graphs of nursery air temperature (*fig. 12*).

Source variability—First-year survival was 90 percent or higher in the field tests that cooperators managed intensively. Yet success always depended on when the seedlings were lifted and stored (*table 3*). Survival was practically zero for the October lifts, but reached high levels for the November lifts of many sources. Lifting windows are indicated by consecutive lifts that show uniformly higher survivals

excellent or poor. Significant decreases from highest survivals (LSD) mark the dates that the windows open or close.

Source lifting windows range from 6 weeks wide to more than 4 months wide. They open on dates ranging from early November to late January, and close on dates ranging from late February to late March. For most sources, the last safe date is in mid- to late March, coincident with the onset of rapid root elongation in the nursery. The narrowest lifting window found was 49 days for source CH 082.25 from the southern Oregon Coast Range, and the widest, 127 days for source OK 321.40 from the eastern Klamath Mountains (*table 4*).

For Douglas-fir, all of the source lifting windows in Humboldt Nursery overlap in the 5-week period from late January to early March (*table 3*). First-year survivals in most of the field tests supported the generalization that seedlings lifted in late winter have high survival potential (Cleary, Greaves, and Owston 1978). More importantly, however,

windows repeatedly demonstrated that Humboldt's potential lifting season consistently extends from late autumn to early spring.

Survivals within the lifting windows averaged 80 to 99 percent in 52 tests, 60 to 80 percent in 15 tests, and 50 to 55 percent in 3 tests. Low survivals in a fourth of the tests were caused by various problems. Chronic browsing by mammals and tough plant competition for soil water were common. Offsite planting, poor root placement, and planting too early or late were also encountered. Even so, seedlings lifted outside the source window always showed the lowest survival.

Width of the lifting window was not correlated with survival, and high survivals were as readily obtained for sources with wide windows as for those with narrow ones. In the 1978 tests, for example, sources IL 512.35 and HA 312.25 in the northern and southern Klamath Mountains, showed lifting windows of 101 and 106 days, with average survivals of 55 and 89 percent, while sources CH 082.25 and OK 321.40 in the southern Oregon Coast Range and eastern Klamath

Table 4—Stability of seed source lifting windows for Douglas-fir in Humboldt Nursery

Seed source ¹	Lifting window width	First-year field survival ²	First safe lifting date	Seedling chilling in nursery ³
	days	pct		h
Oregon Coast Range, N				
AL 252.10 77	112	98	Nov 24	590
AL 252.10 81	111	97	Nov 25	—
Oregon Coast Range, S				
CH 082.25 76	55	89	Jan 17	—
CH 082.25 77	66	76	Jan 11	1481
CH 082.25 78	49	88	Jan 26	797
Klamath Mtns, W				
GQ 301.30 77	124	97	Nov 12	491
GQ 301.30 78	111	98	Nov 25	376
Klamath Mtns, central				
HC 301.30 77	102	92	Dec 4	777
HC 301.30 78	110	89	Nov 26	376
HC 301.30 79	114	92	Nov 22	459
Klamath Mtns, E				
OK 321.40 78	120	90	Nov 16	277
OK 321.40 79	127	96	Nov 9	225
OK 321.30 80o	96	81	Dec 10	—
OK 321.30 81	105	83	Dec 1	—
Klamath Mtns, S				
HA 312.25 78	106	89	Nov 30	387
HA 312.25 79	110	94	Nov 26	542
HA 312.25 79o	110	90	Nov 26	542

¹ See *fig. 10*, and *table 3*. The letter o denotes 1-0 planting stock.

² Value is the average for seedlings lifted within the source lifting window.

³ Air temperature was <10° C (50° F) for the number of hours indicated, in the period from October 1 to the first safe lifting date.

Mountains showed windows of 49 and 120 days, with survivals of 88 and 89 percent. In the 1979 tests, sources IL 512.40 and SA 311.40 in the northern and central Klamath Mountains, showed lifting windows of 117 and 116 days, with survivals of 71 and 97 percent, while sources CH 082.10 and HC 301.30 in the southern Oregon Coast Range and central Klamath Mountains showed windows of 83 and 114 days, with survivals of 91 and 92 percent.

Geographic variability—Width of the lifting window varied among and within forest regions (table 3, fig. 17). About 14 percent of the variation was explained by seed source latitude, longitude, and elevation, and 13 percent by source latitude and elevation (R^2 significant at $p = 0.05$). For 13 Ranger Districts that tested sources from different elevations, 40 percent of the variation was explained by source latitude and elevation, and most of that by elevation alone (R^2 significant at $p = 0.01$). Window width increased by 12 to 39 days with increases of 1000 to

2000 ft (305 to 610 m) for sources in inland regions, but decreased or remained the same for those in coastal regions. For sources from the same elevation but adjacent Districts, window widths differed by 1 to 25 days.

Width of the lifting window increased with seed source latitude in the North Coast-Oregon Coast Ranges and the Sierra Nevada-Cascade Ranges, but decreased with source latitude in the Klamath Mountains (table 3; figs. 3, 4, 10). Lifting windows of Coast Range sources increased from an average of 85 days for Upper Lake to Orleans (sources UP to OR) to 113 days for Mapleton to Hebo (sources MA to HE), and windows of Sierra Nevada-Cascades sources, from 83 days for Mi-Wok to Mt Shasta (sources MI to SH) to 108 days for Tiller to McKenzie (sources TI to MK). Lifting windows of Klamath Mountains sources opposed the overall trend, decreasing from an average of 114 days for Yolla Bolla to Salmon River (sources YO to SA) to 103 days for Ukonom to Illinois Valley (sources UK to IL).

Window stability—Lifting windows of repeated seed sources, seedlots that were sown and evaluated in 2 or more years, were practically stable in tests on typical Douglas-fir sites (table 4, fig. 17). First safe lifting dates, window widths, and even the first-year field survivals were consistent from year to year. Differences between first safe dates ranged from 1 day for source AL 252.10 from the northern Oregon Coast Range to 17 days for source CH 082.25 from the southern Oregon Coast Range. Variation in window width ranged up to 35 percent for narrow-window source CH from the southern Oregon Coast Range, but was never more than 1 to 12 percent for wide-window sources, such as source AL from the northern Oregon Coast Range and sources GQ, HC, OK, and HA from the western, central, eastern, and southern Klamath Mountains.

Sources with wide windows showed narrowed windows when planted offsite, in edaphic or climatic environments different from those of the parent stands. On their natural sites, sources GQ 301.30, OK 321.40, and SC 322.40 from the western and eastern Klamath Mountains showed windows that were open for 4 months, in late November to late March (table 3). On an unstable landslide or on shallow, infertile ultramafic soils, the same sources indicated windows that were open for 2 to 3 months, in December to late February.

Source lifting windows are stable for Douglas-fir, and illustrate the futility of using seedling cold exposure to schedule lifting and cold storage in Humboldt Nursery (table 4). The amount of seedling chilling associated with first safe lifting dates ranged from 225 hours for wide-window source OK from the eastern Klamath Mountains to 1481 hours for narrow-window source CH from the southern

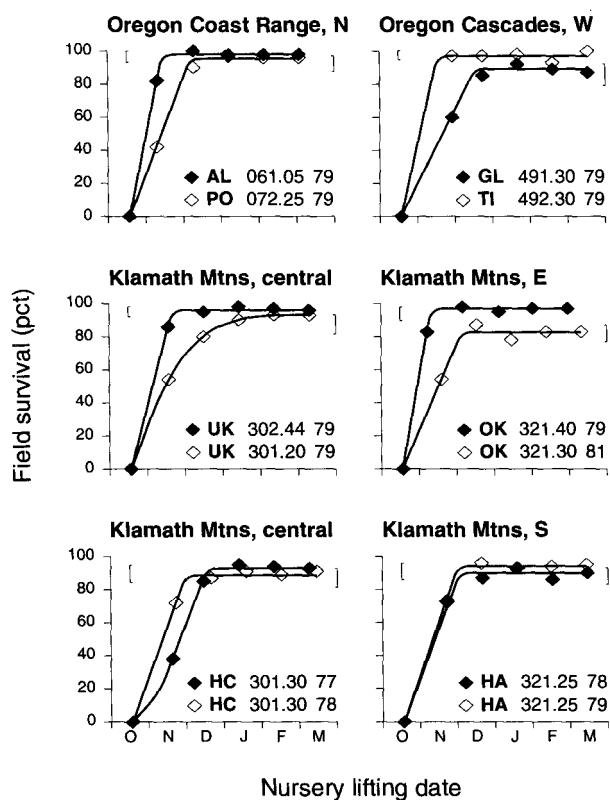


Figure 17—Seed source and lifting date effects on first-year survival of Douglas-fir from Humboldt Nursery. The graphs show survival patterns that define wide and narrow lifting windows for sources in the Oregon Coast Range and Cascades, wider lifting windows for sources at higher elevations in the central and eastern Klamath Mountains, and stability of lifting windows for sources in the central and southern Klamath Mountains. Brackets indicate least significant difference ($p = 0.05$).

Oregon Coast Range. Moreover, the chilling that repeated sources received before their windows opened often differed by 50 percent or more.

Greater chilling was associated with earliest first safe dates for source CH from the southern Oregon Coast Range and sources GQ and HA from the western and southern Klamath Mountains, but with latest first safe dates for sources HC and OK from the central and eastern Klamath Mountains.

Autumn dormancy of Douglas-fir in Humboldt Nursery is induced by moderate water stress in late summer, by the seasonal decrease in photoperiod, and sometimes by cold weather. The chilling that most seedlings get before their lifting windows open is minimal. At least one-fourth of the sources assessed were safely lifted for cold storage with fewer than 400 hours of chilling, and three-fourths were safely lifted and stored with fewer than 800 hours. Cumulative cold exposure in the 1977-78 lifting season did not reach 800 hours until February (*fig. 12*), after every lifting window had already opened (*table 3*).

Lifting Windows and Tree Growth

Seed source lifting windows were confidently accepted by Humboldt's clientele after the field tests of repeated sources proved that the windows were stable (*table 4*). Confirmation was obtained for coastal and inland regions, specifically sources AL 252.10 and CH 082.25 in the northern and southern Oregon Coast Range, source KI 390.20 (1-0) in the North Coast Range, and sources GQ 301.30, HC 301.30, OK 321.30, OK 321.40, and HA 312.25 in the western, central, eastern, and southern Klamath Mountains (*table 3*).

After seeing the first-year results, cooperators promptly wanted to know if 2-year survivals or growth might narrow the source lifting windows. Specifically, will seedlings lifted in the middle of the window survive and grow better than those lifted near its limits, just after the window opens or just before it closes? Analyses of growth after 2 to 5 years in 47 tests in western Oregon and northern California indicate that the precise answer is almost never. The practical answer is a confident, universal **no** (*table 5*).

Source lifting windows are defined by first-year field survival, and neither 2-year survival nor growth provides any useful refinement. Problems on the planting site explained practically all of the second-year mortality, and 2-year survivals showed the same lifting windows as 1-year survivals. Similarly, 2-year growth never differed significantly ($p = 0.05$) among lifts within any source window, except in the tests of inland sources AL 252.10 and AL 252.05 in the northern Oregon Coast Range (see later).

Lifting date effects on seedling growth on the planting site were meaningfully evaluated in a total of 22 tests in the Oregon Coast Range, the Oregon Cascades, and the Klamath Mountains of Oregon and California. Because nursery effects are obliterated when new growth is suppressed or eaten, meaningful evaluations were possible only where the plantings were protected or had fortuitously escaped tough competition and browse damage.

In 10 tests situated in known elk or deer areas, planted seedlings were protected with diamond-mesh vexar tubes. The tubes were 3 to 4 inches (7 to 10 cm) in diameter, and were slipped over the seedlings and tied to lath, dowel, or bamboo stakes. Tubes used in coastal regions were 30 inches (76 cm) tall, and were installed in the tests of sources HE 053.10, AL 252.10, AL 252.05, AL 061.05, MA 062.10, PO 072.25, and CH 082.25 79 in the Oregon Coast Range. Tubes used in inland regions were 20 inches (51 cm) tall, and were installed in the tests of sources GA 51 1 .30, GA 512.25, and SC 322.40 79 in the northern and eastern Klamath Mountains.

In 12 other tests, seedlings were lightly browsed or were recovering rapidly from moderate browse damage. Tests in the lightly browsed category included source MK 472.45 in the Oregon Cascades and sources OR 302.30, HC 301.50, HC 301.30 77, 78, 79; UK 301.20, UK 302.44, SA 311.40, and OK 321.40 79 in the western, central, and eastern Klamath Mountains. Tests in the recovery category included sources ST 491.30 and TI 492.30 in the Oregon Cascades.

Seedlings lifted within the source window grew uniformly, and often grew more in height and stem diameter than seedlings lifted outside the window (*fig. 18*). Significant differences ($p = 0.05$) between lifts within the window were sometimes detected after the first growing season on the planting site, but most of these differences were minor and vanished the second year. The only notable exceptions were found in the tests of inland sources AL 252.10 and AL 252.05 in the northern Oregon Coast Range. Between lifts within the window, tree heights differed by up to 18 percent after 2 years, and still differed by up to 14 percent after 4 years (*table 5*).

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Oregon Coast Range, N						
HE 053.10 79 (May 1)⁴						
1-yr height, <i>cm</i>	41.0	46.3	46.3	46.0	43.2	2.83
leader, <i>cm</i>	8.3	13.7	12.6	14.7	13.3	1.93
survival, <i>pct</i>	79	99	99	97	97	7.9
2-yr height, <i>cm</i>	72.2	87.5	85.7	88.6	82.7	7.07
leader, <i>cm</i>	37.7	46.3	44.6	46.3	44.1	4.61
diam, <i>mm</i>	11.0	13.7	14.1	14.4	13.4	1.2
survival, <i>pct</i>	77	99	99	97	97	7.8
WA 061.10 77 (Apr 15)⁵						
2-yr height, <i>cm</i>	27.2	29.7	35.7	33.5	31.0	5.34
leader, <i>cm</i>	15.1	17.9	20.4	18.3	17.4	4.58
diam, <i>mm</i>	7.2	9.1	8.6	8.5	8.3	1.82
survival, <i>pct</i>	17	34	37	34	58	13.7
4-yr height, <i>cm</i>	88.8	87.7	74.6	74.3	76.3	24.4
leader, <i>cm</i>	44.9	43.4	34.9	33.7	36.9	13.0
diam, <i>mm</i>	16.6	18.7	17.0	15.7	15.8	4.27
survival, <i>pct</i>	13	29	34	33	51	13.6
AL 252.10 77 (Apr 21)⁴						
2-yr height, <i>cm</i>	68.7	67.2	79.3	75.9	72.2	7.84
leader, <i>cm</i>	36.5	33.9	40.2	39.0	35.1	5.17
diam, <i>mm</i>	10.0	10.0	11.7	11.1	10.9	1.32
survival, <i>pct</i>	56	89	90	88	94	9.7
3-yr height, <i>cm</i>	106.7	105.8	122.6	113.5	111.7	10.7
leader, <i>cm</i>	43.8	42.6	49.1	42.7	45.4	4.63
diam, <i>mm</i>	15.1	15.3	17.8	17.4	17.1	1.58
survival, <i>pct</i>	56	89	90	88	93	10.0
4-yr height, <i>cm</i>	177.1	170.4	188.7	182.0	179.6	14.0
leader, <i>cm</i>	72.6	67.5	72.1	71.2	70.1	6.29
diam, <i>mm</i>	21.9	22.4	26.6	25.1	24.2	2.27
survival, <i>pct</i>	56	89	89	88	93	10.1
AL 252.05 78 (Apr 13)⁴						
1-yr height, <i>cm</i>	35.8	41.8	48.2	48.3	42.2	4.15
leader, <i>cm</i>	13.9	20.2	24.5	25.1	19.5	3.63
diam, <i>mm</i>	5.0	5.9	6.7	7.3	6.1	.62
survival, <i>pct</i>	88	96	99	100	100	7.5
2-yr height, <i>cm</i>	67.6	78.2	91.7	91.9	81.2	5.66
leader, <i>cm</i>	40.2	44.2	50.9	53.2	45.9	4.79
diam, <i>mm</i>	11.2	12.4	14.8	14.5	13.3	1.22
survival, <i>pct</i>	86	95	99	99	100	7.5
3-yr height, <i>cm</i>	120.2	133.6	153.6	153.2	139.8	9.36
leader, <i>cm</i>	57.3	60.2	67.0	67.2	62.9	5.62
diam, <i>mm</i>	18.2	19.4	22.0	22.3	20.4	1.60
survival, <i>pct</i>	86	95	99	99	100	7.5
4-yr height, <i>cm</i>	189.2	206.1	234.6	228.3	210.4	11.7
leader, <i>cm</i>	72.4	75.3	81.7	76.9	75.1	4.63
diam, <i>mm</i>	29.4	31.9	34.3	36.6	35.0	3.44
survival, <i>pct</i>	83	95	99	99	100	7.7
AL 061.05 79 (Apr 10)⁴						
1-yr height, <i>cm</i>	33.4	35.4	38.4	36.4	35.8	2.01
leader, <i>cm</i>	5.5	7.1	8.6	8.9	9.1	1.01
diam, <i>mm</i>	4.6	5.1	5.4	5.5	5.9	.44
survival, <i>pct</i>	82	100	98	98	98	6.8

¹ Seedlings were stored at 1°C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir—continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Oregon Coast Range, N						
AL 061.05 79 (Apr 10)⁴						
2-yr height, <i>cm</i>	51.7	59.0	64.2	66.0	64.8	5.41
leader, <i>cm</i>	22.4	26.4	30.1	31.7	31.2	4.81
diam, <i>mm</i>	7.7	9.2	9.8	10.0	10.0	.80
survival, <i>pct</i>	79	98	98	98	97	8.0
3-yr height, <i>cm</i>	88.9	98.2	103.3	103.9	103.4	10.5
leader, <i>cm</i>	38.0	40.8	41.4	41.4	41.2	5.90
diam, <i>mm</i>	12.2	14.4	15.2	15.0	15.7	1.55
survival, <i>pct</i>	77	98	98	98	97	8.3
4-yr height, <i>cm</i>	116.4	130.2	135.7	137.5	140.4	13.5
leader, <i>cm</i>	28.4	31.2	33.3	33.4	36.9	4.93
diam, <i>mm</i>	18.4	22.1	24.0	23.6	24.0	2.56
survival, <i>pct</i>	78	98	98	98	97	8.2
MA 062.10 79 (Apr 24)⁴						
2-yr height, <i>cm</i>	68.8	70.9	73.9	74.1	75.2	7.02
leader, <i>cm</i>	38.0	39.4	39.1	41.8	42.7	5.96
diam, <i>mm</i>	14.9	15.2	15.5	16.1	16.5	1.76
survival, <i>pct</i>	77	83	94	91	93	9.6
3-yr height, <i>cm</i>	111.2	108.3	111.4	112.0	118.0	10.9
leader, <i>cm</i>	49.0	44.3	45.5	46.1	51.0	5.72
survival, <i>pct</i>	77	83	94	90	93	9.7
Oregon Coast Range, S						
PO 072.25 79 (Apr 26)⁴						
1-yr height, <i>cm</i>	25.0	28.7	28.9	29.6	29.7	2.73
leader, <i>cm</i>	3.2	4.4	5.1	5.5	5.8	1.34
survival, <i>pct</i>	42	90	97	96	96	9.5
2-yr height, <i>cm</i>	36.1	48.0	48.7	54.3	54.3	6.26
leader, <i>cm</i>	12.8	19.9	22.8	24.9	25.1	4.22
diam, <i>mm</i>	6.6	9.0	9.8	11.3	10.9	1.32
survival, <i>pct</i>	41	88	96	93	94	10.3
GO 081.20 79 (Apr 5)⁵						
2-yr height, <i>cm</i>	30.8	29.2	28.8	30.3	29.3	3.39
leader, <i>cm</i>	3.1	3.1	2.7	2.7	2.9	.84
diam, <i>mm</i>	5.7	5.7	4.6	5.5	5.1	1.41
survival, <i>pct</i>	25	55	67	58	49	17.1
CH 082.25 76 (Apr 23)⁵						
3-yr height, <i>cm</i>	—	50.1	51.8	55.1	50.2	6.59
leader, <i>cm</i>	—	11.6	15.1	13.1	13.6	4.64
diam, <i>mm</i>	—	16.4	15.8	18.2	16.3	2.38
survival, <i>pct</i>	0	26	69	93	84	10.0
4-yr height, <i>cm</i>	—	72.0	75.0	79.9	76.0	10.4
leader, <i>cm</i>	—	24.8	26.8	27.2	29.2	6.09
diam, <i>mm</i>	—	24.2	23.2	25.4	24.4	2.93
survival, <i>pct</i>	0	26	69	92	84	9.9
5-yr height, <i>cm</i>	—	118.5	132.9	139.2	134.1	15.8
leader, <i>cm</i>	—	50.3	60.1	61.8	61.0	6.65
diam, <i>mm</i>	—	31.5	32.8	33.2	31.0	4.02
survival, <i>pct</i>	0	26	69	92	84	9.9
CH 082.25 77 (Mar 15)⁵						
2-yr height, <i>cm</i>	—	26.6	25.9	29.0	29.8	3.53
leader, <i>cm</i>	—	6.6	6.5	6.5	6.0	2.03
diam, <i>mm</i>	—	6.0	6.0	7.0	6.8	.92
survival, <i>pct</i>	10.0	52.5	62.5	73.8	75.0	17.7

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir—continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Oregon Coast Range, S						
CH 082.25 78 (Apr 6) ⁵						
1-yr height, <i>cm</i>	24.4	23.8	26.2	27.1	26.1	1.95
leader, <i>cm</i>	4.5	4.8	5.3	6.2	5.1	.98
diam, <i>mm</i>	6.3	5.9	6.6	7.6	7.4	.74
survival, <i>pct</i>	70	64	67	88	89	14.4
3-yr height, <i>cm</i>	48.4	48.8	52.7	53.6	52.3	6.00
leader, <i>cm</i>	22.1	23.4	25.6	23.9	23.3	3.44
diam, <i>mm</i>	14.1	13.8	15.2	17.0	17.1	1.56
survival, <i>pct</i>	70	64	67	86	87	14.7
CH 082.25 79 (Apr 23) ⁶						
1-yr height, <i>cm</i>	26.6	33.6	32.6	30.2	33.1	2.77
leader, <i>cm</i>	4.9	6.2	6.4	5.5	6.4	1.18
diam, <i>mm</i>	5.1	6.0	6.4	5.2	5.9	.72
survival, <i>pct</i>	52	84	93	89	93	9.5
2-yr height, <i>cm</i>	44.1	49.4	51.8	43.8	50.4	7.24
leader, <i>cm</i>	18.8	18.2	20.2	15.0	18.3	5.20
diam, <i>mm</i>	9.7	11.4	11.6	9.5	10.8	1.54
survival, <i>pct</i>	50	81	93	87	92	10.6
CH 082.10 79 (Apr 23) ⁵						
1-yr height, <i>cm</i>	33.5	33.2	34.1	37.6	34.3	2.78
leader, <i>cm</i>	3.8	4.8	5.9	6.0	6.0	1.06
diam, <i>mm</i>	5.4	5.9	5.9	6.2	6.2	.60
survival, <i>pct</i>	43	87	95	91	83	9.5
CH 082.10 79 (Apr 23) ⁵						
2-yr height, <i>cm</i>	37.2	41.7	43.5	42.7	40.7	3.68
leader, <i>cm</i>	6.1	9.1	9.3	8.1	8.2	1.51
survival, <i>pct</i>	43	85	95	91	82	10.1
Klamath Mtns, N						
GA 511.30 79 (Apr 14) ⁴						
2-yr height, <i>cm</i>	37.7	39.8	41.4	37.5	37.5	4.31
leader, <i>cm</i>	8.8	8.4	9.3	7.3	7.9	2.45
diam, <i>mm</i>	6.2	6.5	6.4	6.3	6.4	.64
survival, <i>pct</i>	73	79x	80	72	89	14.7
GA 512.25 79 (Apr 14) ⁴						
2-yr height, <i>cm</i>	38.7	39.8	38.8	40.0	39.4	3.53
leader, <i>cm</i>	10.6	11.8	9.8	9.8	9.9	3.03
diam, <i>mm</i>	6.4	7.0	6.7	7.1	7.0	.69
survival, <i>pct</i>	71	85	85	85	80	11.7
IL 512.35 78 (May 16) ⁵						
1-yr height, <i>cm</i>	25.0	27.7	26.3	25.0	27.6	3.78
leader, <i>cm</i>	4.0	4.5	4.7	4.5	4.5	.68
diam, <i>mm</i>	4.1	4.4	4.2	4.6	4.4	.66
survival, <i>pct</i>	36	59	55	61	44	16.3
2-yr height, <i>cm</i>	24.9	25.8	24.4	22.9	26.7	5.23
leader, <i>cm</i>	5.7	7.3	7.2	5.4	7.3	2.31
survival, <i>pct</i>	32	38	41	48	36	17.5
IL 512.40 79 (Apr 24) ⁵						
1-yr height, <i>cm</i>	25.7	24.3	23.9	23.6	26.0	—
leader, <i>cm</i>	3.2	3.2	3.7	3.2	4.3	—
survival, <i>pct</i>	85	73	61	71	67	17.7

¹ Seedlings were stored at 1°C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

⁶ Protected after damage by deer; see *table 8*.

⁷ Planted on infertile soil on a ridgetop (source GQ) or on ultramafic soil (sources OK, SC).

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir—continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Klamath Mtns, N						
IL 512.40 79 (Apr 24) ⁵						
2-yr height, <i>cm</i>	26.7	24.9	26.7	24.5	28.0	—
leader, <i>cm</i>	5.1	4.4	5.7	4.2	5.8	—
diam, <i>mm</i>	6.9	6.4	6.6	6.2	7.1	—
survival, <i>pct</i>	64	48	48	47	47	—
Klamath Mtns, W						
GQ 301.30 77 (Apr 25) ⁶						
2-yr height, <i>cm</i>	22.0	24.3	22.1	24.1	22.4	2.93
leader, <i>cm</i>	3.8	3.8	3.2	3.1	3.1	.89
diam, <i>mm</i>	5.6	6.6	5.5	5.8	5.7	.77
survival, <i>pct</i>	64	90	80	85	73	10.4
4-yr height, <i>cm</i>	31.9	36.3	31.0	34.0	30.4	4.58
leader, <i>cm</i>	7.5	7.2	6.5	6.6	6.2	1.83
diam, <i>mm</i>	6.8	7.9	6.5	6.9	6.7	.91
survival, <i>pct</i>	63	87	77	87	69	11.2
GQ 301.30 78 (May 1) ⁷						
1-yr height, <i>cm</i>	18.9	19.6	19.7	21.1	20.7	3.02
leader, <i>cm</i>	5.3	6.5	7.5	7.4	6.3	.66
diam, <i>mm</i>	5.0	5.0	4.9	5.2	5.1	.52
survival, <i>pct</i>	83	96	98	99	97	7.8
3-yr height, <i>cm</i>	21.7	22.5	22.6	23.7	24.4	3.39
leader, <i>cm</i>	2.3	2.8	2.3	2.2	2.8	.94
diam, <i>mm</i>	4.7	4.5	4.9	5.1	5.1	.62
survival, <i>pct</i>	82	90	95	93	91	8.6
OR 302.30 79 (Apr 4)						
1-yr height, <i>cm</i>	35.8	39.7	41.2	40.8	37.9	3.49
leader, <i>cm</i>	3.9	4.2	4.4	4.6	5.0	.75
survival, <i>pct</i>	67	73	81	78	88	11.4
2-yr height, <i>cm</i>	44.2	46.9	48.4	48.6	49.4	4.31
leader, <i>cm</i>	11.2	11.4	12.1	13.0	13.2	2.89
diam, <i>mm</i>	11.0	11.3	12.1	12.9	13.4	1.04
survival, <i>pct</i>	59	66	71	67	83	18.7
Klamath Mtns, central						
HC 301.50 79 (May 23)						
1-yr height, <i>cm</i>	21.7	24.5	22.5	22.7	24.2	2.19
leader, <i>cm</i>	6.6	7.4	7.6	7.4	7.8	.66
survival, <i>pct</i>	88	97	98	97	100	5.1
2-yr height, <i>cm</i>	29.0	32.7	30.9	30.0	31.6	3.06
leader, <i>cm</i>	8.6	9.1	8.6	8.7	8.6	1.37
diam, <i>mm</i>	7.3	8.6	7.7	7.9	8.1	.81
survival, <i>pct</i>	80	94	80	82	94	10.8
HC 301.30 77 (Mar 10)						
2-yr height, <i>cm</i>	29.9	34.4	31.2	30.5	29.7	3.06
leader, <i>cm</i>	10.0	9.9	11.6	10.8	11.5	1.85
survival, <i>pct</i>	38	80	92	93	94	10.9
3-yr height, <i>cm</i>	46.4	51.6	51.9	49.4	48.8	4.89
leader, <i>cm</i>	17.5	18.2	21.4	18.5	19.6	2.50
diam, <i>mm</i>	13.0	14.3	14.9	13.6	13.2	1.13
survival, <i>pct</i>	38	80	92	93	94	10.9
4-yr height, <i>cm</i>	76.8	82.9	88.5	82.6	83.0	8.66
leader, <i>cm</i>	29.2	31.8	36.8	34.2	34.7	.90
diam, <i>mm</i>	19.2	21.5	22.3	20.9	20.6	1.84
survival, <i>pct</i>	38	80	92	93	94	10.9

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Klamath Mtns, central						
HC 301.30 78 (Apr 28)						
1-yr height, <i>cm</i>	20.2	20.8	22.5	23.4	22.3	2.86
leader, <i>cm</i>	5.4	5.6	6.4	6.0	5.6	.66
survival, <i>pct</i>	64	90	95	89	91	10.7
2-yr height, <i>cm</i>	29.6	30.4	33.3	33.8	33.4	3.76
leader, <i>cm</i>	11.6	11.1	12.0	11.8	12.3	1.70
diam, <i>mm</i>	6.4	6.8	6.9	6.7	6.8	.73
survival, <i>pct</i>	63	86	93	87	91	11.1
3-yr height, <i>cm</i>	48.6	51.5	55.2	54.4	55.3	5.77
leader, <i>cm</i>	18.6	19.6	21.8	19.7	21.2	2.87
diam, <i>mm</i>	10.8	11.5	12.5	12.0	12.4	1.26
survival, <i>pct</i>	63	84	90	86	90	11.4
HC 301.30 79 (Mar 20)						
1-yr height, <i>cm</i>	39.3	39.2	39.7	40.4	41.7	2.73
leader, <i>cm</i>	5.5	5.4	5.6	5.7	5.7	.65
survival, <i>pct</i>	59	89	93	98	91	11.2
2-yr height, <i>cm</i>	54.5	59.9	55.5	57.6	55.3	4.74
leader, <i>cm</i>	13.9	15.7	13.1	13.2	12.3	3.42
diam, <i>mm</i>	12.1	13.6	12.3	13.3	11.9	1.39
survival, <i>pct</i>	58	87	91	96	88	11.0
UK 301.20 79 (Mar 23)						
1-yr height, <i>cm</i>	36.4	40.1	41.3	42.1	38.4	3.93
leader, <i>cm</i>	4.1	4.8	5.9	5.1	5.3	.74
survival, <i>pct</i>	54	80	90	93	92	11.5
2-yr height, <i>cm</i>	46.2	51.5	52.9	53.4	47.7	6.32
leader, <i>cm</i>	9.8	11.3	11.5	11.3	9.3	4.19
diam, <i>mm</i>	8.9	9.7	10.4	10.0	9.6	1.14
survival, <i>pct</i>	52	78	87	88	89	11.6
UK 302.44 79 (Mar 24)						
1-yr height, <i>cm</i>	20.5	21.9	23.7	22.1	22.2	1.68
leader, <i>cm</i>	5.1	6.2	6.0	6.1	5.6	.57
survival, <i>pct</i>	87	95	98	97	96	6.2
2-yr height, <i>cm</i>	34.0	32.6	34.9	33.7	32.5	4.14
leader, <i>cm</i>	13.6	10.7	11.2	11.7	10.4	3.28
diam, <i>mm</i>	9.7	9.4	9.9	9.9	9.5	1.14
survival, <i>pct</i>	80	90	93	91	92	8.6
UK 311.40 79 (Apr 9) ⁵						
1-yr height, <i>cm</i>	34.1	33.1	33.2	33.2	33.4	3.48
leader, <i>cm</i>	3.4	4.3	5.2	4.4	5.0	.65
survival, <i>pct</i>	30	71	90	71	74	16.3
2-yr height, <i>cm</i>	41.7	40.1	39.7	39.3	39.1	3.78
diam, <i>mm</i>	8.7	9.1	9.4	9.1	9.6	.94
survival, <i>pct</i>	16	51	75	47	53	16.0
SA 311.40 79 (Mar 25)						
1-yr height, <i>cm</i>	37.5	39.0	37.6	37.2	37.0	3.82
leader, <i>cm</i>	4.8	5.9	5.7	5.9	6.2	.64
survival, <i>pct</i>	87	97	96	99	100	6.4
2-yr height, <i>cm</i>	43.2	44.5	44.4	44.5	46.5	4.34
leader, <i>cm</i>	8.8	10.1	10.0	10.0	11.8	1.87
diam, <i>mm</i>	9.2	9.9	9.9	10.6	11.0	.94
survival, <i>pct</i>	82	93	93	98	98	8.4

¹ Seedlings were stored at 1 °C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference (p = 0.05).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

⁶ Protected after damage by deer; see *table 8*.

⁷ Planted on infertile soil on a ridgetop (source GO) or on ultramafic soil (sources OK, SC).

⁸ Grasshoppers damaged most of the seedlings in blocks 1 to 4.

¹ Seedlings were stored at 1 °C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

⁶ Protected after damage by deer; see *table 8*.

⁷ Planted on infertile soil on a ridgetop (source GO) or on ultramafic soil (sources OK, SC).

⁸ Grasshoppers damaged most of the seedlings in blocks 1 to 4.

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir-continued'

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Klamath Mtns, central						
SA 311.40 79 (Mar 25)						
3-yr height, <i>cm</i>	54.8	59.0	59.2	60.4	64.4	5.64
leader, <i>cm</i>	13.4	15.2	15.4	17.0	19.6	2.67
survival, <i>pct</i>	77	90	88	90	97	11.3
Klamath Mtns, E						
OK 321.40 77 (May 4) ⁷						
2-yr height, <i>cm</i>	—	30.0	31.1	31.6	28.2	3.73
leader, <i>cm</i>	—	5.2	6.1	6.8	6.2	1.38
survival, <i>pct</i>	1	34	48	63	40	18.0
4-yr height, <i>cm</i>	—	42.5	45.2	49.3	45.2	5.68
leader, <i>cm</i>	—	6.9	5.5	8.1	7.5	2.67
diam, <i>mm</i>	—	14.3	16.6	16.6	15.1	2.04
survival, <i>pct</i>	1	31	36	48	34	16.0
OK 321.40 78 (Apr 11) ⁵						
1-yr height, <i>cm</i>	18.9	21.5	24.4	21.8	19.3	2.64
leader, <i>cm</i>	5.1	5.4	5.5	5.3	4.6	.42
survival, <i>pct</i>	92	88	88	95	90	7.4
2-yr height, <i>cm</i>	23.6	24.6	26.8	24.6	24.0	2.79
diam, <i>mm</i>	8.4	9.2	9.5	9.7	9.0	1.83
survival, <i>pct</i>	90	88	87	93	87	8.8
3-yr height, <i>cm</i>	40.4	40.4	42.6	39.6	40.7	3.99
leader, <i>cm</i>	19.1	18.0	19.0	17.5	19.4	1.98
diam, <i>mm</i>	10.9	11.3	12.0	11.6	11.5	.9
survival, <i>pct</i>	90	88	87	93	87	8.8
OK 321.40 79 (Apr 5)						
1-yr height, <i>cm</i>	24.6	26.3	27.7	29.0	27.4	2.54
leader, <i>cm</i>	6.1	7.0	7.7	8.1	7.2	.73
survival, <i>pct</i>	82	98	95	97	96	7.5
2-yr height, <i>cm</i>	39.4	43.7	44.6	46.8	44.0	4.53
leader, <i>cm</i>	16.6	18.8	18.4	19.7	19.4	2.47
diam, <i>mm</i>	7.4	8.4	8.5	8.4	7.9	1.04
survival, <i>pct</i>	81	97	95	97	96	8.3
SC 322.40 78 (May 3) ⁵						
3-yr height, <i>cm</i>	20.5	22.5	25.5	21.2	23.6	6.05
leader, <i>cm</i>	8.3	8.9	8.3	7.3	7.5	2.70
diam, <i>mm</i>	5.9	6.7	7.0	6.5	7.3	1.37
survival, <i>pct</i>	27	59	58	49	54	13.5
SC 322.40 79 (May 15) ^{4, 7}						
2-yr height, <i>cm</i>	—	24.4	25.0	25.7	24.4	3.25
leader, <i>cm</i>	—	6.1	6.1	6.1	6.3	1.99
diam, <i>mm</i>	—	5.9	7.1	7.5	6.3	1.13
survival, <i>pct</i>	15	61	78	75	58	15.2
(blocks 5 to 10 only) ⁸						
height, <i>cm</i>	21.7	27.0	28.3	28.3	27.2	4.39
leader, <i>cm</i>	6.2	7.4	7.5	7.5	7.2	2.71
diam, <i>mm</i>	6.9	6.7	8.2	8.7	7.1	1.95
survival, <i>pct</i>	23.3	83.3	95.0	86.7	76.7	12.4

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Klamath Mtns, S						
BI 312.40 77 (Mar 17) ⁵						
2-yr height, <i>cm</i>	24.0	24.3	24.8	25.7	24.3	3.06
leader, <i>cm</i>	4.0	4.2	4.1	4.5	4.3	1.01
survival, <i>pct</i>	41	74	79	67	70	14.3
3-yr height, <i>cm</i>	30.6	30.8	30.3	31.8	31.3	3.19
leader, <i>cm</i>	6.8	6.6	6.6	7.2	7.6	1.30
diam, <i>mm</i>	9.3	9.7	10.0	10.1	10.4	1.05
survival, <i>pct</i>	35	69	75	66	63	14.7
4-yr height, <i>cm</i>	39.3	39.9	39.6	41.9	40.8	4.60
leader, <i>cm</i>	9.9	7.6	8.9	10.1	9.4	2.50
diam, <i>mm</i>	11.8	12.1	12.2	12.8	12.9	1.66
survival, <i>pct</i>	34	67	74	66	61	15.4
BI 312.30 78 (May 17) ⁵						
2-yr height, <i>cm</i>	26.5	28.9	28.4	30.2	30.6	2.15
leader, <i>cm</i>	5.8	5.9	6.5	6.4	6.6	.78
diam, <i>mm</i>	9.0	9.3	9.6	9.5	9.3	.63
survival, <i>pct</i>	85	85	94	90	95	9.2
3-yr height, <i>cm</i>	33.0	35.2	36.1	36.0	36.2	3.00
leader, <i>cm</i>	10.2	10.7	10.8	9.5	9.8	1.81
diam, <i>mm</i>	12.1	12.9	13.2	13.0	12.7	.91
survival, <i>pct</i>	84	85	94	90	95	9.8
HA 312.25 78 (Apr 27) ⁵						
2-yr height, <i>cm</i>	21.0	21.6	19.2	24.6	23.2	2.29
leader, <i>cm</i>	2.6	1.5	1.0	1.3	2.7	1.60
diam, <i>mm</i>	6.1	6.2	6.3	6.6	7.2	.62
survival, <i>pct</i>	65	81	89	82	85	13.0
N Coast Range, coastal						
KI 390.25 77 (Mar 18) ⁵						
2-yr height, <i>cm</i>	—	45.5	46.4	35.1	40.9	5.36
leader, <i>cm</i>	—	5.3	5.2	6.8	5.7	1.98
diam, <i>mm</i>	—	6.6	7.6	7.4	7.4	1.52
survival, <i>pct</i>	3.3	44.4	57.8	60.0	65.5	16.7
3-yr height, <i>cm</i>	—	57.3	55.1	48.0	50.0	6.86
leader, <i>cm</i>	—	10.7	11.3	11.5	12.0	3.34
diam, <i>mm</i>	—	13.6	13.3	12.8	13.6	2.20
survival, <i>pct</i>	3.3	44.4	57.8	62.2	61.1	18.4
4-yr height, <i>cm</i>	—	71.9	67.3	61.1	64.8	8.86
leader, <i>cm</i>	—	21.2	18.6	20.7	21.3	4.65
diam, <i>mm</i>	—	19.2	17.8	18.2	17.7	2.47
survival, <i>pct</i>	2.2	44.4	56.7	62.2	62.2	18.2
KI 390.20 79 (Mar 30) ⁵						
1-yr height, <i>cm</i>	29.7	30.0	24.9	30.5	24.6	3.73
leader, <i>cm</i>	3.3	3.8	3.7	3.3	3.3	.61
diam, <i>mm</i>	5.9	6.0	5.4	5.9	5.3	.56
survival, <i>pct</i>	79	88	85	90	87	10.6
2-yr height, <i>cm</i>	32.7	33.7	28.3	33.1	28.1	3.86
leader, <i>cm</i>	4.1	3.9	4.2	3.7	3.4	1.38
diam, <i>mm</i>	7.9	8.5	7.3	8.3	7.2	.76
survival, <i>pct</i>	67	79	73	81	69	11.0
3-yr height, <i>cm</i>	40.2	43.0	35.8	41.4	36.4	4.92
leader, <i>cm</i>	7.0	6.8	6.7	5.8	5.9	1.42
diam, <i>mm</i>	13.8	13.7	12.9	13.6	12.4	1.00
survival, <i>pct</i>	63	72	67	69	59	13.6

¹ Seedlings were stored at 1 °C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
N Coast Range, coastal						
KI 390.20 79 (Mar 30)⁵						
7-yr height, <i>cm</i>	79.2	80.5	71.4	76.6	72.0	10.2
leader, <i>cm</i>	19.4	18.7	16.8	19.2	20.4	5.17
diam, <i>mm</i>	21.0	21.7	20.1	21.8	19.3	1.94
survival, <i>pct</i>	62	72	67	69	59	13.6
RE 093.25 78 (Apr 6)⁵						
1-yr height, <i>cm</i>	30.5	28.1	30.9	30.0	42.2	3.66
leader, <i>cm</i>	3.4	2.9	3.6	3.0	3.8	1.22
diam, <i>mm</i>	7.2	7.0	7.4	7.4	7.6	.98
survival, <i>pct</i>	20	69	82	75	86	16.9
2-yr height, <i>cm</i>	32.4	31.2	33.0	31.8	44.7	3.98
leader, <i>cm</i>	5.1	5.1	4.9	4.9	5.6	1.53
diam, <i>mm</i>	11.1	11.1	11.8	11.4	13.6	1.12
survival, <i>pct</i>	15	61	73	65	81	17.5
3-yr height, <i>cm</i>	45.4	39.3	40.1	40.4	53.0	6.40
leader, <i>cm</i>	13.4	12.5	12.7	12.4	13.2	2.19
diam, <i>mm</i>	13.8	13.1	14.0	13.9	15.6	1.56
survival, <i>pct</i>	13	59	71	60	80	17.3
N Coast Range, inland						
MR 303.45 79 (Apr 14)⁵						
1-yr height, <i>cm</i>	27.2	26.2	24.8	26.5	25.1	3.18
leader, <i>cm</i>	2.9	3.4	3.9	4.0	3.9	.80
survival, <i>pct</i>	40	55	74	75	66	13.6
2-yr height, <i>cm</i>	30.4	28.6	26.4	27.9	28.5	4.15
leader, <i>cm</i>	3.5	3.1	2.8	3.1	3.4	1.04
diam, <i>mm</i>	7.0	7.8	7.0	7.3	7.2	.87
survival, <i>pct</i>	29	50	62	65	59	15.0
MR 340.36 78 (Apr 24)⁵						
1-yr height, <i>cm</i>	22.4	23.8	23.6	25.5	23.3	2.46
leader, <i>cm</i>	4.4	5.1	5.7	5.6	5.2	.68
survival, <i>pct</i>	64	74	88	92	91	13.0
2-yr height, <i>cm</i>	20.2	21.0	21.5	22.7	23.0	2.82
leader, <i>cm</i>	4.9	4.6	4.6	3.8	4.4	.88
diam, <i>mm</i>	6.5	6.8	6.8	7.1	7.7	.70
survival, <i>pct</i>	56	64	72	80	76	12.9
3-yr height, <i>cm</i>	26.1	26.1	28.9	29.4	30.8	4.65
leader, <i>cm</i>	4.4	4.8	4.8	5.4	6.5	1.66
diam, <i>mm</i>	8.5	8.4	7.9	8.5	9.3	1.11
survival, <i>pct</i>	51	56	65	69	66	15.8
Oregon Cascades, W						
MK 472.45 79 (Jun 19)						
1-yr height, <i>cm</i>	24.7	25.8	26.2	25.2	26.6	2.14
leader, <i>cm</i>	6.3	6.8	7.4	7.4	7.0	.92
diam, <i>mm</i>	5.1	5.3	5.4	5.3	5.8	.43
survival, <i>pct</i>	75	79	84	75	84	10.5
2-yr height, <i>cm</i>	34.6	37.1	38.1	37.4	37.1	3.65
leader, <i>cm</i>	12.6	13.2	14.8	14.9	12.7	2.67
diam, <i>mm</i>	9.4	10.7	10.8	11.6	10.5	1.44
survival, <i>pct</i>	60	64	76	66	67	10.8

Table 5—Growth and survival in field performance tests of 2-0 Douglas-fir-continued¹

Seed source ² (planting date)	Performance, by nursery lifting date					LSD ³
	Nov	Dec	Jan	Feb	Mar	
Oregon Cascades, W						
BL 472.30 77 (Apr 8) ⁵						
2-yr height, <i>cm</i>	24.8	23.6	24.6	24.7	21.5	3.41
leader, <i>cm</i>	9.6	11.2	10.2	11.2	10.0	2.75
diam, <i>mm</i>	6.6	6.6	6.9	6.7	6.1	.78
survival, <i>pct</i>	47	67	59	65	60	16.6
ST 491.30 79 (Apr 17) ⁵						
1-yr leader, <i>cm</i>	6.3	6.6	7.2	7.4	7.2	0.88
survival, <i>pct</i>	87	85	90	88	92	11.7
2-yr height, <i>cm</i>	26.0	25.9	31.9	29.2	31.7	4.71
leader, <i>cm</i>	8.9	10.5	13.5	10.4	11.1	3.42
survival, <i>pct</i>	78	76	85	79	86	18.7
GL 491.30 79 (Jun 5) ⁵						
1-yr height, <i>cm</i>	27.6	29.4	29.4	28.0	28.7	2.84
leader, <i>cm</i>	3.5	4.0	4.0	4.0	4.0	.56
survival, <i>pct</i>	60	85	92	89	87	13.0
2-yr height, <i>cm</i>	29.5	29.7	30.0	28.3	29.0	2.74
leader, <i>cm</i>	8.0	8.8	7.8	7.9	7.6	1.53
diam, <i>mm</i>	5.9	6.6	6.3	6.2	6.2	.56
survival, <i>pct</i>	52	78	91	85	86	12.5
TI 492.30 79 (Apr 16) ⁵						
1-yr height, <i>cm</i>	25.9	25.6	25.1	26.6	26.3	2.01
leader, <i>cm</i>	4.2	4.3	4.8	4.1	4.3	.89
diam, <i>mm</i>	6.2	6.1	6.2	6.6	6.7	.57
survival, <i>pct</i>	97	97	98	93	100	5.4
2-yr height, <i>cm</i>	34.2	34.4	34.7	34.7	34.5	3.65
leader, <i>cm</i>	10.3	10.5	11.8	10.3	9.8	1.85
diam, <i>mm</i>	9.0	8.8	9.3	9.6	9.3	.78
survival, <i>pct</i>	95	91	93	88	96	9.6
Sierra Nevada, N						
GR 523.45 77 (Apr 25) ⁶						
2-yr height, <i>cm</i>	—	24.0	20.8	25.0	26.9	4.28
leader, <i>cm</i>	—	5.5	6.4	6.1	7.4	2.02
diam, <i>mm</i>	—	8.4	7.7	8.9	9.1	1.12
survival, <i>pct</i>	0	30	58	69	64	14.0
3-yr height, <i>cm</i>	—	36.6	33.8	37.8	40.4	6.32
leader, <i>cm</i>	—	10.4	12.4	12.7	12.8	3.66
diam, <i>mm</i>	—	12.9	11.4	13.0	13.2	1.79
survival, <i>pct</i>	0	26	54	65	64	13.7
4-yr height, <i>cm</i>	—	52.0	48.2	53.1	56.7	10.8
leader, <i>cm</i>	—	13.2	13.9	16.6	18.5	6.50
diam, <i>mm</i>	—	16.3	15.2	16.6	17.3	3.03
survival, <i>pct</i>	0	26	54	65	64	13.7

¹ Seedlings were stored at 1 °C (34° F) and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 10*, and *table 3*.

³ Least significant difference ($p = 0.05$).

⁴ Protected immediately against deer, or elk (sources HE, AL, MA, PO).

⁵ Browsed repeatedly by deer, or elk (source WA); see *table 8*.

⁶ Protected after damage by deer; see *table 8*.

⁷ Planted on infertile soil on a ridgetop (source GO) or on ultramafic soil (sources OK, SC).

⁸ Grasshoppers damaged most of the seedlings in blocks 1 to 4.

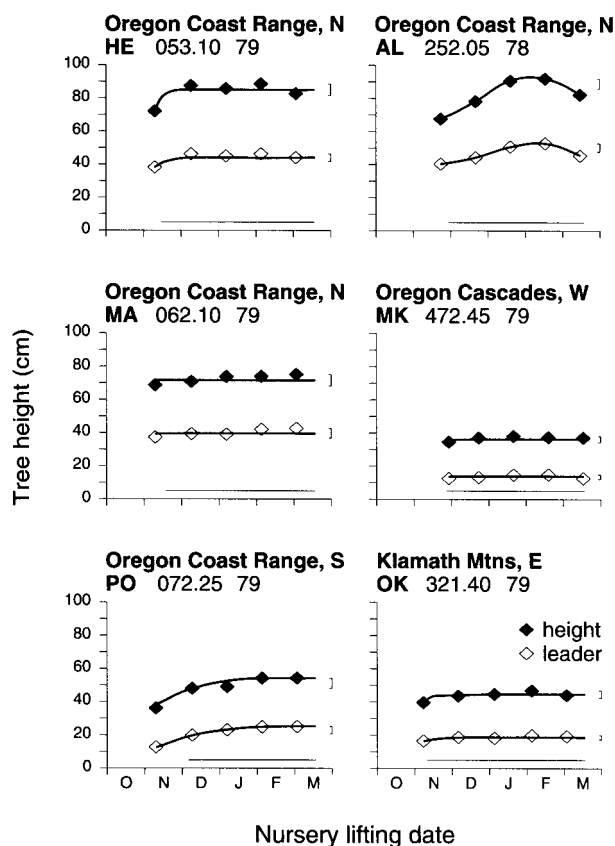


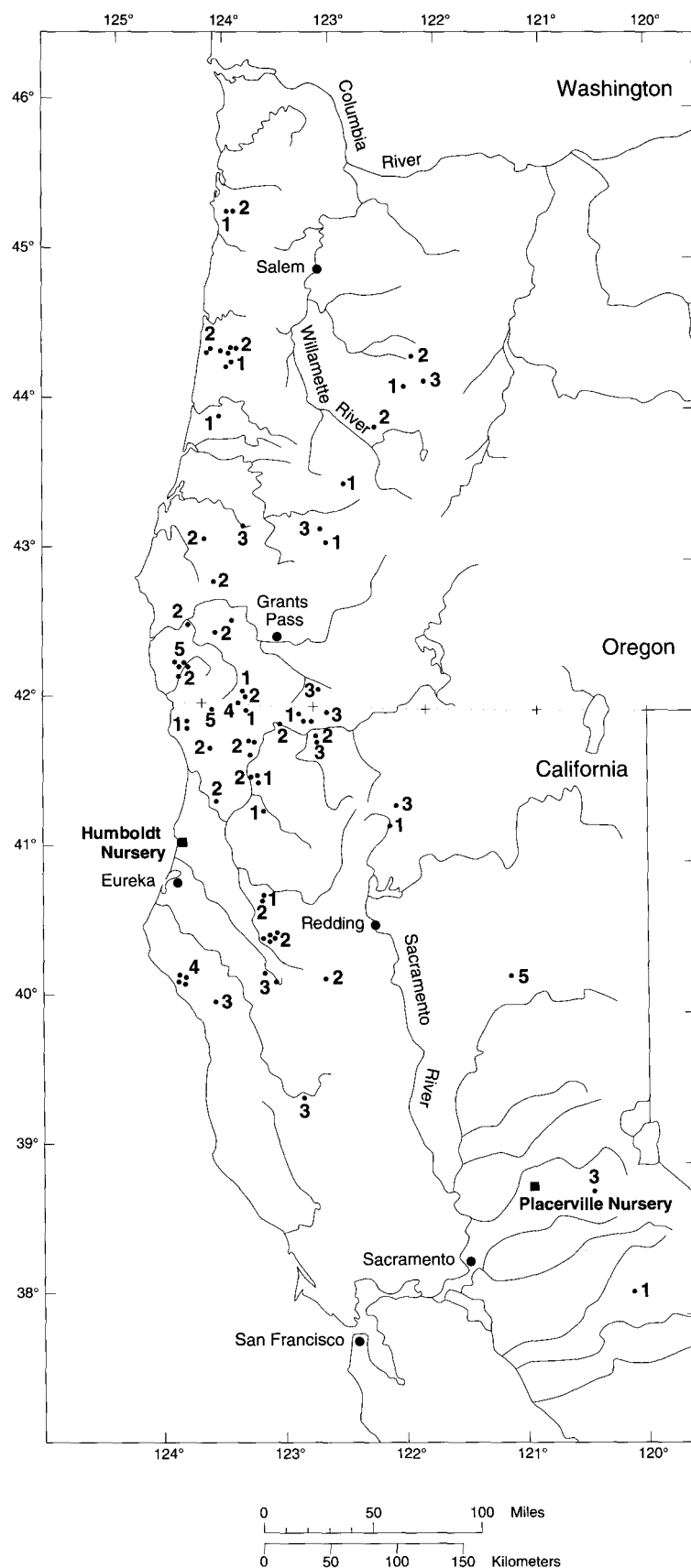
Figure 18—Seed source and lifting date effects on 2-year growth of Douglas-fir from Humboldt Nursery. The graphs show typical growth patterns in field performance tests of sources from the Oregon Coast Range, Oregon Cascades, and Klamath Mountains, and the unique pattern of an inland source from the northern Oregon Coast Range (top right). Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.

NURSERY MANAGEMENT GUIDES

Results of the seedling testing program proved conclusively that nursery schedules for autumn-winter lifting and cold storage of Douglas-fir for spring planting should be keyed to seed source. Seed source affects the development of seedling growth capacity and field survival potential, in the nursery and in cold storage. Because source effects are locked in the day seedlings are lifted, source lifting windows are the nursery's best guide to safe cold storage, and the clientele's best guide to planting stock quality.

For spring planting programs in western Oregon and northern California, Humboldt Nursery can safely lift seedlings for cold storage anytime from late autumn to early spring. By using the lifting windows determined for known sources, Humboldt can assign safe lifting times to untested sources from the same region. Sources with wide lifting windows permit exceptional flexibility in the harvest schedule because those seedlings can be lifted and stored anytime without sacrificing growth capacity and survival potential. Sources with narrow windows are the critical ones, and demand special attention from the nursery and clientele. Narrow-window sources should be lifted in midwinter to late winter to insure high survival potential at planting time.

Given the demonstrated ability to expand the lifting season up to 4 months, Humboldt is able to confine lifting operations to times when the soil and weather conditions are optimum or nearly so. Such conditions allow the nursery to control root damage and water stress, and thereby to secure high growth capacities and field survival potentials. Seedlings lifted outside the source window or when the soil is too wet or too cold are characterized by low growth capacity and poor survival potential, and the planting site environment is rarely forgiving.



Seed source¹

Oregon Coast Range, N

Siuslaw NF		
Hebo RD		
HE 053.20 83o	2	
HE 053.10 79	1	
Waldport RD		
WA 061.20 83o	2	
WA 061.10 77	2	
Alsea RD		
AL 252.15 80o	2	
AL 252.10 77	1	
AL 252.10 81	1	
AL 252.05 78	2	
AL 061.20 83o	2	
AL 061.05 79	2	

Mapleton RD

Oregon Coast Range, S

MA 062.10 79	1	
Coos Bay RA		
CO 072.10 84o	2	
Siskiyou NF		
Powers RD		
PO 072.25 79	2	
Gold Beach RD		
GO 081.20 79	2	
Chetco RD		
CH 082.25 76	5	
CH 082.25 77	5	
CH 082.25 78	5	
CH 082.25 79	2	
CH 082.10 79	2	

Klamath Mtns, N

Roseburg RA		
RO 270.20 84o	3	
Siskiyou NF		
Galice RD		
GA 511.30 79	2	
GA 512.25 79	2	
Illinois Valley RD		
IL 512.40 79	1	
IL 512.35 78	2	
IL 512.13 79	4	

Klamath Mtns, W

Six Rivers NF		
Gasquet RD		
GQ 301.30 77	1	
GQ 301.30 78	1	
GQ 301.30 79	5	
Orleans RD		
OR 302.30 79	2	

Klamath Mtns, central

Klamath NF		
Happy Camp RD		
HC 301.50 79	1	
HC 301.30 77	2	
HC 301.30 78	2	
HC 301.30 79	2	
Ukonom RD		
UK 301.20 79	2	
UK 302.44 79	1	
UK 311.40 79	1	
Salmon River RD		
SA 311.40 79	1	

Klamath Mtns, E

Rogue River NF		
Applegate RD		
AP 511.40 79	3	
Klamath NF		
Oak Knoll RD		
OK 321.40 77	3	
OK 321.40 78	1	
OK 321.40 79	1	
OK 321.30 80o	2	
OK 321.30 81	2	
Scott River RD		
SC 322.40 78	2	
SC 322.40 79	3	

Klamath Mtns, S

Shasta-Trinity NF		
Big Bar RD		
BI 312.40 77	1	
BI 312.30 78	2	
Hayfork RD		
HA 312.50 80	2	
HA 312.25 78	2	
HA 312.25 79	2	
HA 312.25 79o	2	
HA 312.25 80	2	
Yolla Bolla RD		
YO 371.45 78	2	

N Coast Range, coastal

Six Rivers NF		
Gasquet RD		
GQ 091.20 81	2	
Ukiah RA		
King Range		
KI 390.25 77	4	
KI 390.20 79	4	
KI 390.20 80o	4	
KI 390.20 84o	4	
Red Mountain		
RE 093.25 78	3	

N Coast Range, inland

Six Rivers NF		
Mad River RD		
MR 303.45 79	3	
MR 340.36 78	3	
Mendocino NF		
Upper Lake RD		
UP 372.30 77	3	

Oregon Cascades, W

Willamette NF		
McKenzie RD		
MK 472.45 79	2	
MK 472.30 80o	3	
Blue River RD		
BL 472.30 77	1	
Oakridge RD		
OA 482.30 81	2	
Umpqua NF		
Steamboat RD		
ST 491.30 79	1	
Glide RD		
GL 491.30 79	3	
Tiller RD		
TI 492.30 79	1	

California Cascades				Sierra Nevada, W			
Shasta-Trinity NF				Eldorado NF			
Mt Shasta RD				Placerville RD			
SH	516.30	77	3	PL	526.40	77	3
SH	521.40	79o	1	Stanislaus NF			
Sierra Nevada, N				Mi-Wok RD			
Plumas NF				MI	531.40	77	1
Greenville RD							
GR	523.45	77	5				

¹ Seed sources are listed by physiographic region and management unit of origin, National Forest (NF) and Ranger District (RD) or Bureau of Land Management Resource Area (RA). The entries show tree seed zone (USDA Forest Service 1969, 1973), elevation (x100 ft), test year, and lifting window type. The letter o denotes a test of 1-0 planting stock.

Figure 19—Types of seed source lifting windows for Douglas-fir in Humboldt Nursery. Seedlings lifted within their source window have high survival and growth potentials after cold storage, at spring planting time. Seedlings of window type 1 are safely lifted after November 30; type 2, after December 10; type 3, after December 25; type 4, after January 10; and type 5, after February 1. The last safe date is March 16, except March 1 for window type 5. Seedlings of untested sources are safely lifted within the narrowest window of known sources nearby, or in the forest region if known sources are too far away.

Safe Cold Storage

Growth capacity tests at planting time indicated that seedlings lifted within the source windows and stored at 1° C (34° F) were fully programmed for budburst and root elongation (figs. 15, 16). First-year survivals in field performance tests on coastal and inland planting sites in western Oregon and northern California showed that seedlings lifted earliest within the source windows were stored just as successfully as those lifted last (table 3). Two-year survival and growth in these tests affirmed the efficacy of overwinter cold storage (table 5).

Seedlings lifted just after the source window opened were successfully stored for periods ranging from 7 weeks for narrow-window source CH 082.25 from the southern Oregon Coast Range to 7 months for wide-window source MK 472.45 from the Oregon Cascades. Successful storage exceeded 3 months in 58 tests, 4 months in 31 tests, and 5 months in 5 tests. Had seedlings been stored on actual first safe dates, successful storage would have exceeded 4 months in 50 tests and 5 months in 17 tests. Longer storage periods will rarely be needed, because cooperators delayed test installations until their spring planting programs were completed.

Lifting Window Types

Few of the seed sources requested at Humboldt Nursery need ever be considered critical for early lifting and overwinter cold storage. First-year survivals showed that 68 percent of the sources assessed had lifting windows that opened before December 6. Fully 28 percent had windows that opened before November 21, and 88 percent had windows that opened before December 21. At least 90 percent had windows that remained open past the middle of March (table 3).

To simplify planning of lifting and cold storage schedules, seed sources were grouped into lifting window types (table 6, fig. 19). Windows of type 1 sources open before November 21; type 2 sources, in the 2 weeks after November 21; type 3, in the 2 weeks after December 6; type 4, in the 2 weeks after December 21; and type 5, in the 2 weeks after January 5. To insure successful cold storage, Humboldt currently lifts all type 1 sources after November 30; type 2 sources, after December 10; type 3, after December 25; and so on. Every source is lifted by March 15. A critical few are lifted before March 1 or February 21 (table 3).

Once unlifted seedlings resume root growth, root growth capacity and storability dive and lifting windows close. Spring conditions in the nursery permit seedlings to dehardening, mobilize and translocate reserves, and increase respiration, photosynthesis, and transpiration. Activated seedlings resume root growth immediately, and depending on warming air temperatures, initiate bud swell 3 to 6 weeks later.

Table 6—Types of seed source lifting windows for Douglas-fir in Humboldt Nursery¹

Lifting window type	Seed sources in type	Lifting window width	First safe lifting dates ²	First date used in the nursery
	pct	days		
1	28	114-127	Nov 7-21	Nov 30
2	40	100-113	Nov 22-Dec 6	Dec 10
3	20	< 100	Dec 7-21	Dec 25
4	8	< 86	Dec 22-Jan 5	Jan 10
5	4	< 72	Jan 6-26	Feb 1

¹ Types are based on 54 known source lifting windows.

² Last safe lifting date is March 16, except six sources; see table 3.

Scheduling Untested Sources

Safe times to lift untested seed sources are based on the lifting windows of known sources from the same or adjacent regions (*fig. 19*). For example, all untested sources from the Oregon Coast Range are confidently lifted as window type 2, because the windows of known sources from this region are either type 1 or 2, except one small area of known type 5 in extreme southwest Oregon. Untested sources from the North Coast Range are lifted as window type 3, except those from areas of known type 4.

Untested sources from the Klamath Mountains are safely lifted as window type 2, except those from low elevations, peripheral Ranger Districts, and marginal soils, which are lifted as type 3. Untested sources from the Oregon and California Cascades are lifted as type 3, which seems as common as either type 1 or 2. Untested sources from the Sierra Nevada assume a type 5 window in Humboldt Nursery, because one of the three known sources is type 5.

PLANTATION ESTABLISHMENT

By its nature, the seedling testing program was inextricably linked to plantation establishment. Field performance tests were designed to assess planting stock quality by the same criteria that are used to judge plantation success. Establishment occurs when planted seedlings capture the planting site resources. Success is assured when survival is 80 to 90 percent and the trees grow fast enough to overtop and suppress the competing vegetation and developing understory.

First-year survivals in spring plantings depend primarily on root growth capacity (RGC) after cold storage. Site and weather conditions during the growing season determine the minimum RGC that seedlings must have to survive. Put another way, survival reflects the percentage of seedlings that had RGC higher than critical for the site environment. Seedlings lifted within the seed source windows consistently average high RGC after storage, but distributions of individual seedling RGC are such that mortality can be excessive if site preparation is ineffectual, root placement is poor, or protection falls short.

Geographic variation in critical RGC indicated that differences among planting sites can be as great within regions as between regions (*table 7*). In every region, low critical RGC depended on effective site preparation, proper planting methods, and prompt seedling protection. High critical RGC was

invariably tied to poor planting methods, tough plant competition, or chronic browse damage. Experience repeatedly showed that attention must be paid to all factors to keep critical RGC low and promote high survival. Any neglect inflates critical RGC and promotes mortality.

RGC, Site, and Survival

Critical RGC varied widely on coastal and inland sites in both western Oregon and northern California (*fig. 11*). Critical RGC was estimated in 25 field performance tests (*table 7, fig. 20*). Values ranged from 1 to 105 cm, and the percentage of seedlings that had RGC higher than critical explained 86 to 100 percent ($r^2 = 0.86$ to 1.00) of the variation in first-year survival. Critical RGC was magnified more by aggressive plants and hungry mammals than by site climate or soil type, and was typically low in tests that were protected and moderate to high in those that were not.

Tests of sources from our coast-inland transect of western Oregon were installed on climatically mild sites on the Waldport, Alsea, and Blue River Ranger Districts. The Waldport and Alsea tests were located in the northern Oregon Coast Range, in clearcut units of Douglas-fir/western hemlock forest at 900 ft (275 m) and 750 ft (230 m) of elevation and 8 miles (13 km) and 16 miles (26 km) from the Pacific Ocean (see Appendix D, Planting Site Descriptions). The Blue River test was located in the western Oregon Cascades, in a clearcut unit of Douglas-fir/western redcedar/western hemlock forest at 2300 ft (700 m). Substantial rains fell in all three areas in May and August, yet critical RGC was 30, 1, and 15 cm in the Waldport, Alsea, and Blue River tests, respectively (*table 7, fig. 20*). Seedlings in the Waldport test were devastated by elk, deer, and mountain beaver, whereas those in the Alsea test (source AL 252.10) were protected with vexar tubes and displayed phenomenal growth (*table 5*).

Tests of source CH 082.25 on the Chetco Ranger District in the southern Oregon Coast Range, in extreme southwest Oregon, repeatedly showed a narrow lifting window (*table 3*). The tests were installed on different sites in consecutive years, on April 23 in a clearcut unit of Douglas-fir forest at 1600 ft (490 m) of elevation and 12 miles (19 km) from the Pacific Ocean, March 15 in a tanoak conversion unit at 2700 ft (825 m) and 17 miles (27 km) inland, and April 6 in a tanoak conversion unit at 2300 ft (700 m) and 16 miles (26 km) inland (see Appendix D, Planting Site Descriptions). Deer browsed most seedlings, but competing vegetation was light in the first test and heavy in the second. Critical RGC was 15, 50, and 25 cm, respectively (*table 7, fig. 20*).

Successful tests of sources from our coast-inland transect through the Klamath Mountains were installed on the Gasquet, Happy Camp, and Oak

Knoll Ranger Districts in consecutive years. The Gasquet tests were side by side in a reforestation backlog unit of Douglas-fir/sugar pine forest at 1700

Table 7—Critical root growth capacity (RGC) in field performance tests of 2-0 Douglas-fir from Humboldt Nursery

Seed source ²	Site planting date	RGC testing date	Critical RGC	Regression	
				b	r ²
			cm		
Oregon Coast Range, N					
WA 061.10 77	Apr 15	May 2	30	1.02	0.98
AL 252.10 77	Apr 21	Apr 11	1	1.01	.99
Oregon Coast Range, S.					
CH 082.25 76	Apr 23	Apr 20	15	1.02	0.99
CH 082.25 77	Mar 15	Mar 28	50	.97	.90
CH 082.25 78	Apr 6	Apr 10	25	.98	.89
Klamath Mtns, N					
IL 512.35 78	May 16	May 30	30	0.99	0.86
Klamath Mtns, W					
GQ 301.30 77	Apr 25	Apr 25	1	1.01	0.98
GQ 301.30 78	May 1	May 1	1	1.00	1.00
Klamath Mtns, central					
HC 301.30 77	Mar 10	Mar 28	10	1.03	0.99
HC 301.30 78	Apr 28	May 1	5	.97	1.00
Klamath Mtns, E					
OK 321.40 77	May 4	May 23	45	1.04	0.98
OK 321.40 78	Apr 11	Apr 18	5	1.04	.99
SC 322.40 78	May 3	Jun 5	5	1.04	.92
Klamath Mtns, S					
BI 312.40 77	Mar 17	May 9	15	0.98	0.95
BI 312.3078	May 17	Jun 27	1	1.06	.99
HA 312.25 78	Apr 27	Apr 4	15	1.00	.99
YO 371.45 78	May 2	May 8	15	1.00	.99
N Coast Range, coastal					
KI 390.25 77	Mar 18	Apr 4	60	1.01	0.92
RE 093.25 78	Apr 6	Apr 3	45	1.00	.99
N Coast Range, inland					
MR 340.36 78	Apr 24	May 1	1	1.04	0.99
UP 372.30 77	Mar 10	Apr 4	105	1.00	.97
Oregon Cascades, W					
BL 472.30 77	Apr 8	May 2	15	1.00	0.97
California Cascades					
SH 516.30 77	May 6	May 9	45	1.01	0.89
Nevada, N					
GR 523.45 77	Apr 25	Apr 13	75	1.01	0.96
Nevada, W					
PL 526.40 77	Apr 1	Apr 13	15	1.02	0.99

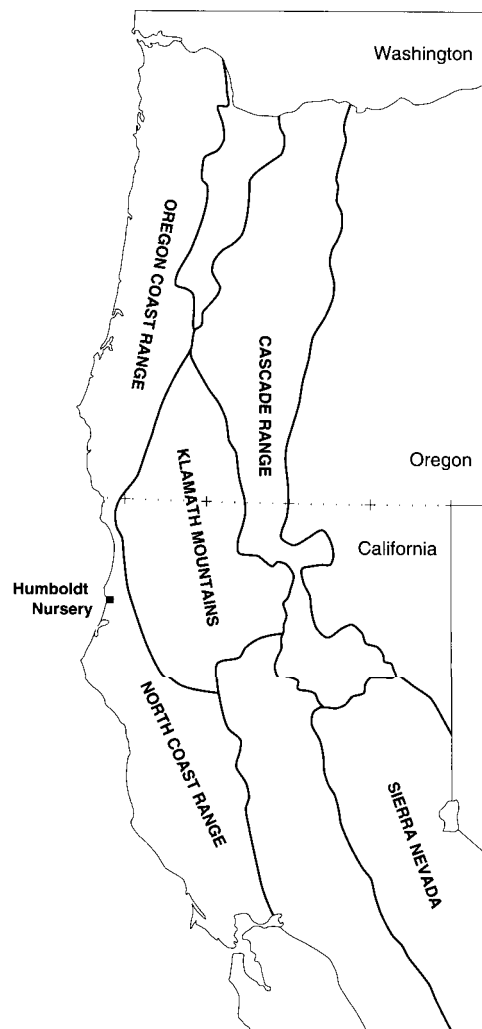
ft (520 m) of elevation and 9 miles (14 km) from the Pacific Ocean (see Appendix D, Planting Site Descriptions). Critical RGC was 1 cm in both tests. The Happy Camp tests were side by side in a clearcut unit of Douglas-fir/tanoak/madrone forest at 2100 ft (640 m) in the Klamath River drainage of the Western Siskiyou. Critical RGC was 10 cm in the first test and 5 cm in the second test. The Oak Knoll tests were on contrasting xeric and mesic sites in the Eastern Siskiyou, in a clearcut unit of mixed conifer/ Jeffrey pine forest on a rocky ultramafic soil at 4000 ft (1220 m) and in a recent burn in mixed conifer forest on a deep, fertile soil at 3500 ft (1065 m). Critical RGC was 45 cm on the harsher Jeffrey pine site and 5 cm on the Douglas-fir site. In the same year, critical RGC was also 5 cm in another test in the Eastern Siskiyou, in a clearcut unit of mixed conifer forest at 4400 ft (1340 m) on the Scott River Ranger District.

Tests of sources from the southern Klamath Mountains were installed in clearcut units in mixed conifer/evergreen hardwood forest at 3250 ft (990 m) and mixed conifer forest at 3000 ft (915 m) on the Big Bar Ranger District, a clearcut unit in mixed conifer forest at 2950 ft (900 m) on the Hayfork Ranger District, and a reforestation backlog unit in mixed conifer forest at 4500 ft (1370 m) on the Yolla Bolla Ranger District (see Appendix D, Planting Site Descriptions). Competing vegetation was cleared after ample rains in May, and summer drought lasted 4 months, until autumn rains recharged the soils. First-year survivals within the source lifting windows averaged 77 to 93 percent, and 88 percent overall (table 3). Critical RGC was 15 and 1 cm in the Big Bar tests, and 15 cm in both the Hayfork and Yolla Bolla tests (table 7, fig. 20).

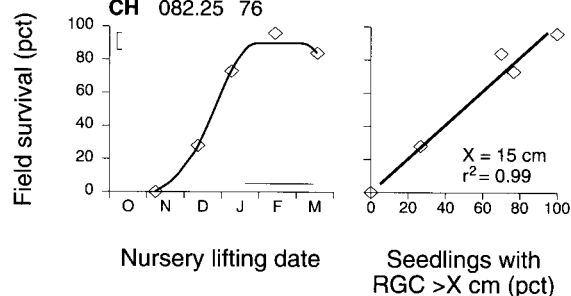
¹ Seedlings were lifted monthly in autumn to spring, stored at 1 ° C (34° F), and planted in the seed zone of origin; see Assessing Planting Stock Quality, Standard Testing Procedures

² See figs. 11, 20; and table 3.

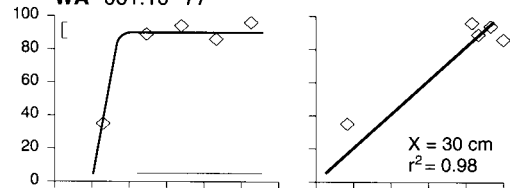
³ Y= bX, where Y is first-year survival (pct) and X is percent of seedlings with RGC higher than critical; b is line slope and r² is coefficient of determination.



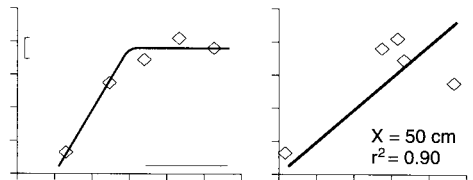
Oregon Coast Range, S
CH 082.25 76



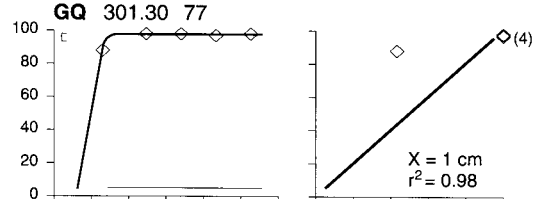
Oregon Coast Range, N
WA 061.10 77



Oregon Coast Range, S
CH 082.25 77



Klamath Mtns, W
GQ 301.30 77



N Coast Range, coastal
KI 390.25 77

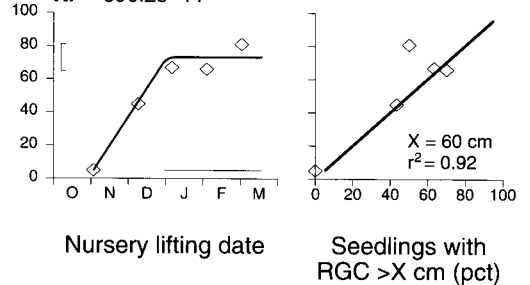
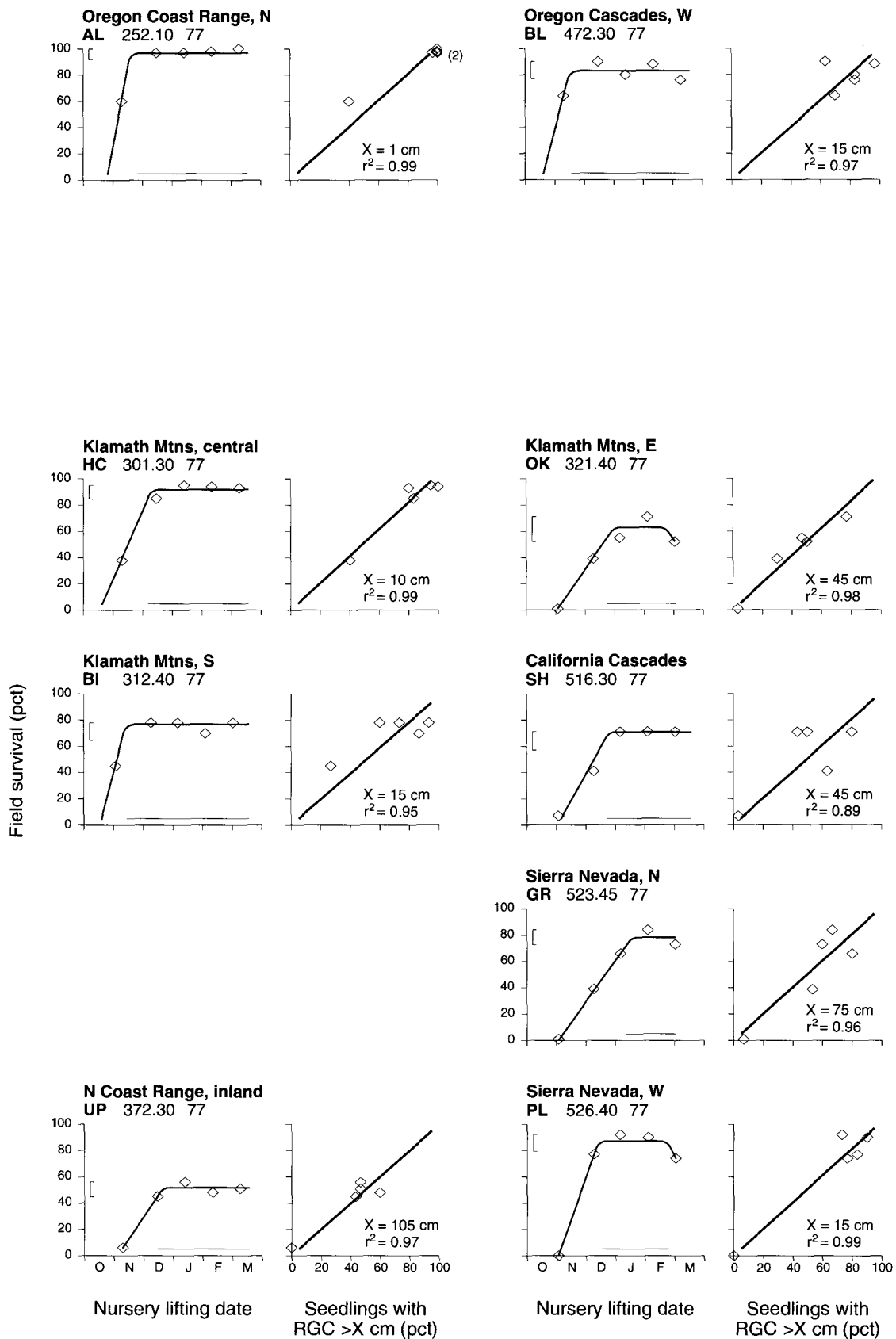


Figure 20—Critical root growth capacity (RGC) for first-year survival of 2-0 Douglas-fir from Humboldt Nursery. Survivals and critical RGC (X) were determined in field performance tests of seed sources from coastal and inland regions of western Oregon and northern California. Critical RGC ranged from 1 to 105 cm, depending on planting site, root placement, and seedling protection (see table 7). The percentages of seedlings with RGC greater than critical explain most of the variation in survival. The graphs are arrayed by test year, forest region, and source latitude. Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.



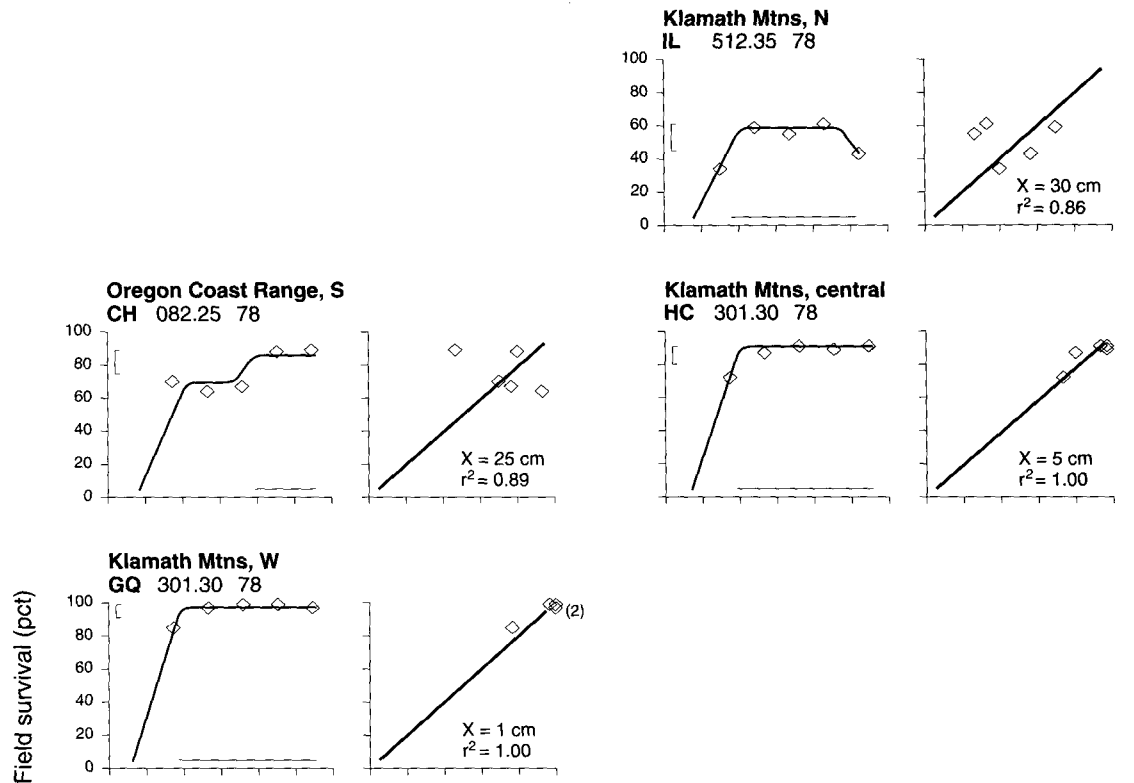
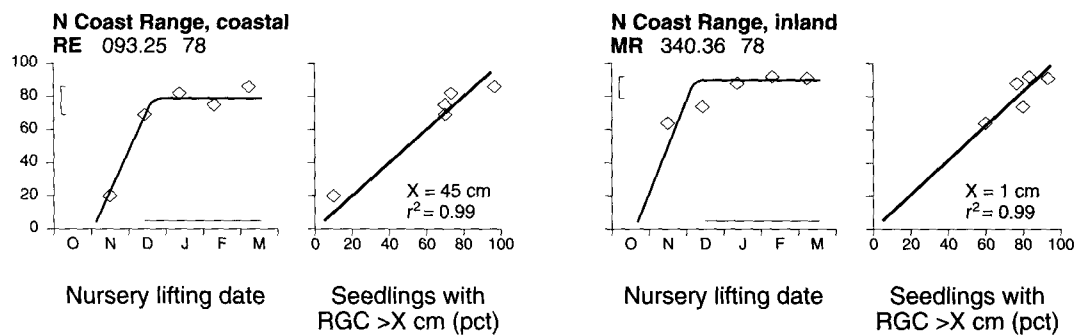


Figure 20 (continued)—Critical root growth capacity (RGC) for first-year survival of 2-0 Douglas-fir from Humboldt Nursery. Survivals and critical RGC (X) were determined in field performance tests of seed sources from coastal and inland regions of western Oregon and northern California. Critical RGC ranged from 1 to 105 cm, depending on planting site, root placement, and seedling protection (see table 7). The percentages of seedlings with RGC greater than critical explain most of the variation in survival. The graphs are arrayed by test year, forest region, and source latitude. Brackets indicate least significant difference ($p = 0.05$). Horizontal bars indicate the source lifting windows.

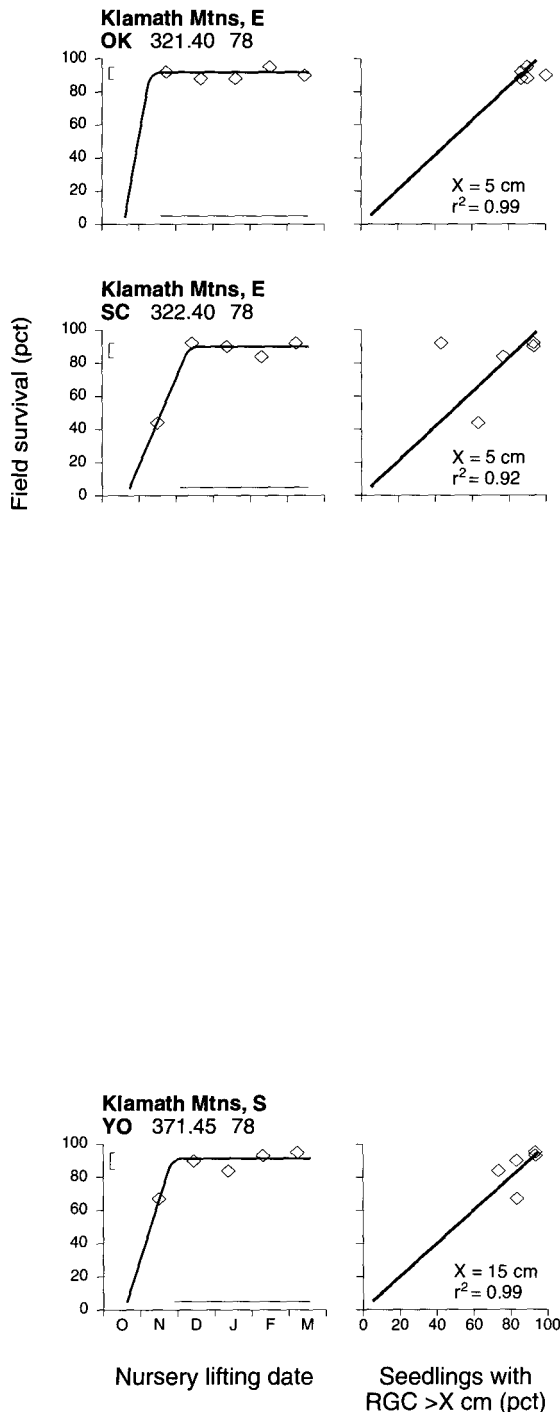


Tests of coastal sources in the North Coast Range were installed on comparatively harsh sites in the Ukiah Resource Area. The first was located in a salvage unit of Douglas-fir/evergreen hardwood forest at 2000 ft (610 m) in the King Range, and the second, in a clearcut unit of mixed conifer forest at 1800 ft (550 m) in the Red Mountain Creek area (see Appendix D, Planting Site Descriptions). Summer drought lasted 4 to 5 months in the King Range and 5 months in the Red Mountain area. Deer browsed most seedlings, and first-year survivals within the source lifting windows averaged 71 and 78 percent, respectively (*table 3*). Critical RGC was 60 cm in the King Range test and 45 cm in the Red Mountain test (*table 7, fig. 20*).

Tests of inland sources in the North Coast Range were installed in the middle of an old burn in ponderosa pine/Douglas-fir forest at 3400 ft (1035 m) of elevation on the Upper Lake Ranger District and in a clearcut unit of Douglas-fir forest at 3700 ft (1130 m) on the Mad River Ranger District (see Appendix D, Planting Site Descriptions). Ample rains fell in both areas in May. Seedlings in the Upper Lake test were exposed to 10 straight days of hard freezes in March and 4 months of hot, dry winds in summer-autumn. First-year survival within the lifting window averaged 50 percent (*table 3*) and critical RGC was 105 cm (*table 7, fig. 20*). Seedlings in the Mad River test were cleared of competing vegetation and endured 5 months of drought. First-year survival within the window averaged 90 percent and critical RGC was 1 cm.

Seedlings in the King Range and Upper Lake tests varied widely in RGC after cold storage, and in effect, in survival potential at planting time. RGC was near zero in 15 percent of all seedlings lifted within the source windows, yet exceeded 100 cm in 40 percent of the King Range seedlings and 52 percent of the Upper Lake seedlings. Known wide variation in RGC warrants planting at close spacings on climatically tough sites, to secure acceptable stocking and avoid the need to replant or interplant.

Tests of sources in the California Cascades and Sierra Nevada were installed in a clearcut unit of white fir/ponderosa pine forest at 5200 ft (1585 m) of elevation on the Mount Shasta Ranger District in the western Cascades, a poorly stocked burn in mixed conifer forest at 4300 ft (1310 m) on the Greenville Ranger District in the northern Sierra Nevada, and a clearcut unit of mixed conifer forest on a northeast slope at 4600 ft (1400 m) on the Placerville Ranger District in the western Sierra Nevada (see Appendix D, Planting Site Descriptions). The Mount Shasta test was 2200 ft (670 m) higher than seed origins,



gophers held the site, and critical RGC was 45 cm. The Greenville test underwent 5 months of drought, deer severely damaged the survivors, and critical RGC was 75 cm. The Placerville test underwent 5 months of drought, prickly sowthistle covered the site in July, and critical RGC was 15 cm (*table 7, fig. 20*).

The Forest Service's Placerville Nursery is the principal supplier of planting stock for Federal lands in the California Cascades and Sierra Nevada. If the need ever arose, however, Humboldt Nursery could produce successful Douglas-fir for these regions. In northern areas, for example, first-year survivals of 2-0 stock reached 72 and 84 percent for specific lifts in the Mount Shasta and Greenville tests, on sites where critical RGCs were 45 and 75 cm, respectively. In southern areas, first-year survivals reached 92 percent in the Placerville test, and averaged 93 percent in burned units on the Mi-Wok Ranger District in the western Sierra Nevada (Jenkinson and Nelson 1978 and Appendix D, Planting Site Descriptions). Humboldt could also supply these regions with 1-0 stock. In a 1979 test of 1-0 Douglas-fir on the Mount Shasta Ranger District, first-year survival averaged 89 percent within the lifting window (*table 3*).

Humboldt Douglas-fir has repeatedly displayed the survival and growth potentials needed to meet and exceed the targets set for planting programs in western Oregon and northern California. Compliance with proven reforestation guides has consistently resulted in high survivals on diverse sites in coastal and inland regions. First-year survival within the lifting window averaged 80 to 99 percent in 43 of our first 57 tests (*table 3, 1976-79*), and protected growth was often spectacular (*table 5*).

Animal Damage

Field performance tests showed that browsing mammals are a widespread problem. Mammal-caused losses can be dramatic because they are instantaneous and highly visible, compared to those caused by plant competition. Seedlings are clipped, chewed, girdled, or eaten in minutes, and entire plantations can be damaged in days and at any time of the year.

First-year survivals were sufficient to define the seed source lifting windows. Thereafter, elk, deer, mountain beaver, gophers, or cattle damaged or destroyed one or more tests in every region (*fig. 21*). In tests that were destroyed, damage was usually extensive in autumn of the first year, but not always. Surprise depredations in the first winter and chronic browsing in the second year commonly reduced

growth and survival, and often precluded the growth needed to confirm the source lifting window. Comparable losses in operational plantings spell failure. Seedlings that are repeatedly stripped of leaders can be buried by an aggressive understory. At best, free growth and plantation establishment may be delayed for years.

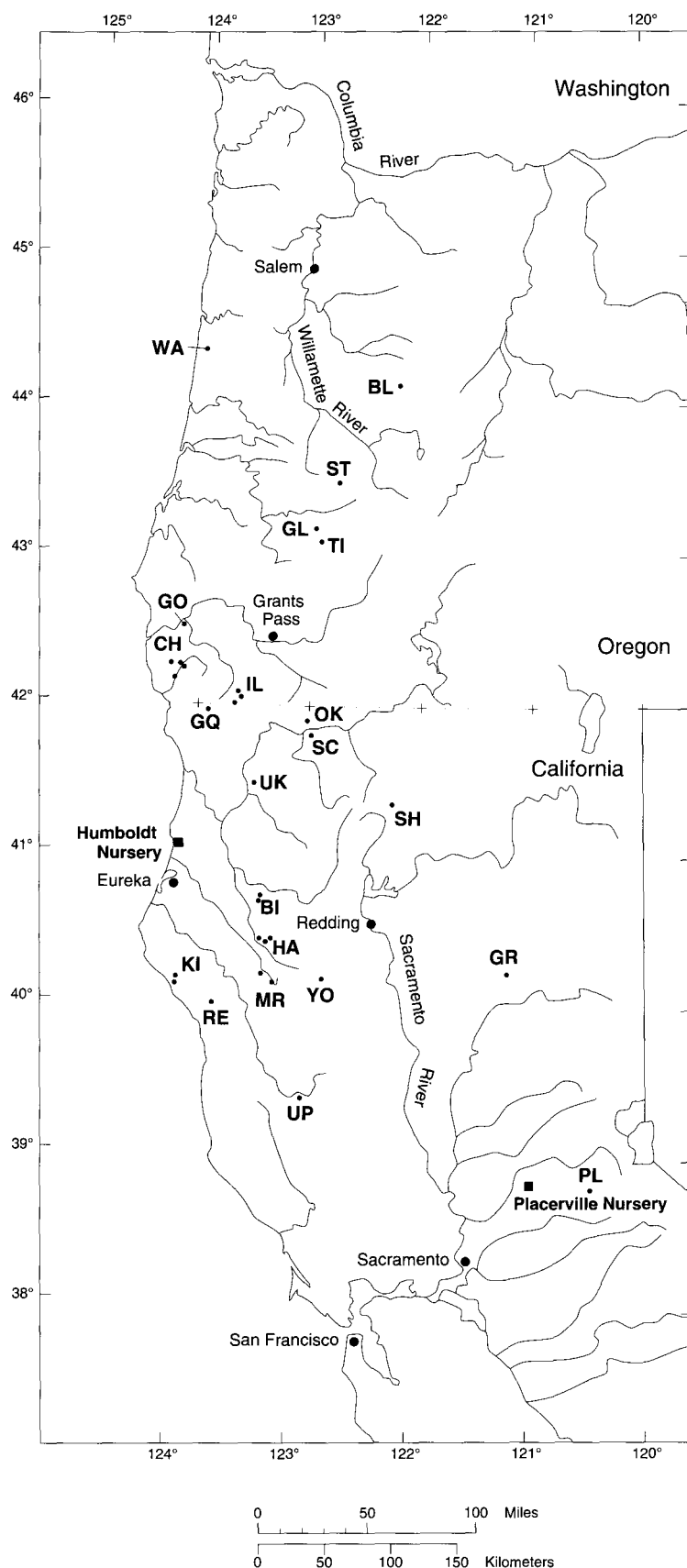
Mammals destroyed eight tests during the first winter or spring after planting (*table 8*). Elk, deer, and mountain beaver ruined the test of source WA 061.10 in the northern Oregon Coast Range. Deer finished off tests of sources IL 512.40, IL 512.35, IL 512.13, GQ 301.30, and YO 371.45 in the northern, western and southern Klamath Mountains and obliterated that of source PL 526.40 in the western Sierra Nevada. Gophers devoured the test of source SH 516.30 in the California Cascades.

Resident deer damaged 20 tests by periodically eating the new shoots and older foliage. Browsing caused up to 40 percent mortality and abolished height growth in 11 of the 1977 and 1978 tests, including source CH 082.25 in the southern Oregon Coast Range, sources OK 321.40, SC 322.40, BI 312.40, BI 312.30, and HA 312.25 in the eastern and southern Klamath Mountains, sources KI 390.25, RE 093.25, and MR 340.36 in the North Coast Range, source BL 472.30 in the Oregon Cascades, and source GR 523.45 in the northern Sierra Nevada. Similar damage was found in 9 of the 1979 tests, including sources GO 081.20 and CH 082.10 in the southern Oregon Coast Range, sources UK 311.40 and HA 312.25 in the central and southern Klamath Mountains, source KI 390.20 in the coastal North Coast Range, and sources ST 491.30, GL 491.30, and TI 492.30 in the Oregon Cascades. Cattle damaged the test of source MR 303.45 in the inland North Coast Range.

Tree Growth

Douglas-firs in 47 field performance tests were evaluated for height, basal stem diameter, and leader length after 2 growing seasons (*table 5*). In 22 of these tests, trees were evaluated for growth after 3 or more years on the planting site.

Cooperators cleared invading shrubs, herbs, and grasses from 32 tests in the first summer or second spring, and documented such actions on the forms provided (see Appendix E, Field Test Data Forms). As already noted, whether or not competing vegetation was cleared, deer usually ate the new shoots of seedlings that were not protected (*table 8*). Partly because of the differential damage that resulted, growth varied widely within and between regions.



Seed source¹

Oregon Coast Range, N

Siuslaw NF
Waldport RD
WA 061.10 77◊

Oregon Coast Range, S

Siskiyou NF
Gold Beach RD
GO 081.20 79
Chetco RD
CH 082.25 76
CH 082.25 77
CH 082.25 78
CH 082.10 79

Klamath Mtns, N

Siskiyou NF
Illinois Valley RD
IL 512.40 79◊
IL 512.35 78◊
IL 512.13 79◊

Klamath Mtns, W

Six Rivers NF
Gasquet RD
GQ 301.30 79◊

Klamath Mtns, central

Klamath NF
Ukonom RD
UK 311.40 79

Klamath Mtns, E

Klamath NF
Oak Knoll RD
OK 321.40 78
Scott River RD
SC 322.40 78

Klamath Mtns, S

Shasta-Trinity NF
Big Bar RD
BI 312.40 77
BI 312.30 78
Hayfork RD
HA 312.25 78
HA 312.25 79
HA 312.25 79◊
Yolla Bolla RD
YO 371.45 78◊

N Coast Range, coastal

Ukiah RA
King Range
KI 390.25 77
KI 390.20 79
Red Mountain
RE 093.25 78

N Coast Range, inland

Six Rivers NF
Mad River RD
MR 303.45 79
MR 340.36 78
Mendocino NF
Upper Lake RD
UP 372.30 77

Oregon Cascades, W

Willamette NF
Blue River RD
BL 472.30 77
Umpqua NF
Steamboat RD
ST 491.30 79
Glide RD
GL 491.30 79
Tiller RD
TI 492.30 79

California Cascades

Shasta-Trinity NF
Mt Shasta RD
SH 516.30 77◊

Sierra Nevada, N

Plumas NF
Greenville RD
GR 523.45 77

Sierra Nevada, W

Eldorado NF
Placerville RD
PL 526.40 77◊

¹ Seed sources are listed by physiographic region and management unit of origin, National Forest (NF) and Ranger District (RD) or Bureau of Land Management Resource Area (RA). The entries show tree seed zone (USDA Forest Service 1969, 1973), elevation (x100 ft), and test year. The symbol ◊ denotes a test that was destroyed, and the letter o, a test of 1-0 planting stock.

Figure 21—Field performance tests of 2-0 Douglas-fir that were damaged by deer, elk, or gophers. Severe damage was recorded in 31 tests in coastal and inland regions of western Oregon and northern California. Eight tests were destroyed and deer frequently ate new leaders and lateral shoots in the other 23 (see *table 8*).

Table 8—Height, survival, and browse damage in field performance tests of 2-0 Douglas-fir from Humboldt Nursery¹

Seed source ² (height, cm) ³	Height		Survival		Browse damage ⁴
	1 yr	2 yr	1 yr	2 yr	
	-----cm-----		----- pct-----		pct
Oregon Coast Range, N					
WA 061.10 77	—	32.8	91.2	40.8	100
Oregon Coast Range, S					
GO 081.20 79	26.8	29.7	65.8	57.2	77
CH 082.25 76	—	38.5	84.3	82.0	82
CH 082.25 77	—	28.2	75.7	70.4	100
CH 082.25 78	26.5	28.6	81.3	80.0	100
CH 082.10 79 (34)	34.5	42.2	89.0	88.5	57
Klamath Mtns, N					
IL 512.40 79 (24)	24.7	26.2	71.4	50.8	100
IL 512.35 78	26.6	25.0	54.8	40.8	100
IL 512.13 79	43.6	48.3	55.0	41.7	93
Klamath Mtns, W					
GQ 301.30 79	36.5	34.3	65.0	37.7	100
Klamath Mtns, central					
UK 311.40 79	33.2	39.6	76.5	56.5	91
Klamath Mtns, E					
OK 321.40 78	21.2	24.7	90.6	89.0	55
SC 322.40 78	—	22.7	89.2	55.0	100
Klamath Mtns, S					
BI 312.40 77	—	24.8	76.8	72.5	78
BI 312.30 78	—	28.8	92.0	90.0	84
HA 312.25 78	—	22.2	89.0	84.2	89
HA 312.25 79 (30)	—	30.4	94.5	92.0	100
HA 312.2579o (20)	—	15.2	89.8	85.5	100
YO 371.45 78	—	—	90.5	—	—
N Coast Range, coastal					
KI 390.25 77	—	40.7	71.3	61.1	50
KI 390.20 79	27.9	31.2	85.8	73.8	92
RE 093.25 78	32.8	35.2	78.0	70.0	89
N Coast Range, inland					
MR 303.45 79 (24)	25.5	27.6	71.7	62.0	100
MR 340.36 78 (20)	24.0	22.0	86.2	73.0	100
UP 372.30 77	—	31.3	50.0	26.2	100
Oregon Cascades, W					
BL 472.30 77 (22)	—	23.6	83.5	62.8	100
ST 491.30 79	22.0	29.0	88.4	80.8	83
GL 491.30 79	28.9	29.2	88.2	85.0	87
TI 492.30 79	25.9	34.5	97.0	92.6	74
California Cascades					
SH 516.30 77	—	—	71.3	1.3	—
Sierra Nevada, N					
GR 523.45 77 (23)	23.0	24.3	74.3	64.0	87
Sierra Nevada, W					
PL 526.40 77	—	—	83.2	1.0	—

¹ Means are for seedlings lifted within the seed source window; see *table 3*.

² See *figs. 10, 21; and table 5*. The symbol denotes a test that was destroyed by deer, or elk (source WA), or gophers (source SH), and the letter o, a test of 1-0 planting stock.

³ Seedlings of eight sources were measured just after planting.

⁴ Seedling leaders were eaten by deer, or elk (sources WA, GO).

Growth was normally faster in tests in northern and coastal regions than in southern and inland regions, and coincided with known environmental gradients on the Pacific Slope. The regional trends were evident in 2-year height, diameter, leader length, and current height gain, that is, leader length/ (tree height - leader length) x 100, within the source lifting windows in 22 tests that were cleared of competing vegetation. Seedlings in 10 tests were protected against deer, and those in the other 12 fortuitously escaped with light to moderate browse damage.

Regional trends in the tests where seedlings were free to grow are seen in the following summary from *table 5*. The t after the test year indicates that seedlings were protected with vexar tubes:

2 years:

Seed source	Height	Diam	Leader	Gain
	<i>cm</i>	<i>mm</i>	<i>cm</i>	<i>pct</i>
Oregon Coast Range, N				
HE 053.10 79t	86.1	13.9	45.3	111
AL 252.10 77t	72.7	10.9	36.9	103
AL 252.05 78t	85.8	13.8	48.6	131
AL 061.05 79t	63.5	9.8	29.8	88
MA 062.10 79t	72.6	15.8	40.2	124
Oregon Cascades, W				
MK 472.45 79	36.9	10.6	13.6	58
ST 491.30 79	28.9	6.6	10.9	61
TI 492.30 79	34.5	9.2	10.5	44
Oregon Coast Range, S				
PO 072.25 79t	51.3	10.2	23.2	83
CH 082.25 79t	48.9	10.6	17.9	58
Klamath Mtns, N				
GA 511.30 79t	38.8	6.4	8.3	27
GA 512.25 79t	39.5	7.0	10.3	35
Klamath Mtns, W				
OR 302.30 79	48.3	12.8	12.4	34
Klamath Mtns, central				
HC 301.50 79	30.8	8.1	8.7	39
HC 301.30 77	31.4	—	11.0	54
HC 301.30 78	32.7	6.8	11.8	56
HC 301.30 79	57.0	12.8	13.6	31
UK 301.20 79	51.4	9.9	10.9	27
UK 302.44 79	33.5	9.7	11.5	52
SA 311.40 79	45.0	10.4	10.5	30
Klamath Mtns, E				
OK 321.40 79	44.8	8.3	19.1	74
SC 322.40 79t	27.7	7.5	7.4	36

Most of the tests summarized above were models of rapid establishment. In 25 others, growth was

- slow on nutrient-poor soils, as in sources GQ 301.30 77 and 78, and OK 321.40 77
- severely browsed, as in sources WA 061 .10, GO 081.20, CH 082.25 77, CH 082.10., IL 512.40, IL 512.35, UK 311.40, SC 322.40 78, HA 312.25, KI 390.20, MR 303.45, MR 340.36, BL 472.30, and GL 491.30
- repeatedly browsed but able to break away, as in sources CH 082.25 76 and 78, OK 321.40 78, BI 312.40, BI 312.30, KI 390.25, RE 093.25, and GR 523.45

Some cooperators decided to measure growth the first year, and thereby enabled us to document early establishment (*table 5*). High survival and rapid free growth within 2 years were evident in tests on coastal and inland sites in both western Oregon and northern California. Within the source lifting windows, leader growth doubled, tripled, or quadrupled in the second year, depending on site, and 2-year survival averaged 88 to 98 percent, down 0 to 4 percent from the first year. The best of these unplanned demonstrations were the following:

- Oregon sources HE 053.10, AL 252.05, AL 061.05, PO 072.25, and CH 082.25 79 in the northern and southern Oregon Coast Range, and source TI 492.30 in the Oregon Cascades
- California sources HC 301.30 78 and 79, UK 301.20, UK 302.44, SA 311.40, and OK 321.40 79 in the central and eastern Klamath Mountains

Many cooperators measured tests for more than 2 years because histories of the planting stock and planting sites were fully known, circumstances that were seldom encountered in reforestation at the time. Whether growth was superb or poor, they wished to see how the plantings would fare. Thus, trees in 19 tests were measured after 3 years on the site, and trees in 11 tests, after 4 years or more.

Growth performances after 3 years are shown for 19 tests in the following summary from *table 5*:

3 years:

Seed source	Height	Diam	Leader	Gain
	<i>cm</i>	<i>mm</i>	<i>cm</i>	<i>pct</i>
Oregon Coast Range, N				
AL 252.10 77	113.4	16.9	45.0	66
AL 252.05 78	145.0	21.0	64.3	80
AL 061.05 79	102.2	15.1	41.2	68
MA 062.10 79	112.2	—	47.2	73
Oregon Coast Range, S				
CH 082.25 76	52.4	16.8	13.5	35
CH 082.25 78	52.9	16.4	24.3	85
Klamath Mtns, W				
GQ 301.30 78	23.0	4.9	2.5	12
Klamath Mtns, central				
HC 301.30 77	50.4	14.0	11.0	54
HC 301.30 78	32.7	6.8	11.8	56
SA 311.40 79	60.8	—	16.8	38
Klamath Mtns, E				
OK 321.40 78	40.7	11.5	18.6	84
SC 322.40 78	23.2	6.9	8.0	53
Klamath Mtns, S				
BI 312.40 77	31.0	10.0	7.0	29
BI 312.30 78	35.3	12.8	10.2	41
N Coast Range, coastal				
KI 390.25 77	52.6	13.3	11.4	28
KI 390.20 79	39.4	13.3	6.4	19
RE 093.25 78	43.2	14.1	12.7	42
N Coast Range, inland				
MR 340.36 78	29.7	8.6	5.6	23
Sierra Nevada, N				
GR 523.45 77	37.3	12.5	12.6	51

Growth performances after 4 years are shown for 11 tests in the following summary from *table 5*:

4 years:

Seed source	Height	Diam	Leader	Gain
	<i>cm</i>	<i>mm</i>	<i>cm</i>	<i>pct</i>
Oregon Coast Range, N				
WA 061.10 77	78.2	16.8	37.2	91
AL 252.10 77	180.2	24.6	70.2	64
AL 252.05 78	219.8	34.4	77.2	54
AL 061.05 79	136.0	23.4	33.7	33
Oregon Coast Range, S				
CH 082.25 76	77.0	24.3	27.7	56
Klamath Mtns, W				
GQ 301.30 77	32.7	7.0	6.8	26
Klamath Mtns, central				
HC 301.30 77	84.2	21.3	34.4	69
Klamath Mtns, E				
OK 321.40 77	45.6	15.6	7.0	18
Klamath Mtns, S				
BI 312.40 77	40.6	12.5	9.0	28
N Coast Range, coastal				
KI 390.25 77	66.3	18.2	20.4	57
Sierra Nevada, N				
GR 523.45 77	52.7	16.4	16.3	45

Growth depended on seed source, planting site, and seedling protection. Within the source lifting windows, 3-year height ranged from 23 to 145 cm, and 4-year height, from 33 to 220 cm (see sources GQ 301.30 in the western Klamath Mountains and AL 252.05 in the northern Oregon Coast Range). Leaders increased tree height by 12 to 85 percent the third year (sources GQ 301.30 in the western Klamath Mountains and CH 082.25 78 in the southern Oregon Coast Range) and 18 to 69 percent the fourth year (sources OK 321.40 and HC 301.30 in the eastern and central Klamath Mountains). The 91 percent gain shown by source WA 061.10 in the northern Oregon Coast Range reflects bolting above the browse plane (*table 8*).

California Cascades	Sierra Nevada, W
Shasta-Trinity NF	Eldorado NF
Mt Shasta RD	Placerville RD
SH 516.30 77	PL 526.40 77
SH 521.40 79o	Stanislaus NF
Sierra Nevada, N	Mi-Wok RD
Plumas NF	MI 531.40 77
Greenville RD	
GR 523.45 77	

¹ Seed sources are listed by physiographic region and management unit of origin, National Forest (NF) and Ranger District (RD) or Bureau of Land Management Resource Area (RA). The entries show tree seed zone (USDA Forest Service 1969, 1973), elevation (x100 ft), and test year. The letters o, u, p, and f denote tests that were used to evaluate nursery culture alternatives (see *table 15*):

- o = 1-0 planting stock
- u = undercutting for 2-0 planting stock
- p = mycorrhizal inoculation, or root wrenching
- f = fall and winter planting on coastal sites

Figure 10—Seed sources used to determine lifting windows for Douglas-fir in Humboldt Nursery. Seedlings of 57 sources from coastal and inland regions of western Oregon and northern California were lifted monthly in autumn to spring, graded, root-pruned, and stored at 1° C (34° F) until spring planting time. Survival and growth of stored seedlings were evaluated in field performance tests on cleared planting sites in the seed zones of origin (see *table 1* in Appendix B).

through the Klamath Mountains of southwest Oregon and northwest California.

To formulate comprehensive lifting and cold storage schedules, we still had to sample sources on environmental gradients associated with elevation, and to fill in a few geographic voids. Fortuitous orders for suitable sources of planting stock and a platoon of zealous cooperators gave us our chance the fourth year. By a supreme effort in the 1978-79 lifting season, Humboldt Nursery's administrative studies group set up field performance tests for 30 sources, including 24 new sources and 6 repeats from past seasons.

In later years, field performance tests of 1-0 Douglas-fir and 2-0 Douglas-fir produced from holdover 1-0 seedlings generated the same kinds of data for additional sources (see *Assessing Nursery Culture Alternatives*). By 1985, assessments had covered a total of 57 sources in 74 field tests. Successful tests were installed in 34 seed zones, on 32 Ranger Districts and 3 Resource Areas in the physiographic regions served by Humboldt Nursery (*fig. 10*).

SEASONAL PATTERNS OF GROWTH CAPACITY

During three consecutive winter lifting seasons, the planned series of monthly tests of seedling top and root growth capacity (TGC, RGC) revealed strong seasonal patterns in the nursery. Pattern shape and timing were markedly affected by seed source, and to a lesser extent, by autumn-winter temperature regimes.

Invariably, TGC traced some form of sigmoid curve, starting at zero in November and increasing rapidly in December and January to high levels in February and March. In every winter season, the cumulative chilling received by seedlings in the nursery was enough to permit rapid budburst in every source tested.

Unlike TGC, RGC traced three distinct pattern types, showing either a single peak, or two separate peaks, or a high plateau. In a typically cool lifting season, all of the seed sources from coastal regions had two peaks: RGC was high in late autumn, depressed in early winter, high in late winter, and declining by early spring. Concurrently, most of the sources from inland regions had a single peak: RGC was low in autumn, high sometime in winter, and declining or low by early spring. A few other inland sources showed either two peaks within the lifting season or a high plateau extending from autumn to spring. In a comparatively warm lifting season, most of the coastal sources had single peaks like inland sources, a repeated inland source peaked 2 months later than in the cool lifting season, and a few inland sources showed a high plateau in winter.

That genetic differences might characterize the seasonal patterns found in Douglas-fir in Humboldt Nursery was suggested by research on ponderosa pine at the Forest Service's Institute of Forest Genetics, at 2750 ft (838 m) of elevation in the western Sierra Nevada. Four innate seasonal patterns of RGC were found in 1-0 seedlings through the winter lifting season, and field survival of the 1-0 stock indicated that RGC could serve as an index to safe lifting and cold storage times if the seed source response to nursery climate were known (Jenkinson 1980). Accordingly, the first step taken to assess Douglas-fir was to evaluate the seasonal patterns of TGC and RGC of known sources through the winter lifting season.

Groups of five to seven seed sources were sampled and tested monthly, just after lifting in late autumn to spring (see *Assessing Planting Stock*

The inaugural test of source CH 082.25 in the southern Oregon Coast Range was measured for 5 years (*table 5*). Survival stabilized the second year, and leaders of many survivors bolted above the browse plane the third year. Within the source lifting window, leader length doubled annually after 2 years, averaging 13, 28, and 61 cm in years 3, 4, and 5, and clearly signaled establishment, albeit delayed. The trees averaged 137 cm in height and 31 mm in basal diameter after 5 years, and dominants were 6 m tall after 10 years.

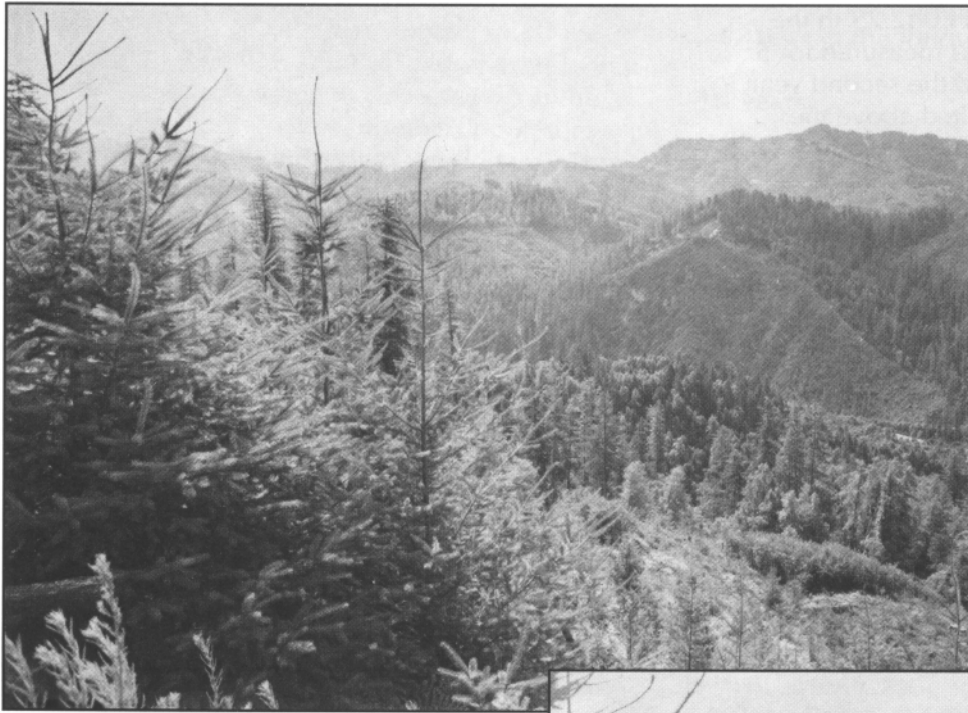
The test of source KI 390.20 in the North Coast Range was measured for 7 years to see if leaders there might bolt above the browse plane (*table 5*). Survival leveled off at 66 percent the third year, but chronic browsing made shrubs of the survivors. After 7 years, these trees averaged 76 cm in height and 21 mm in basal diameter, and establishment was not in sight.



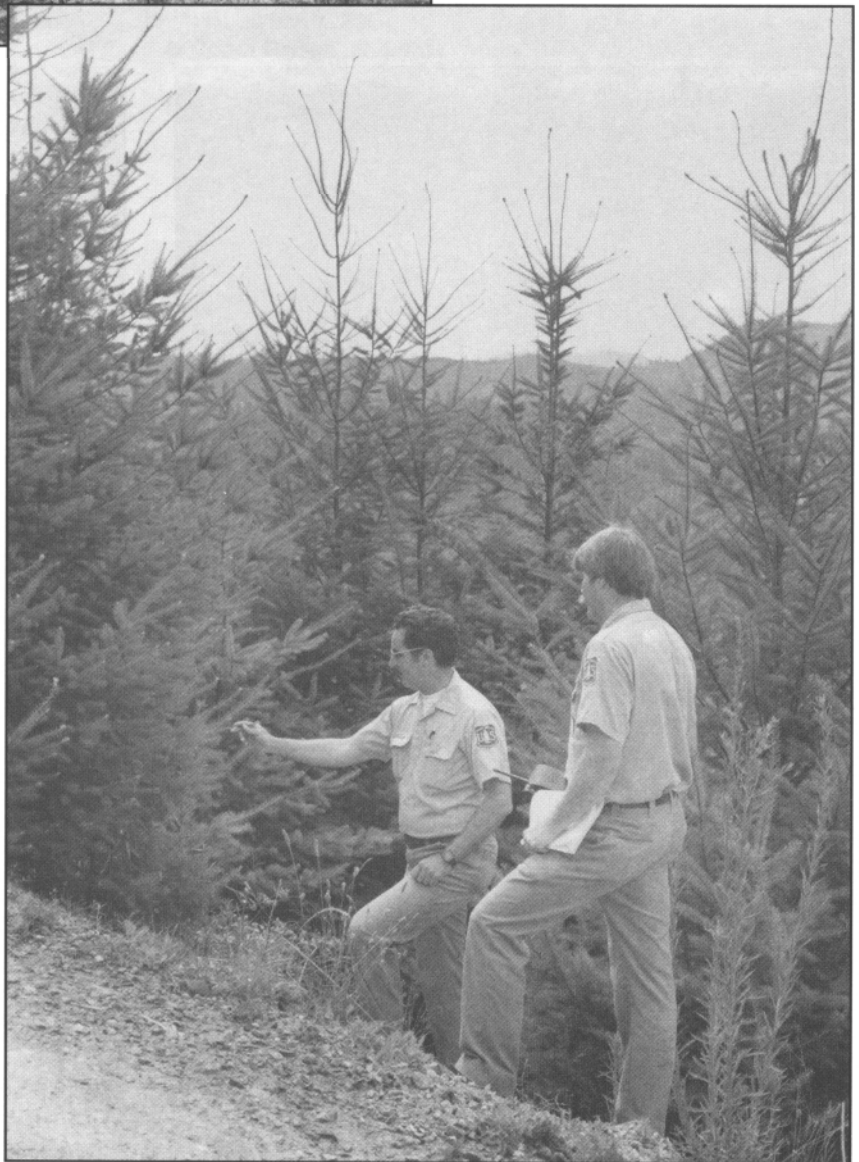
Douglas-fir in its first summer after planting in Flat Cant unit 30, showing spring shoots expanded and winter buds formed



Free-to-grow Douglas-fir 3 years after planting in Flat Cant unit 21, showing height has doubled annually (vexar tube is 30 inches high)



Douglas-fir plantation at age 7, 1 year after clearing regrowth of brush and hardwoods: View of Fox Ridge unit 6, and closeup of vigorous released trees



ASSESSING PLANTING STOCK QUALITY

Comprehensive assessments of planting stock quality are essential for building an efficient seedling production program. Assessments are needed to clarify seedling requirements in the nursery's operational environment, that is, climate, soils, cultural regimes, and lifting schedules for cold storage, and to evaluate effects of traditional and proposed nursery cultural practices on field survival and growth. Field performance tests of seedlings of known seed sources are the most direct way to evaluate planting stock quality and nursery practice. Field tests provide proof of the nursery's ability to deliver planting stock that can survive and grow well, and show unequivocally whether a particular practice is beneficial or harmful, and for which seed sources. Planting stock should be tested on an array of cleared sites in the seed zones of origin, in the physiographic regions that the nursery serves.

Workloads and funding limitations generally prohibit nurseries from doing independent extensive field testing. The strength of any seedling testing program, therefore, largely depends on the nursery's ability to enlist the help of clientele. Field foresters are willing to provide test sites and plant, protect, and measure seedlings of local seed origin because they recognize the direct benefits. Field testing directly supports their tree planting programs, and experience has shown that it is easier and cheaper to insure planting stock of high quality than to explain and rectify plantation failures.

Besides a dedicated nursery cadre, some modest but reliable funding, and enough field cooperators to sample the physiographic regions served, a complete testing program needs a controlled-environment facility. Such a facility is highly desirable even if not absolutely essential. A small greenhouse equipped with basic air conditioning, simple water baths, light banks, and an overhead shade screen serves the purpose and is easily maintained. Field tests provide proof of planting stock quality. Growth capacity tests supply the underlying physiological explanations for success or failure and improve our understanding of seedling requirements. Knowing the **why** of success is the key to achieving and sustaining reliable outputs of high-quality planting stock.

Humboldt's experience shows that an ongoing testing program can build a factual and relevant data base, nail down real nursery problems, indicate studies that are needed to assess and improve cultural practices, permit informed biological decisions, and facilitate nursery management. Nurseries in need of or contemplating such a program should not be deterred by what might appear to be a massive and complex undertaking. The Humboldt program was aggressively managed, but was never unwieldy. To make workloads manageable and guarantee good data, nursery and field tests were deliberately limited in size, design, and number. Cooperators were easily enlisted to carry out the field tests, and the manifest results built confidence in Humboldt's ability to supply high-quality stock for Pacific Slope forests.

THE PROGRAM DESIGN

Planting stock quality was assessed by using standard tests of seedling growth capacity and field performance (*fig. 8*). Beginning with the testing program's initial winter lifting season in 1975-76, studies were designed to assess effects of seed source and cultural practice on

- Seedling top and root growth capacity (TGC, RGC; Stone and Jenkinson 1970, 1971) just after lifting and after cold storage to spring planting time
- Field survival and growth of outplanted seedlings after 1 and 2 years on cleared planting sites in the seed zones of origin

Following a standard sampling scheme, seed sources were selected in the nursery, and seedlings were lifted monthly from autumn to spring, starting in late October or early November and ending in late March. Lifted seedlings were graded, root-pruned, packed in polyethylene bags, and stored at 1° C (34° F). The graded seedlings were subsampled for growth capacity tests just after lifting and after cold storage, and for field performance tests at spring planting time. This approach allowed us to evaluate

Testing Planting Stock Quality

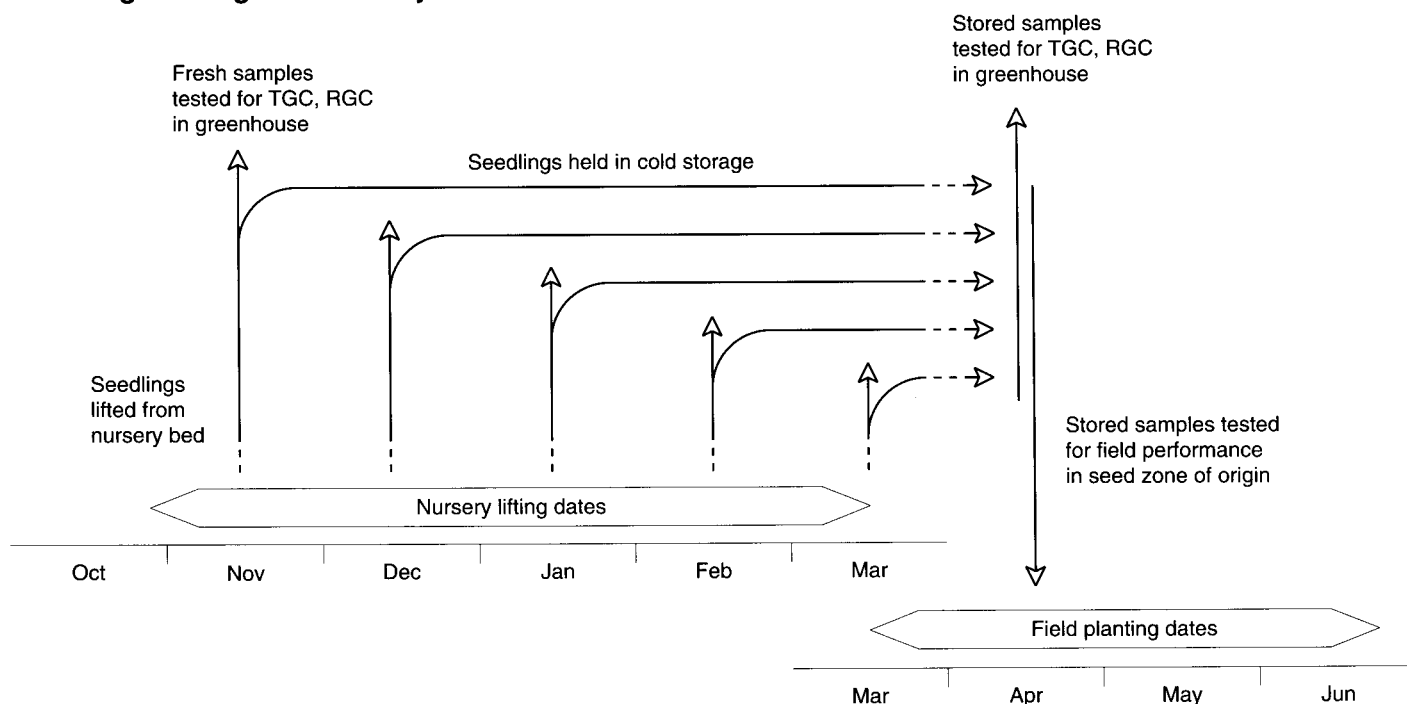


Figure 8—Sequence of standard tests of planting stock quality at Humboldt Nursery. Seedlings in the beds were sampled monthly in autumn to spring, graded, root-pruned, and held in cold storage at 1° C (34° F). Seedling top and root growth capacities (TGC, RGC; Stone and Jenkinson 1970, 1971) were evaluated in greenhouse tests just after lifting and after cold storage, at spring planting time (see fig. 9). Survival and growth were evaluated in field performance tests on cleared planting sites in the seed zones of origin.

- Seasonal patterns of seedling TGC and RGC in the nursery, through the winter lifting season
- Combined effects of lifting date and cold storage on seedling TGC and RGC at spring planting time
- Combined effects of lifting date and cold storage on survival and growth of outplanted seedlings
- Relation of first-year field survival to seedling RGC after cold storage, at spring planting time
- Critical seedling RGC for first-year survivals, to estimate severity of planting site environments

First-year field survivals indicate the percentages of seedlings that had RGC higher than critical, that is, RGC higher than the lowest RGC associated with survival on the planting site. Where seedlings are properly planted and immediately protected, first-year survival depends on the soil type, topographic position, and weather from planting time in spring to onset of winter. Under these conditions, the critical RGC is typically low. Where seedlings are poorly planted or not protected, however, mortality is often excessive, and the critical RGC may be greatly inflated.

PROGRAM ACCOMPLISHMENTS

As accomplishments of the seedling testing program accrued, Humboldt Nursery's cultural regimes and lifting and cold storage schedules were reshaped. By adhering to our new and proven management guides, Humboldt has consistently produced large 1-0, 2-0, and 1-1 Douglas-fir, achieved dramatic gains in seedling yield and planting stock quality, and greatly improved cost efficiency. Annual tests of seedling top and root growth capacity (TGC, RGC) after cold storage, at planting time, have indicated high survival and growth potentials for seedlings of every seed source and stock type.

Results of specific studies led directly to major changes away from Humboldt's traditional practices. Lifting and cold storage schedules were expanded to include November to late March, encompassing the entire winter season. The seedling cultural regime

for 1-0 planting stock was developed by combining extended seed chilling and sowings in midwinter to early spring with heavy fertilization just after seedling emergence was complete. The traditional cultural regime for 2-0 planting stock was replaced with one that coupled the 1-0 cultural regime to double undercutting in spring of the second growing season. Improvements in soil management, seed treatment, and seedling fertilization, irrigation, lifting, handling, and cold storage, together with a system for monitoring soil and seedling conditions during harvest, all stemmed directly from the testing program. In brief, the program

- **Determined seasonal patterns of TGC and RGC of Douglas-fir** from coastal and inland regions in western Oregon and northern California, **Shasta red fir, white fir, and incense-cedar** from the Klamath Region, and **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** from the Oregon Coast Range. The TGC patterns, except those of incense-cedar and western redcedar, which show high TGC in autumn and winter, are sigmoidal and show that winter chilling promotes budburst and shoot extension. The RGC patterns are of three distinct types, showing either a single peak, two separate peaks, or a high plateau, and typify the genetic diversity found in seedling response to nursery climate.
- **Determined cold storage effects on TGC and RGC of Douglas-fir** from coastal and inland regions in western Oregon and northern California, of **Shasta red fir, white fir, and incense-cedar** from the Klamath Region, and of **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** from the Oregon Coast Range. Cold storage at 1° C (34° F) completes the chilling needed for rapid budburst and shoot extension, and either increases or decreases RGC, depending on seed source and lifting date.
- **Determined seed source lifting windows**, that is, the safe calendar periods to lift seedlings for cold storage and spring planting, for **Douglas-fir** in 74 field tests in coastal and inland regions of western Oregon and northern California, for **Shasta red fir and white fir** in 6 tests in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** in 20 tests in the Oregon Coast Range. Lifting windows are reliably defined by first-year survivals on cleared sites in the seed zones of origin, and are used to schedule lifting of tested and untested seed sources.
- **Evaluated 2-year survival and growth of Douglas-fir** in 68 field tests in coastal and inland regions of western Oregon and northern California, of **Shasta red fir and white fir** in 4 tests in the Klamath Region, and of **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** in 19 tests in the Oregon Coast Range. Survival and growth are uniformly high within the seed source lifting windows; outside these windows, survival is lower and growth is often slower.
- **Determined relation of first-year field survival to RGC at planting time** for **Douglas-fir** on 35 sites in western Oregon and northern California, for **Shasta red fir and white fir** on 5 sites in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** on 15 sites in the Oregon Coast Range. In tests in coastal and inland regions, RGC after seedling cold storage explained 90 to 99 percent of the variation in first-year survival.
- **Estimated critical RGC**, that is, the lowest RGC associated with first-year survival, for **Douglas-fir** on 35 sites in western Oregon and northern California, for **Shasta red fir and white fir** on 5 sites in the Klamath Region, and for **noble fir, grand fir, Sitka spruce, western hemlock, and western redcedar** on 15 sites in the Oregon Coast Range. Critical RGCs for known sites can be used to predict first-year survivals of planting stock destined for similar sites in the same or adjacent seed zones.
- **Developed 1-0 Douglas-fir** for coastal and inland regions of western Oregon and northern California. Large 1-0 planting stock with high survival and growth potentials is produced by using the management guides that were developed for soil preparation, extended seed chilling, sowing in midwinter to early spring (January-March), and heavy fertilization after seedling emergence.
- **Developed spring undercutting regimes to carry 1-0 Douglas-fir over for 2-0 stock.** Undercutting second-year seedlings at 15 cm (6 in) in March and again at 20 cm (8 in) in May can control top height, increase root mass, and consistently result in balanced planting stock.

- **Red-flagged mycorrhizal inoculation, root wrenching, and freeze storage**, practices that had been proposed to improve the field performance of traditional **2-0 Douglas-fir**. Inoculating May sowings reduced the survival and growth of coastal seedlings and the survival of inland seedlings. Wrenching reduced the survival of coastal seedlings, but improved that of inland seedlings. Freeze storage at -1° C (30° F) reduced the survival of inland seedlings and the growth of coastal seedlings.
- **Determined safe precooler storage of Douglas-fir** destined for coastal and inland regions of northern California. Seedlings waiting to be graded and packed can be held 15 days at 1° C (34° F) under wet burlap in plastic totes in the precooler, with no loss in field survival and growth potentials.
- **Defined site planting windows for Douglas-fir** at middle elevations in the coastal regions of northwest California and southwest Oregon. Sites dominated by Pacific Ocean air can be safely planted from October to May by using newly lifted seedlings in autumn, either newly lifted or stored seedlings in winter, and stored seedlings only in spring, after root elongation resumes in the nursery.

Field performance tests vividly illustrated the most important results and persuasively communicated implications for reforestation. Cooperators that installed and measured field tests observed take-home lessons right on the planting sites. These tests invariably demonstrated safe times to lift and store seedlings for spring planting, and more often than not, warned clients of possible shortfalls in their planting programs. Improved site preparation and immediate protection of planted seedlings against competing vegetation and browsing mammals proved to be widespread needs.



Douglas-fir seedlings in their second growing season in Humboldt Nursery, looking south in G Block

STANDARD TESTING PROCEDURES

Standard tests and testing procedures save time, avoid confusion, yield reliable data, facilitate the conduct of related studies, provide continuity of results, and permit direct comparisons within and between years. Tests of seedling top and root growth capacity (TGC, RGC) at lifting and after cold storage were run in a controlled-environment greenhouse built at the nursery. Field performance tests were installed in spring on cleared planting sites in the seed zones of origin, with rare exceptions. Data from these standard tests were used to relate first-year field survival to RGC after seedling cold storage, and to estimate values of critical RGC for the planting sites. Detailed instructions were prepared for those who wish to evaluate the growth and survival potentials of delivered planting stock (see Appendix C, Growth Capacity Test Instructions).

Seed Source Selection

The seed sources chosen for testing are of major importance to the scientific credibility of results and the scope and practical application of results. Seed sources typical of forests in the physiographic regions served by the nursery should be assessed in every major study, to insure results that are comprehensive. At Humboldt Nursery, that has always meant testing seedlings destined for coastal and inland regions of western Oregon and northern California.

To the extent possible, seed sources were chosen to sample the genetic variation associated with environmental gradients on the Pacific Slope, on coast-inland transects from the Pacific Ocean to the Cascade Range-Sierra Nevada and along latitudinal transects in the coastal and inland regions of western Oregon and northern California. In every region, practical choices were made to include seed zones that covered extensive areas of current and projected future reforestation efforts.

Choices available in most years were dictated by the seedlots sown, that is, by whatever seed sources the clientele had ordered. Possible best sources for testing were first located in the nursery inventory and then inspected in the seedbeds. Pacific Northwest and Southwest Region seed bank records were used to identify large seedlots of broad genetic base, and

to avoid small seedlots or older seedlots of uncertain origin. Selections of sources in the nursery were made in October, to be sure that seedlings of good morphological grade were available in quantity.

For studies designed to explore alternative nursery practices and new seedling cultural regimes, large seedlots of broad genetic base and high seed quality were selected from the seed bank inventories of both Regions. Again, seed sources were chosen in seed zones and elevations typical of coastal and inland regions in western Oregon and northern California.

Monitoring Nursery Climate

Nursery soil and air temperatures and rainfall occurrence and amounts were recorded to describe environmental conditions during seed germination and seedling emergence, early growth, and dormancy, and to address questions about influences of maritime climate on seedling physiological condition. In most years, monitoring extended from September to April, to cover the autumn onset and spring release of seedling dormancy and span the winter lifting season.

Soil temperatures were recorded at depths of 8 cm (3 in) and 13 cm (5 in). Thermograph probes were inserted horizontally into the soil profile in plots that were kept free of weeds but not cultivated. Temperature traces at 8 cm reflect diurnal changes in air temperature and show fluctuations typical of the upper root zone. Traces at 13 cm reflect the more stable environment of the lower root zone, and are paired with traces at 8 cm to evaluate daily and seasonal temperature gradients in the soil-root profile.

Air temperatures were recorded by a calibrated hygrothermograph and min-max thermometers housed 1.5 m (5 ft) above ground in a weather shelter. Rainfall was measured by a precipitation gauge positioned near the weather shelter, and was recorded at 8 A.M. on workdays during and after each storm.

Natural cold exposure or chilling of seedlings in the nursery was estimated from the diurnal traces of air temperature graphed in late autumn and winter. Seedling chilling from October 1 to any particular lifting date was expressed as the sum of hours that air in the nursery was cooler than 10° C (50° F). The use of any lower threshold temperature practically precluded meaningful estimates of chilling rates in Humboldt's maritime climate.

Seedling Sampling and Handling

Douglas-fir seedlings that were sampled in the first 4 years of the testing program (see Seed Source Assessments-Douglas-fir), and all of the seedlings that were sampled for other conifers (see Seed Source Assessments-Other Conifers), were grown under Humboldt's traditional cultural regime (see Reforestation and the Nursery, Standard Cultural Practices). In 1979, the program was necessarily expanded to include the development of two new cultural regimes, one to produce 1-0 Douglas-fir and the other to carry holdover 1-0 seedlings for 2-0 planting stock (see Assessing Nursery Culture Alternatives).

Sampling in most years was done through the calendar period in which seedlings conceivably might be lifted. Seedlings of selected seed sources were sampled monthly, beginning in November and ending in March. Seedlings of a few sources were also sampled in October, to test the belief that lifting for overwinter cold storage before root growth had ceased in the nursery would result in planting stock that had zero growth capacity and no survival potential at spring planting time.

Intervals of 1 month between lifts were sufficient to reveal changes in seedling growth capacity and to provide the time needed for growth capacity tests. Actual calendar dates for sampling and testing were mapped out in October, to skirt weekends and holidays and schedule the work needed to end the preceding test, lift the next set of seedlings, and install the new test. Each sampling schedule included a series of short time cushions to allow for the anticipated, unavoidable delays caused by inclement weather or wet soil conditions.

Sampling plots in the nursery were flagged in October. All sampling was done in beds containing average and larger seedlings at stockings of 25 to 35 stems per square foot (270 to 380 stems per m²). Seed source plots measured 10 ft (3 m) long, were mapped by field (block), section, bed, and distance in from the ends of the bed, and were recorded in the study plan and sampling schedule. The source

plot areas were staked with colored plastic flags to mark them for the sampling crew and prevent accidental lifting by the harvest crew. Locations where sampling plots would unduly interfere with harvest operations were avoided.

About 200 seedlings were sampled for each seed source and lifting date, or for each combination of source, date, and cultural treatment. Seedlings were dug with round-point shovels with sharpened blades that measured 5 inches (13 cm) wide and 12 inches (30 cm) long. Monthly sampling spanned the width of the bed and proceeded in sequence from one end of the plot. This strategy sampled all eight rows and standardized cutting of the lateral roots of residual seedlings. Machine lifting causes less root damage and is much easier, but is too costly and wasteful an option for the periodic taking of small samples.

Lifted seedlings were labeled with plastic tags to show seed source and cultural treatment, wrapped in wet burlap in plastic totes or polyethylene bags, and brought to the greenhouse. Following standard practice for 2-0 planting stock, seedlings were graded to a stem diameter of 4 mm (0.16 in), root-pruned 25 cm (10 in) below the cotyledon node, and culled for damage, deformity, or excessive size. Graded seedlings were randomly sorted into 16 sets of 10 each, and each set was labeled to show seed source, lifting date, and treatment.

Seedlings of three randomly drawn sets were tested for top and root growth capacity (TGC, RGC) just after lifting ($n = 30$). The remaining 13 sets were held in cold storage until spring planting time, when three more sets were drawn and used to test seedling TGC and RGC ($n = 30$) and 10 sets were used to test field performance ($n = 100$).

Stored seedlings were sealed in new polyethylene bags or double-walled, polyethylene-lined paper packing bags and maintained in coolers that were operated to hold seedling temperatures at 0-1° C (32-34° F), not to exceed 1.5° C (35° F) in the bag. The seedling tops were dipped in a suspension of captan fungicide (0.4 percent) to prevent molds, and the roots were packed in moist shingle tow to absorb any free water in the bag.

Growth Capacity Tests

Seedling top and root growth capacities (TGC, RGC) were determined by planting seedlings in a controlled-environment greenhouse and measuring their new shoots and roots after 28 days (*fig. 9*). Groups of five to seven seed sources were tested concurrently just after lifting. Groups of two to three sources that had been sampled on the same lifting dates were tested together after cold storage, at spring planting time. Series of tests were started at weekly intervals in order to have enough time to install each new test and evaluate that just completed. Three sets of 10 seedlings each were tested for each combination of seed source, lifting date, and cultural treatment ($n = 30$).

Each seedling set was planted in a stainless steel container, or tray. Each tray was 7.5 by 37.5 by 30 cm (3 by 15 by 12 in) deep, and held 8 liters (2 gal) of a moist soil mix of shredded redwood, perlite, river sand, and Humboldt Nursery's Arcata sandy loam (1:1:1:1). After planting, trays were irrigated until water flowed freely from the drain ports, drained overnight, weighed to the nearest 0.1 kg (0.25 lb), and sealed with rubber stoppers.

The watertight trays were immersed to within 1 cm (0.4 in) of their rims in stainless steel water baths. The trays were randomized to place seedlings of each seed source in three separate baths. The baths, arranged in rows of four each, held six trays apiece and were individually controlled to maintain the soil and seedling roots at temperatures of $20^{\circ} \pm 0.5^{\circ} \text{C}$ ($68^{\circ} \pm 1^{\circ} \text{F}$). Water was circulated constantly through an external tube-bundle heat exchanger, to extract the excess heat generated by a submersible water pump positioned on the bath floor.

Greenhouse air was circulated by a ducted fan, and was warmed or cooled as needed to hold air temperatures above 17°C (63°F) at night and below 25°C (78°F) in sunlight. Photoperiod was extended to 16 hours. Self-ballasted mercury-phosphor lights, centered 1 m (3.28 ft) above the baths, were set to operate from 6 to 8 A.M. and 4 to 10 P.M., and produced 30 W/m^2 at seedling level. In October and in March-June, a polypropylene screen (53

percent shade) was installed over the greenhouse to reduce incident sunlight and permit effective air conditioning.

Water lost by transpiration and evaporation was replaced weekly. Trays were removed from the baths, unstoppered to permit even percolation, placed on a scale, watered to the initial recorded weights, stoppered, and returned to the baths. Bath water levels and thermistor readings were checked morning and evening to insure uniform soil-root temperatures.

After 28 days, the trays were removed from the baths, unstoppered, flooded from below in a tank of water, and gently emptied onto a sloped drain table. Seedlings were washed free of soil by using the dispersing stream of a waterbreak, wrapped in wet paper towels, stored in polyethylene bags at 1°C (34°F), and measured within 3 days in order to avoid browning of the new roots. New root elongation is white and is easily seen and measured (Stone and Schubert 1959a, Stone and others 1962).

Seedling top and root growth capacities (TGC, RGC) were expressed as follows:

TGC

- Budburst, the percent of seedlings with new shoots extended $>2.5 \text{ mm}$
- Shoot extension, the length of the longest new shoot $>1 \text{ cm}$, per seedling

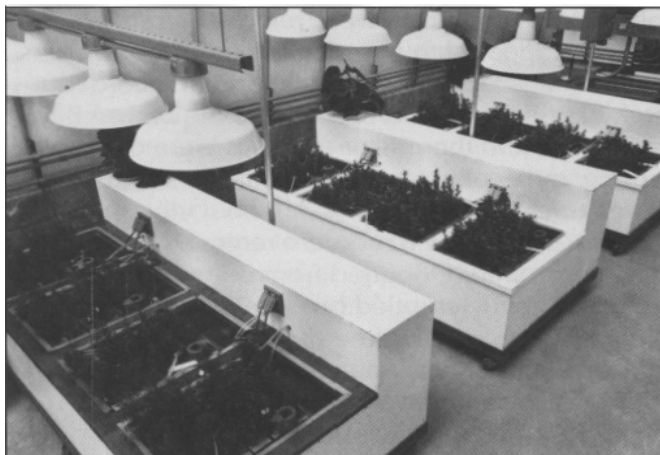
RGC

- Root elongation, the new length of roots elongated $\geq 1.5 \text{ cm}$, per seedling
- Roots elongated, including the number $\geq 1.5 \text{ cm}$ and the number $>2 \text{ mm}$ but $<1.5 \text{ cm}$, per seedling

New root length is a direct measure of a planted seedling's ability to reach available soil water, and is the preferred measure of RGC. Counting the longer new roots is a satisfactory alternative, however, and is less tedious and faster than evaluating length. Tallying new roots in both the long and short categories estimates the number of active root tips, and is a useful way to measure RGC when root elongation is especially slow.

TESTING SEEDLING TOP AND ROOT GROWTH CAPACITY

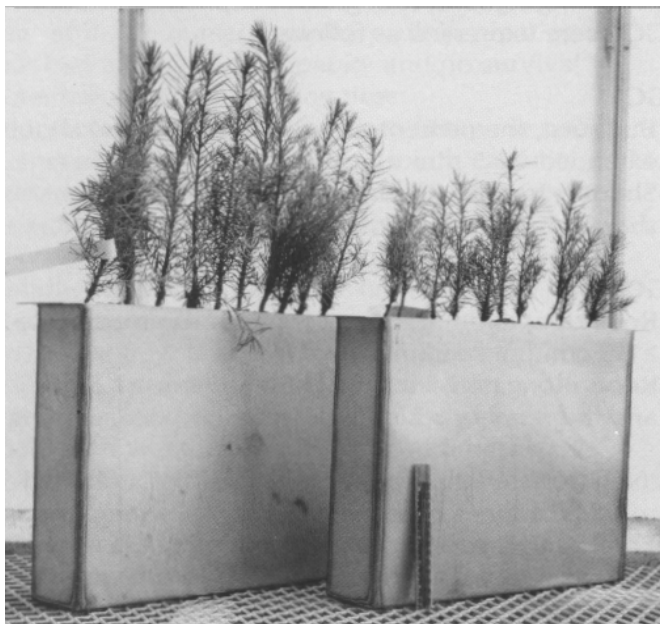
A Overview of test environment



B Plant seedlings in watertight trays



C Irrigate seedlings, drain overnight



D Hold trays in water baths 28 days



Figure 9—Procedure for testing seedling top and root growth capacities (TGC, RGC) at Humboldt Nursery. Test seedlings were held in a standard controlled environment and evaluated for budburst or shoot extension and new root elongation after 28 days.

The tests were run under a 16-hour photoperiod in an airconditioned greenhouse (A). The seedlings were planted in a moist soil mix in watertight trays (B, C). The trays were irrigated, drained overnight, sealed with rubber stoppers, and immersed to the rims in constant-temperature water baths (C, D). The bath thermostats were set to maintain the seedling roots at 20° C (68° F).

To lift seedlings for evaluation, stoppers were removed and the trays were flooded from below in a plastic tote filled with water (E). The soil mass was eased onto a sloped drain table, and the roots were washed clean with the dispersing stream of a waterbreak (F).

E Flood trays from below



F Wash soil from roots



Field Performance Tests

Survival and growth of outplanted seedlings were determined on cleared planting sites in the seed zones of origin. Ten sets of 10 seedlings each were tested for each combination of seed source, lifting date, and cultural treatment ($n = 100$).

Outplanting arrangements were made well in advance of spring planting. The program manager (J. Nelson) lined up field test cooperators in autumn, as soon as seed lots were screened and selected in the nursery beds. Copies of the completed study plan were mailed soon thereafter. Cooperators were asked to install their tests in the planting units that had been prepared for the stock ordered. By this means, tests were installed on an array of planting sites that covered the spectrum of climatic and edaphic conditions found in clearcuts and after wildfire on the Pacific Slope (see Appendix D Planting Site Descriptions).

Graded seedlings for each field test, labeled in 10 replications of 10 per lifting date and cultural treatment, were held in cold storage at Humboldt Nursery. When cooperators were ready to install their tests, the appropriate seedlings were packed in an insulated ice chest and delivered by the program manager. This procedure allowed him to inspect the clients' cold storage facilities, answer cooperators' last-minute questions about purposes, installation, and maintenance of tests, and guarantee the proper handling of test seedlings right up to planting time. Additional copies of the study plan, planting design, and report form to be used were delivered with the seedlings.

Most cooperators installed their field tests after their own planting programs were completed for the year. This practical approach prolonged seedling cold storage and enhanced the credibility of test results. Almost every test was planted within the site planting window, that is, after soil was daily warming above 5°C (41°F) at a depth of 8 cm (3 in) and before the last spring rain (Jenkinson 1980).

The test layout consisted of 10 replications of a randomized complete block of lifting date plots. Where the lifting date plots were simple in design, each plot contained a single row of 10 seedlings. Where they were split for cultural treatment, each of the treatment plots contained a single row of 10 seedlings. Test blocks were oriented so that the plot rows ran up the prevailing slope. The blocks were clustered or separated as needed to avoid rock outcrops, tree stumps, and logging slash.

Planting holes were supposed to be made with a powered soil auger, and seedlings were to be spaced 2 ft (0.6 m) apart. Most cooperators, however, used the traditional planting hoes, that is, hoedags or

used shovels (Greaves and Hermann 1978). A few cooperators opted to use a spacing of 3 ft (0.9 m) or 4 ft (1.2 m), but wider spacings were discouraged because they greatly increase the work needed to install, maintain, and evaluate tests.

Every study plan contained a planting design and a standard report form for the specific test layout. Two types of forms were devised, one for tests using a simple plot design and the other for those using a split-plot design. The forms were used to map seedlings in each plot and block, and to monitor site conditions, score seedling vigor, top activity, and damage, and record survival and growth (see Appendix E, Field Test Data Forms).

First-year survival was recorded in autumn. In most tests, survival was recorded monthly through the first summer, and in some it was recorded again in the following spring. During the monthly checks, live seedlings were individually scored for budburst, shoot extension, and general appearance, and for any damage caused by deer, elk, mountain beaver, gophers, rabbits, or cattle. Invading vegetation was noted as it developed, and was removed at the discretion of cooperators.

Seedlings were measured for height, leader length, and basal stem diameter in autumn of the second year. If a seedling was missing its leader, the length of its longest new shoot was measured instead. Because they wanted additional information, dedicated cooperators measured a few tests the first year and a host of tests for 3, 4, and more years.

All tests were supposed to be protected against plant competition and animal damage (Greaves and others 1978). In reality, protection ranged from prompt and highly effective to none. Browsing mammals destroyed some tests outright, ate the new leaders and laterals in many others, and repeatedly proved the high cost of inattention to seedling protection. Such losses did not cripple the testing program, but did create annoying gaps in our data base. The level of protection depended largely on the Ranger District or Resource Area, that is, on local practices for new plantations and the workloads and resources of individual cooperators.

All new tests were reviewed on the ground in autumn. Reviews in later years included most of the second-year tests and many highly successful older tests. The program manager arranged these trips to photograph the planting sites, test blocks, and typical surviving seedlings, and was accompanied by the Pacific Southwest Region's reforestation specialist (M. Knight) and the Pacific Southwest Station's cooperating plant physiologist (J. Jenkinson). Local cooperators always joined in, and usually included the forest silviculturist and other timber staff. The reviews were informal, and time spent on any one

site was short, but the perspectives and slide files gained proved invaluable for interpreting results, judging implications, and reporting findings. Perhaps as important, these reviews quickly became open forums for candid exchanges on all aspects of reforestation. They stimulated great interest in the testing program, developed strong support for it, and sustained the morale and efforts of people on the ground and in the nursery.

Variance Analyses

Variance analyses were run to assess seed source and lifting date effects on seedling top and root growth capacities (TGC, RGC) just after lifting and after cold storage, and to assess lifting date effects on survival and growth on cleared planting sites in the seed zones of origin.

Seedling TGC and RGC—Analyses of TGC and RGC just after lifting were run on groups of seed sources that were sampled on the same set of lifting dates. Seed source and lifting date effects were assessed using variance analysis program BMD P8V, with sources and dates fixed and replications random (Jennrich and Sampson 1985).

Because the field tests of stored seedlings were installed on dates ranging from March 10 to June 19, the analyses of TGC and RGC after cold storage were run on each seed source separately. The combined effects of lifting date and cold storage were assessed using variance analysis program BMD P2V, with dates fixed and replications random (Jennrich and others 1985).

Least significant differences (LSD, $p = 0.05$) between lifts were calculated by $LSD = q[ems/r]^{1/2}$, where ems is error mean square from program P2V run on individual seedling data for the seed source. In tests of five lifts of 30 seedlings each, for example, $r = 30$ and $q = 2.81$ for 116 degrees of freedom (Steel and Torrie 1960).

Field survival and growth—Analyses of survival and growth in field tests, like those of TGC and RGC after cold storage, were run for each seed source separately. Survival was analyzed using the number of live seedlings remaining in each plot. Growth traits, that is, height, leader length, and basal stem diameter, were analyzed using the mean of survivors in each plot. Lifting date and cultural treatment effects were assessed using variance analysis program BMD P8V, with dates and treatments fixed and blocks random (Jennrich and Sampson 1985).

Least significant differences (LSD, $p = 0.05$) between lifts were calculated by $LSD = q[ems/r]^{1/2}$, where ems is error mean square from program P8V. In tests of five lifts and 10 blocks, for example, $r = 10$ and $q = 2.87$ for 36 degrees of freedom (Steel and Torrie 1960).

Correlation Analyses

Correlation analyses were used to survey the effects of seedling cold storage on TGC and RGC, to evaluate the relation of first-year survival to RGC after cold storage, at spring planting time, and to estimate critical RGC for the planting site.

Surveying cold storage effects—Coefficients of determination, r^2 , were calculated for $Y = a + bX$, where Y is TGC or RGC after cold storage and X is TGC or RGC just after lifting. Seedling TGC is expressed as budburst, percent, and RGC, as new root length, cm ($n = 30$ seedlings per lift). Low values of r^2 indicate large changes in TGC and RGC during cold storage, and warn that survival should be related to TGC and RGC at spring planting time, after cold storage and not just after lifting.

Relating field survival to RGC—Coefficients of multiple determination, R^2 , were calculated for $Z = b \ln(Y + 1) + c[\ln(Y + 1)]^2$, where Z is first-year survival, percent ($n = 100$ seedlings per lift), and Y is RGC after cold storage, at spring planting time. Seedling RGC is expressed as new root length, cm, or number of roots elongated ($n = 30$ seedlings per lift). This equation reflects the fact that zero RGCs in greenhouse tests invariably signal near-zero survivals in field tests.

Estimating critical RGC for the site—Coefficients of determination, r^2 , were calculated for $Z = bY_1$, where Z is first-year survival, percent ($n = 100$ seedlings per lift), and Y, is the percent of seedlings ($n = 30$ per lift) having RGC greater than some minimum level after cold storage, at spring planting time. Critical RGC is estimated as the minimum new root length, cm, or number of roots elongated, that generates values of r^2 and line slope, b, closest to 1.00. The array of RGC values tried will normally include $\geq 5, 10, 20, \dots 100$ for both root length and roots elongated.



*Douglas-fir regeneration unit after broadcast burning and spring planting:
Internal views of Flat Cant unit 30, looking toward Quartz Creek and across
slope to Muslatt Mountain*



MOVING INTO THE '90'S

Studies and accomplishments described in the preceding chapter allowed us to develop two entirely new seedling cultural regimes, one for 1-0 and one for 1-1 planting stock, as well as to transform the traditional cultural regime for 2-0 stock. Each regime was tested and adjusted in operational trials in Humboldt Nursery before it was adopted as standard practice. Humboldt ran the trials to gain confidence in the guides derived from the seedling testing program, and to translate our findings into working procedures without wholesale risks to reforestation.

All traditional cultural regimes should be revised with care, and never before the changes proposed have been evaluated by appropriate testing. Most traditional regimes have been compromised at one time or another, usually by dropping established practices or by adding unproven ones. The worst changes have invariably been made without actual knowledge of their final effects on the yields, sizes, and growth capacities of harvested seedlings, much less on the field survivals and growth of outplanted stock.

Traditional regimes may be derived empirically, but they work because seedling requirements are accommodated, whether or not those requirements are known. Because every nursery operates with a unique combination of climate, soil, and seed sources, no wise manager drops old practices or adopts new ones without first assessing the effects on seedling production and planting stock quality. To do otherwise risks losses of valuable seeds, site resources, and years of forest productivity, not to mention added costs of repeated seed collection, seedling production, site preparation, tree planting, and plantation protection. Such risks are never acceptable, economically or professionally.

Past shortfalls in Humboldt Nursery have shown that arbitrary changes in the traditional regime can imperil seedling production. We remember the sorry outcomes of discontinuing critical practices and importing "improved" ones from nurseries situated in other climatic regions. Our assessments of culture alternatives witness the fact that adopting proposed practices without first evaluating them in nursery and field tests will likely harm stock quality, not improve it (see *Assessing Nursery Culture Alternatives, Testing Proposed Practices*).

At the outset of the seedling testing program, we suspected that our findings might lead us to revise Humboldt's traditional regime for 2-0 stock. We had no idea that they would lead us to create new regimes for 1-0 and 1-1 stock (see *Assessing Nursery Culture Alternatives: Growing Seedlings for 1-0 Planting Stock; Evaluating Size and Performance of 1-0 Stock; Topdressing Early Sowings with NPS; Using 1-0 Stock in Planting Programs; Determining Nursery Sowing Windows*). Because the testing program gave us the means to obtain direct answers to fundamental and practical questions, we were able to develop an integrated set of reliable regimes for the three stock types.

Time lines for the standard 1-0, 1-1, and 2-0 regimes currently used in Humboldt Nursery are diagrammed in *figs. 39 and 40*. In brief, high-quality stock of each type is produced as follows:

- 1-0 planting stock (*fig. 39*). Seeds are soaked 24 hours in warm, aerated water at 21° C (70° F), chilled 90 days at 1° C (34° F) (*fig. 41*), and sown sometime in the period from early January to late March (midwinter to early spring). Granular ammonium phosphate sulfate (NPS 16-20-14) fertilizer is banded between the seedling rows from 1 to 2 months after seedling emergence is complete (*fig. 42*). To support continuous growth, seedlings are irrigated to a depth of 30 cm (12 in) twice weekly in summer and autumn. The 1-0 seedlings are lifted sometime in the period from late December to the middle of March, depending on seed source (see *Seed Source Assessments—Douglas-fir, table 3*). Lifted seedlings are root-pruned 25 cm (10 in) below the cotyledon scars, packed in the standard double-walled paper bags, and held in cold storage at 1° C until spring planting time (see *fig. 7N-Y*).
- 1-1 planting stock (*fig. 39*). Fully chilled seeds (*fig. 41*) are sown sometime in late February to early April (late winter to midspring). Granular NPS (16-20-14) fertilizer is banded between the seedling rows from 1 to 2 months after emergence is complete (*fig. 42*). The 1-0 seedlings are lifted sometime from late December to the middle of March, root-pruned 13 cm (5 in) below the cotyledon scars, and stored at 1° C (34° F) until

Cultural Regime for 1-0 and 1-1 Douglas-fir

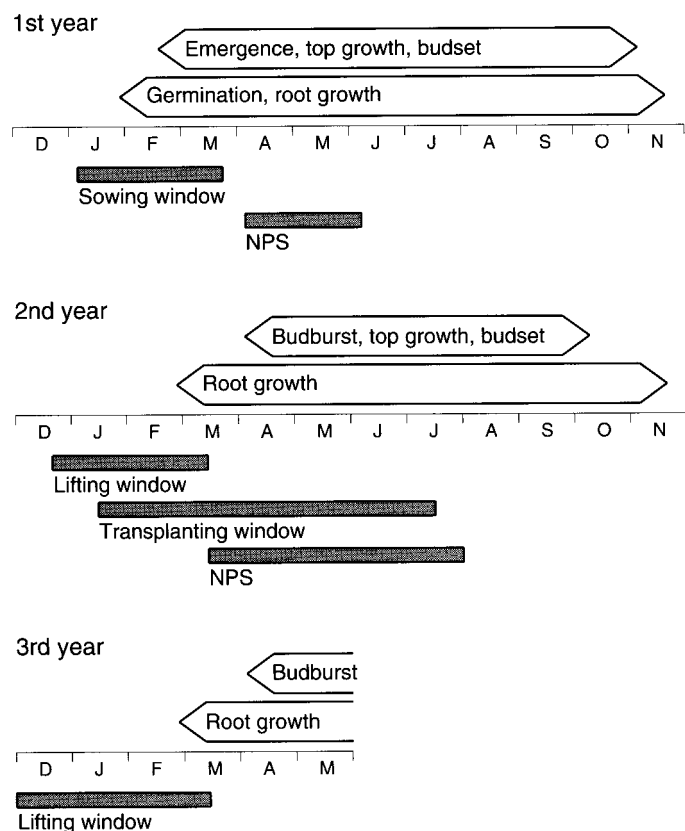


Figure 39—Seedling cultural regime for producing 1-0 and 1-1 Douglas-fir in Humboldt Nursery. Seeds are chilled 90 days and sown in January–March (*fig. 41*). Granular ammonium phosphate sulfate (NPS 16-20-14) is banded 1 inch (2.5 cm) deep between the seedling rows in April–May, to supply 100 lb N per acre (112 kg N per ha) 1 to 2 months after seedling emergence (*fig. 42*).

The 1-0 seedlings are lifted in late December to late March, within known seed source lifting windows (see Seed Source Assessments—Douglas-fir, *table 3*). Seedlings for 1-0 planting stock are graded to a stem diameter of 0.1 inch (2.5 mm), root-pruned at 9 inches (23 cm) below the cotyledon node, and stored at 1° C (34° F) for spring planting in the seed zones of origin (see *fig. 7*).

Seedlings for 1-1 stock are root-pruned at 5 inches (13 cm) below the cotyledon node, stored at 1° C, and machine-planted in the nursery in January to July (*fig. 43*). The transplants are banded with NPS in March to August, to supply 100 lb N per acre about 2 weeks after they start root elongation (*fig. 42*).

The 1-1 seedlings are lifted in early December to late March, within known source lifting windows (see Seed Source Assessments—Douglas-fir, *table 3*). They are graded to a stem diameter of 0.18 inch (4.5 mm), root-pruned at 10 inches (25 cm) below the ground line, and stored at 1° C for spring planting in the seed zones of origin (see *fig. 7N-Y*).

transplanted for a second growing season in the nursery. Stored seedlings are transplanted from January to April to produce large 1-1 stock, or from May to August to produce progressively smaller 1-1 stock (*fig. 43*). Granular NPS is banded between the transplant rows after root elongation is underway. The 1-1 seedlings are lifted sometime from late November to the middle of March, depending on seed source (see Seed Source Assessments—Douglas-fir, *table 3*). Lifted seedlings are root-pruned 25 cm (10 in) below the ground line, packed in the standard or larger bags, and stored at 1° C until spring planting time (see *fig. 7N-Y*).

- 2-0 planting stock (*fig. 40*). Fully chilled seeds (*fig. 41*) are sown sometime in February to early April (late winter to midspring). Granular NPS (16-20-14) fertilizer is banded between the seedling rows from 1 to 2 months after emergence is complete (*fig. 42*). The 1-0 seedlings are held in place for a second growing season in the nursery, but if necessary could be lifted for 1-0 stock or transplanted for 1-1 stock. Granular NPS is banded between the seedling rows just before or after root elongation resumes in March (*fig. 42*). To increase root mass and reduce top growth, second-year seedlings are undercut twice in spring, in March at a depth of 13 cm (5 in) and in May at a depth of 18 cm (7 in). Root systems are vertically pruned to a depth of 10 cm (4 in) between the seedling rows in April. The 2-0 seedlings are lifted sometime from late November to the middle of March, depending on seed source (see Seed Source Assessments—Douglas-fir, *table 3*). Lifted seedlings are root-pruned 25 cm (10 in) below the ground line, packed in the standard or larger bags, and stored at 1° C (34° F) until spring planting time (see *fig. 7N-Y*).

Transplanting 1-0 seedlings for 1-1 stock rather than holding them in place for 2-0 stock vastly improves seedling yield, balance, and quality, and is preferred practice at Humboldt Nursery. Experience has consistently shown that transplanting seedlings to a spacing of 6 to 8 per square foot (65 to 86 per m²) results in greater and more uniform radial growth and yields 1-1 stock with cull rates as low as 1 to 5 percent. Moreover, 1-1 stock size, height, and top-root ratio can be markedly reduced by delaying transplanting until summer. Transplanting in April, May, June, July, and August yields 1-1 stock with progressively shorter tops and lower top-root ratios (Nelson and Jenkinson 1992).

Cultural Regime for 2-0 Douglas-fir

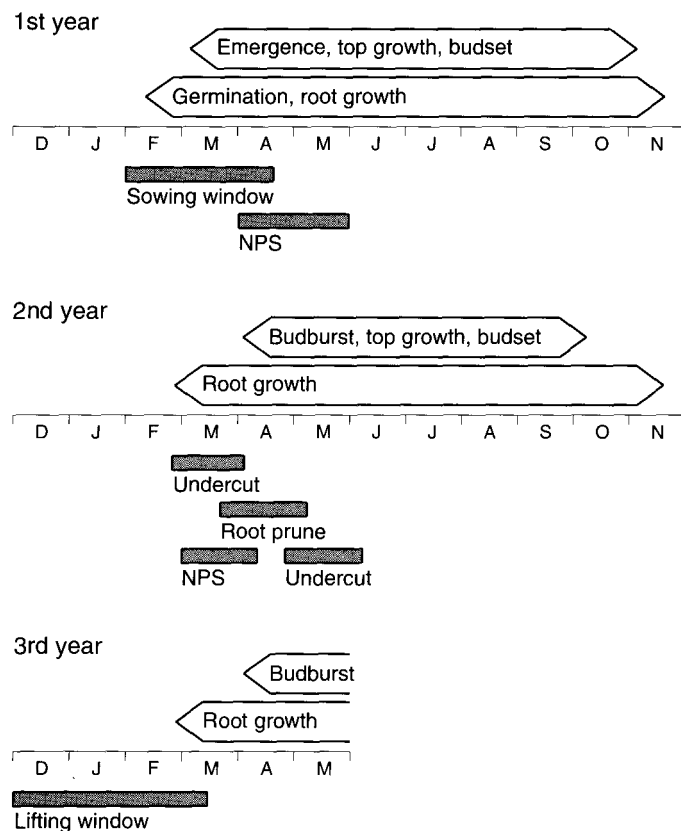


Figure 40—Seedling cultural regime for producing 2-0 Douglas-fir and other conifers in Humboldt Nursery. Seeds are chilled 90 days and sown in February to early April (*fig. 41*). Granular ammonium phosphate sulfate (NPS 16-20-14) is banded 1 inch (2.5 cm) deep between the seedling rows in April-May, to supply 100 lb N per acre (112 kg N per ha) 1 to 2 months after seedling emergence, and again the following March, when root elongation resumes (*fig. 42*).

To develop fibrous root systems, control height growth, and secure balanced planting stock, the second-year seedlings are double-undercut in spring, at 5 inches (13 cm) in March and 7 inches (18 cm) in May, once before budburst and once after shoot extension is well underway. Roots between the seedling rows are vertically pruned to a depth of 4 inches (10 cm) in April, about 1 month after the first undercut.

The 2-0 seedlings are lifted in December to late March, within known seed source lifting windows (see *Seed Source Assessments—Douglas-fir, table 3*, and *Seed Source Assessments—Other Conifers, table 9*). They are graded to a stem diameter of 0.18 inch (4.5 mm), root-pruned at 10 inches (25 cm) below the ground line, and stored at 1° C (34° F) for spring planting in the seed zones of origin (see *fig. 7N-Y*).

By contrast, holding early-sow 1-0 seedlings in place for 2-0 stock can result in highly variable radial growth and yield 1-1 stock with cull rates of 25 to 35 percent, depending on seed source, sowing date, and seedling stocking (see *Assessing Nursery Culture Alternatives: Carrying 1-0 for 2-0 Planting Stock*, and *Undercutting Early Sowings for 2-0 Stock*). Besides being inherently inefficient, the 2-0 regime is difficult to manage for balanced stock. Successful control of seedling height and top-root ratio is critical, and is easily and reliably achieved by using the 1-0 and 1-1 regimes.

Foresters sometimes change their planting plans, or have them changed by events beyond their control, and necessarily have their planting stock held in the nursery for another growing season, to save it for outplanting the next year. Experience has shown that holding large 1-0 seedlings in place has major disadvantages for both the nursery and clientele. Holding seedlings in place results in unavoidably high cull rates, compromises the culture of seedlings growing in adjacent beds, and disrupts the crop rotation and soil management plans. To guarantee the size, balance, quantity, and quality of stock desired, clients should permit Humboldt to transplant all of their holdover 1-0 for 1-1 stock, rather than save it as 2-0 stock.

Nursery experience has repeatedly shown that all 2-0 seedlings, both holdover and returned stock, can be transplanted anytime from April to July and saved successfully for 2-1 stock. Holdover seedlings in the nursery are lifted within the source lifting windows, root-pruned, and held in cold storage for May-June transplanting. To insure balanced 2-1 stock, roots and tops of holdover and returned seedlings are pruned severely. Roots are pruned 13 cm (5 in) below the ground line to prevent root-sweep or L-rooting by the transplant machine, and to promote the development of bushy, fibrous root systems. Tops are cut back to 25 cm (10 in) to limit new shoot growth and minimize height of the 2-1 stock.

Effective management of seedling cultural regimes in Humboldt Nursery, or in any other forest nursery, depends on knowing how to integrate, schedule, and apply specific practices in ways proven to yield planting stock of high survival and growth potentials. Seedling testing programs are now and will remain the best way to monitor planting stock quality and assess proposed cultural practices. To the extent possible, Humboldt's current and future regimes for 1-0, 1-1, and 2-0 stock will continue to depend on the hard evidence of survival and growth on cleared planting sites in seed zones of origin, in climates and environments typical of the physiographic regions that Humboldt serves.

SEED TREATMENT BEFORE SOWING

A Transfer seeds to mesh bags



Figure 41—Standard seed treatment before sowing in Humboldt Nursery. Seeds are placed in nylon mesh bags (A) and soaked 40 hours at 22° C (72° F) in an aerated water bath until the bags sink below the surface (B, C). Soaked seeds are drained by hanging the bags on racks (A). Drained seeds, loosely enclosed in polybags to keep them moist but allow air exchange, are placed on carts, rolled into a cold room (D), and chilled 90 days at 0-1° C (32-34° F). After 30 days, seeds are spread on wire screens in a forced-air environment (E), surface-dried 2 to 4 hours to prevent premature germination, and rebagged to complete chilling (D).

B Transfer bags to water bath



C Soak seeds until bags sink



D Chill seeds for 90 days



E Surface-dry seeds at 30 days





Figure 42—Machine used to band granular ammonium phosphate sulfate (NPS) fertilizer between rows of newly emerged seedlings, second-year seedlings, and transplanted 1-0 seedlings in Humboldt Nursery. Granules of NPS are fed from the hoppers to the bed by a bank of flexible hoses mounted behind two gangs of paired colters. The colters are set to cut soil channels 1 inch (2.5 cm) deep.



Figure 43—Machine used to transplant seedlings for 1-1 planting stock in Humboldt Nursery. The 1-0 seedlings are root-pruned 5 inches (13 cm) below the cotyledons just after lifting, held in cold storage, and transplanted into six rows per bed. Transplanting results in a bed density of 6 to 8 stems per square foot (65 to 86 stems per m²).



Douglas-fir plantation at age 22, 4 years after thinning: Fox Ridge unit 11-3, with Buck Mountain in distance, and closeup of developing stand and understory



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Humboldt Nursery tests used to develop the seedling cultural regime for 1-0 Douglas-fir: June overview of a sowing windows test in A Block, and May installation of a growth performance test in E Block



APPENDIX

A. HUMBOLDT ORIGINS

Humboldt Nursery was the outcome of a meeting on Douglas-fir regeneration policy, held at Willow Creek, California, October 30, 1958.¹ Present were Forest Supervisors Spinney, Yates, Dasmann, and Stathem of the Klamath, Shasta-Trinity, Six Rivers, and Mendocino National Forests, respectively. They met with B. H. Payne, J. M. Buck, and T. H. Harris, Division of Timber Management, Region 5 (Pacific Southwest Region), and R. K. LeBarron, Division of Forest Management Research, California Forest and Range Experiment Station (now Pacific Southwest Research Station).

Anticipating a need for 6 to 8 million seedlings per year, and thinking that existing nurseries (the old Parlin Fork State Nursery and the Forest Service Placerville Nursery) could supply no more than 5 million, even with expansion, the group proposed a new nursery. It would be located on Six Rivers National Forest and would be able to "supply all of northwestern California and southwestern Oregon," assuming that Region 6 (Pacific Northwest Region) "wished to come in" with Region 5. Spinney proposed two agricultural sites on National Forest land, and LeBarron suggested that seedbeds be set out on each site to see what problems might be encountered. The comment was made that "nursery site selection will be dependent upon features of satisfactory stock production and accessibility to units using Douglas-fir planting stock."

According to a 1979 "interview" conversation between E. D. Perry, then Humboldt's second Manager, and C. W. Brown, Forest Silviculturist (retired), Six Rivers National Forest, land availability and costs were the ultimate determining factors.² The sites first suggested apparently had proved unsuitable, so in 1960, Brown, then Forest Culturist on Six Rivers National Forest, was given the task of finding a 60-acre site that had "fairly level ground, sandy soil, water available (preferably well water) with a capacity of 40 gallons per minute, and access for transportation and a labor force." By 1961, Brown, posing as a soil scientist checking the validity of a 1914 soil survey map, had looked at some 60 potential sites scattered the length and breadth of the

Six Rivers region, and all to no avail. Finally, "the Forest Service advertised for a site," and an employee of a meat packing company in Eureka called to say that his boss owned 129 acres in McKinleyville. Part was leased to Cottage Gardens Rhododendron Nursery and the rest was pasture land. The soil and water resources, including rights to the Bullwinkle Creek water supply, were found to be acceptable and the decision was made to acquire the entire property. The understanding was that surplus land, including the Cottage Gardens acres, would be sold at a later time.

To get started, the Six Rivers National Forest leased 46 acres from 1962 to 1964. Henry (Hank) Doll, the new nursery's first superintendent, rented a 28-ft house trailer to use as an office. Survey lines were run, pit toilets were dug, a wheeled tractor and then a crawler were acquired, and Humboldt Nursery was in business with its first sowing in the spring of 1962. As Brown tells it, the first crop was harvested in the winter of 1963-64 and planted on the Six Rivers and Klamath National Forests. "The seedlings did well. In 1963 we contracted for the first packing shed, now our equipment maintenance shop. It had to be portable, as did the reservoir and irrigation system and any other improvements, because we were still leasing the property."

The entire property, 129 acres, rhododendrons and all, was purchased in 1964. Fourteen years later, the remaining rhododendrons were in landscape plantings around the nursery buildings, and the annual harvest was 18 million seedlings. Adjacent properties were purchased from three neighbors in 1975 and 1976, including 30 acres each from Al Thoma and Al Hartman to the west and 20 acres from Robert Balke to the northeast. These purchases increased Humboldt's land base to 209 acres (see *fig. 2*). About 156 acres were cleared for seedbeds, enough to produce the 24 million seedlings per year needed to meet projected future planting stock requests (Perry 1977).

¹ Humboldt Nursery files, 25 November 1958 memorandum on Douglas-fir regeneration policy decisions made at Willow Creek, October 29-30, 1958, from B. H. Payne, Assistant Regional Forester.

² Humboldt Nursery files, 23 November 1979 memorandum on Brown and Perry conversation about Humboldt Nursery history.

B. REFERENCE TABLES

Table 1—Douglas-fir seed sources and locations of cleared sites used to evaluate survival and growth of planting stock from Humboldt Nursery

Forest region, management unit, and seed source ¹	Planting site location				
	Elevation		Slope	Lat	Long
	<i>ft</i>	<i>m</i>		<i>° N</i>	<i>° W</i>
Oregon Coast Range, N					
Siuslaw NF					
Hebo RD					
HE 053.20 83o	—	—	—	—	—
HE 053.10 79	800	244	SW	45	45.30
HE 053.10 88o	250	76	unused field at Humboldt		
Waldport RD					
WA 061.20 83o	—	—	—	—	—
WA 061.10 77	900	274	NW	5	44.37
Alsea RD					
AL 252.15 80o	1500	45	E	30	44.37
AL 252.10 77	800	244	S	50	44.38
AL 252.10 81u	700	213	N	60	44.29
AL 252.05 78	500	152	S	30	44.36
AL 061.20 83o	—	—	—	—	—
AL 061.05 79	500	152	N	55	44.26
Mapleton RD					
MA 062.10 79p	1300	396	SW	50	43.92
MA 062.10 83p	300	92	S	10	—
Oregon Coast Range, S					
Coos Bay RA					
CO 072.10 84o	600	183	N	30	43.07
Siskiyou NF					
Powers RD					
PO 072.25 79	2400	732	NW	30	42.80
Gold Beach RD					
GO 081.20 79p	1800	549	W	25	2.50
Chetco RD					
CH 082.25 76	1600	488	W	20	42.26
CH 082.25 77	2700	823	S	30	42.22
CH 082.25 78	2300	701	S	20	42.25
CH 082.25 79f	2250	686	S	30	42.23
CH 082.10 79	1100	335	NW		42.15
Klamath Mtns, N					
Roseburg RA					
RO 270.20 84o	2800	854	N	10	43.16
Siskiyou NF					
Galice RD					
GA 511.30 79	3100	945	W	30	42.54
GA 512.25 79	2800	854	S	20	42.46
Illinois Valley RD					
IL 512.40 79r	3600	1098	SE	5	.05
IL 512.35 78p	3500	1067	W	15	42.04
IL 512.13 79	2000	610	N	35	42.00

¹ U.S. Department of Agriculture, Forest Service, National Forest (NF) and Ranger District (RD), or Department of Interior, Bureau of Land Management Resource Area (RA). Code indicates RD or RA, tree seed zone, elevational band (for example, .20 = 1500 to 2000 ft; USDA Forest Service 1969, 1973), and year seedlings were outplanted. Tests were run to determine seed source lifting windows (see Seed Source Assessments—Douglas-fir, *table 3*) and to explore nursery culture alternatives (see Assessing Nursery Culture Alternatives, *table 15*). The letters o, u, p, and f denote tests that were used to evaluate the following alternatives:

- o = 1-0 planting stock
- u = undercutting for 2-0 planting stock
- p = proposed practices: mycorrhizal inoculation, root wrenching, freeze storage, or precooler storage
- f = fall and winter planting on coastal sites

Table 1—Douglas-fir seed sources and locations of cleared sites used to evaluate survival and growth of planting stock from Humboldt Nursery—continued

Forest region, management unit, and seed source ¹	Planting site location				
	Elevation		Slope	Lat	Long
	<i>ft</i>	<i>m</i>	<i>pct</i>	<i>°N</i>	<i>°W</i>
Klamath Mtns, W					
Six Rivers NF					
Gasquet RD					
GQ 301.30 77f	1700	518	S 15	41.81	124.02
GQ 301.30 78f	1700	518	S 15	41.81	124.02
GQ 301.30 79	2500	762	SW 60	41.93	123.82
GQ 301.15 85p	—	—	—	—	—
Orleans RD					
OR 302.30 79	3000	915	E 50	41.32	123.76
Klamath Mtns, central					
Klamath NF					
Happy Camp RD					
HC 301.50 79	5000	1524	bench	41.94	123.54
HC 301.30 77	2100	640	E 20	41.73	123.46
HC 301.30 78	2100	640	E 20	41.73	123.46
HC 301.30 79	2450	747	ridge	41.64	123.50
Ukonom RD					
UK 301.20 79	2000	610	SE	41.49	123.49
UK 302.44 79	4500	1372	SW	41.50	123.48
UK 311.40 79	4000	1220	SE 35	41.46	123.42
Salmon River RD					
SA 311.40 79	3750	1143	E 40	41.24	123.36
SA 311.40 86o	250	76	fallow field at Humboldt		
SA 311.40 88o	250	76	unused field at Humboldt		
Klamath Mtns, E					
Rogue River NF					
Applegate RD					
AP 511.40 79	3000	915	ridge	42.09	122.90
Klamath NF					
Oak Knoll RD					
OK 321.40 77	4000	1220	S 10	41.95	122.82
OK 321.40 78	3500	1067	SE 15	41.86	122.97
OK 321.40 79	4000	1220	S 10	41.92	123.08
OK 321.40 83p	4000	1220	S 7	—	—
OK 321.30 80o	3500	1067	SE 10	41.88	123.05
OK 321.30 81u	2800	854	NW 15	41.84	123.23
Scott River RD					
SC 322.40 78	4400	1342	ridge	41.77	122.92
SC 322.40 79	4000	1220	W 30	41.74	122.90
Klamath Mtns, S					
Shasta-Trinity NF					
Big Bar RD					
BI 312.40 77	3250	991	NW 10	40.69	123.33
BI 312.30 78	3000	915	ridge	40.68	123.33
Hayfork RD					
HA 312.50 80u	—	—	—	—	—
HA 312.40 85p	—	—	—	—	—
HA 312.25 78	2950	899	ridge	40.39	123.26
HA 312.25 79	3000	915	ridge	40.38	123.27
HA 312.25 79o	3000	915	ridge	40.38	123.27
HA 312.25 80u	—	—	—	—	—
Yolla Bolla RD					
YO 371.45 78	4500	1372	N 50	40.14	122.78

Table 1—Douglas-fir seed sources and locations of cleared sites used to evaluate survival and growth of planting stock from Humboldt Nursery—continued

Forest region, management unit, and seed source ¹	Planting site location				
	Elevation		Slope	Lat	Long
	<i>ft</i>	<i>m</i>	<i>pct</i>	°N	°W
N Coast Range, coastal					
Six Rivers NF					
Gasquet RD					
GQ 091.25 86o	250	76	fallow field at Humboldt		
GQ 091.25 88o	250	76	unused field at Humboldt		
GQ 091.20 81u	2000	610	S 10	41.69	123.84
Ukiah RA					
King Range					
KI 390.25 77	2000	610	N 50	40.14	124.02
KI 390.20 79	2000	610	ridge	40.09	124.03
KI 390.20 80o	1700	518	ridge	40.10	124.02
KI 390.20 84o	1780	518	ridge	40.07	124.05
Red Mountain					
RE 093.25 78	1800	549	ridge	39.95	123.71
N Coast Range, inland					
Six Rivers NF					
Mad River RD					
MR 303.45 79	4000	1220	ridge	40.11	123.20
MR 340.36 78	3700	1128	ridge	40.17	123.30
Mendocino NF					
Upper Lake RD					
UP 372.30 77	3400	1037	ridge	39.32	122.95
Oregon Cascades, W					
Willamette NF					
McKenzie RD					
MK 472.45 79	4200	1280	SW 35	44.34	122.14
MK 472.45 88o	250	76	unused field at Humboldt		
MK 472.30 80o	2800	854	NW 60	44.18	122.02
Blue River RD					
BL 472.30 77	2300	701	SW 35	44.14	122.22
Oakridge RD					
OA 482.30 81u	2600	793	S 50	43.86	122.45
Umpqua NF					
Steamboat RD					
ST 491.30 79	2400	732	SW 50	43.48	122.73
Glide RD					
GL 491.30 79	3100	945	S 20	43.16	122.92
Tiller RD					
TI 492.30 79	3000	915	SE 20	43.07	122.86
California Cascades					
Shasta-Trinity NF					
Mt Shasta RD					
SH 516.30 77	5200	1585	bench	41.31	122.22
SH 521.40 79o	5400	1646	bench	41.17	122.28
Sierra Nevada, N					
Plumas NF					
Greenville RD					
GR 523.45 77	4300	1311	W 10	0.18	121.19
Sierra Nevada, W					
Eldorado NF					
Placerville RD					
PL 526.40 77	4600	1402	NE 30	38.75	120.46
Stanislaus NF					
Mi-Wok RD					
MI 531.40 77	5000	1524	W 30	38.07	120.11

¹ U.S. Department of Agriculture, Forest Service, National Forest (NF) and Ranger District (RD), or Department of Interior, Bureau of Land Management Resource Area (RA). Code indicates RD or RA, tree seed zone, elevational band (for example, .20 = 1500 to 2000 ft; USDA Forest Service 1969, 1973), and year seedlings were outplanted. Tests were run to determine seed source lifting windows (see Seed Source Assessments—Douglas-fir, *table 3*) and to explore nursery culture alternatives (see Assessing Nursery Culture Alternatives, *table 15*). The letters o, u, p, and f denote tests that were used to evaluate the following alternatives:

- o = 1-0 planting stock
- u = undercutting for 2-0 planting stock
- p = proposed practices: mycorrhizal inoculation, root wrenching, freeze storage, or precooler storage
- f = fall and winter planting on coastal sites

Table 2—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery¹

Seed source ² (stem diam, mm)	TGC and RGC, by nursery lifting date					LSD ³
	Nov 6	Dec 10	Jan 6	Feb 10	Mar 16	
1975-76						
Oregon Coast Range, S						
CH 082.25 (4.5) ⁴						
TGC budburst, <i>pct</i>	0.0	0.0	0.0	56.7	90.0	—
RGC root length, <i>cm</i>	29.7	124.4	88.4	82.5	96.6	39.3
roots ≥1.5 cm	11.9	45.9	36.8	35.6	39.7	14.9
<1.5 cm	32.8	17.0	113.8	112.8	88.2	—
Klamath Mtns, N						
IL 512.25 (4.7)						
TGC budburst, <i>pct</i>	0.0	0.0	0.0	40.0	100.0	—
RGC root length, <i>cm</i>	37.2	42.7	68.2	69.9	51.8	25.9
roots ≥1.5 cm	14.8	18.5	28.4	33.9	23.5	10.0
<1.5 cm	16.0	105.8	138.3	120.0	89.7	—
Klamath Mtns, central						
HC 301.30 (5.2) ⁴						
TGC budburst, <i>pct</i>	0.0	0.0	0.0	66.7	100.0	—
RGC root length, <i>cm</i>	39.4	126.6	199.3	117.9	73.3	32.2
roots ≥1.5 cm	7.2	41.6	70.2	48.4	31.8	12.3
<1.5 cm	22.2	94.7	133.3	141.0	111.6	—
Klamath Mtns, S						
HA 312.25 (4.3)						
TGC budburst, <i>pct</i>	0.0	0.0	3.3	96.7	100.0	—
RGC root length, <i>cm</i>	76.7	45.2	64.0	56.0	47.6	28.8
roots ≥1.5 cm	30.6	20.8	27.3	26.7	21.5	12.2
<1.5 cm	56.3	57.5	125.8	118.3	121.3	—
N Coast Range, inland						
MR 340.40 (4.7)						
TGC budburst, <i>pct</i>	0.0	0.0	0.0	70.0	100.0	—
RGC root length, <i>cm</i>	66.7	29.0	48.6	105.3	66.4	26.8
roots ≥1.5 cm	26.5	13.2	21.5	45.7	33.3	11.3
<1.5 cm	54.8	50.2	113.8	140.0	165.2	—

¹ See Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 2—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)	TGC and RGC, by nursery lifting date						LSD ³
1976-77	Oct 4	Nov 8	Dec 13	Jan 10	Feb 7	Mar 7	
Oregon Coast Range, N							
WA 061.10 (4.6)							
TGC budburst, <i>pct</i>	—	0.0	0.0	80.0	90.0	96.7	—
RGC root length, <i>cm</i>	—	140.0	83.4	179.5	152.6	51.1	32.1
roots ≥1.5 cm	—	51.8	36.7	65.1	55.5	22.8	11.9
<1.5 cm	—	85.5	106.8	113.2	97.5	59.7	—
AL 252.10 (4.8)							
TGC budburst, <i>pct</i>	0.0	0.0	0.0	83.3	90.0	100.0	—
RGC root length, <i>cm</i>	96.8	124.4	87.4	135.1	101.8	36.0	31.3
roots ≥1.5 cm	38.5	50.4	33.4	46.4	38.7	15.6	11.6
<1.5 cm	96.7	97.5	109.0	87.8	96.7	52.3	—
Oregon Coast Range, S							
CH 082.25 (4.2)⁴							
TGC budburst, <i>pct</i>	—	0.0	0.0	75.0	95.0	100.0	—
RGC root length, <i>cm</i>	—	67.3	46.2	57.9	71.0	55.7	20.2
roots ≥1.5 cm	—	23.9	19.0	25.6	25.4	22.9	7.3
<1.5 cm	—	69.7	59.2	53.5	45.0	43.4	—
Klamath Mtns, W							
GQ 301.30 (4.5)⁴							
TGC budburst, <i>pct</i>	0.0	0.0	0.0	46.7	93.3	100.0	—
RGC root length, <i>cm</i>	90.1	109.5	77.6	86.4	128.7	78.5	34.5
roots ≥1.5 cm	30.7	41.1	29.2	32.7	51.6	32.3	11.8
<1.5 cm	95.8	93.3	109.3	64.3	92.2	58.0	—
Klamath Mtns, central							
HC 301.30 (4.7)⁴							
TGC budburst, <i>pct</i>	0.0	0.0	0.0	73.3	100.0	100.0	—
RGC root length, <i>cm</i>	66.7	122.4	163.4	77.7	79.2	39.2	27.5
roots ≥1.5 cm	27.5	41.8	61.5	28.4	27.6	16.5	10.2
<1.5 cm	73.8	98.3	149.5	71.2	67.2	53.8	—
N Coast Range, inland							
UP 372.30 (5.2)							
TGC budburst, <i>pct</i>	0.0	0.0	0.0	50.0	80.0	93.3	—
RGC root length, <i>cm</i>	47.5	119.0	159.6	163.4	190.6	145.9	38.6
roots ≥1.5 cm	16.8	45.7	60.5	52.4	62.8	52.2	13.1
<1.5 cm	57.3	99.5	139.0	85.3	102.8	72.7	—
Oregon Cascades, W							
BL 472.30 (4.4)							
TGC budburst, <i>pct</i>	—	0.0	0.0	66.7	100.0	100.0	—
RGC root length, <i>cm</i>	—	52.6	62.1	108.6	84.6	52.0	27.0
roots ≥1.5 cm	—	23.2	26.1	39.6	31.0	21.9	10.9
<1.5 cm	—	87.2	77.7	107.3	70.8	58.3	—

¹ See Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 2—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)	TGC and RGC, by nursery lifting date					LSD ³
1976-77	Nov 1	Dec 7	Jan 3	Feb 1	Mar 1	
N Coast KI Range, coastal						
KI 390.25 (5.0)						
TGC budburst, <i>pct</i>	0.0	0.0	50.0	76.7	96.7	—
RGC root length, <i>cm</i>	148.9	186.2	116.2	205.6	123.0	52.8
roots ≥1.5 cm	53.9	68.2	45.3	80.1	48.9	20.1
<1.5 cm	132.9	131.3	97.8	154.1	80.5	—
Klamath Mtns, E						
OK 321.40 (5.0) ⁴						
TGC budburst, <i>pct</i>	0.0	0.0	46.7	93.3	100.0	—
RGC root length, <i>cm</i>	61.1	67.0	135.9	112.8	60.3	34.1
roots ≥1.5 cm	24.3	26.4	46.8	44.0	22.7	12.2
<1.5 cm	102.8	61.0	84.7	92.2	44.8	—
Klamath Mtns, S						
BI 312.40 (4.8)						
TGC budburst, <i>pct</i>	0.0	0.0	23.3	83.3	96.7	—
RGC root length, <i>cm</i>	89.1	99.6	83.6	95.9	53.1	29.4
roots ≥1.5 cm	30.9	40.5	29.2	40.1	22.9	10.1
<1.5 cm	90.3	104.3	78.3	107.3	71.8	—
California Cascades						
SH 516.30 (5.1)						
TGC budburst, <i>pct</i>	0.0	0.0	20.0	60.0	96.7	—
RGC root length, <i>cm</i>	95.6	113.6	78.3	157.3	89.7	29.0
roots ≥1.5 cm	40.9	47.4	35.7	63.0	37.1	12.0
<1.5 cm	105.8	100.7	80.7	101.5	76.7	—
Sierra Nevada, N						
GR 523.45 (5.1)						
TGC budburst, <i>pct</i>	0.0	0.0	43.3	96.7	93.3	—
RGC root length, <i>cm</i>	69.3	148.6	103.3	142.0	90.6	36.2
roots ≥1.5 cm	27.3	51.3	37.7	53.5	34.8	11.9
<1.5 cm	78.2	99.3	86.2	109.3	65.3	—
Sierra Nevada, W						
PL 526.40 (5.0)						
TGC budburst, <i>pct</i>	0.0	0.0	63.3	100.0	100.0	—
RGC root length, <i>cm</i>	63.3	74.8	105.9	93.7	50.9	28.4
roots ≥1.5 cm	22.6	29.2	41.1	34.9	21.3	10.5
<1.5 cm	70.0	95.0	90.5	89.0	60.7	—
Sierra Nevada, W						
MI 531.40 (5.3)						
TGC budburst, <i>pct</i>	0.0	0.0	30.0	86.7	100.0	—
RGC root length, <i>cm</i>	84.1	151.3	202.9	172.8	49.2	42.3
roots ≥1.5 cm	30.0	57.8	72.8	61.6	19.3	14.1
<1.5 cm	82.0	109.0	120.8	102.3	46.8	—

Table 2—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)		TGC and RGC, by nursery lifting date						LSD ³
1977-78		Oct 17	Nov 21	Dec 19	Jan 16	Feb 13	Mar 13	
Oregon Coast Range, N								
AL 252.05 (4.8)								
TGC budburst, <i>pct</i>		0.0	0.0	50.0	100.0	100.0	100.0	—
shoot length, <i>cm</i>		.0	.0	.5	4.2	9.0	10.1	—
RGC root length, <i>cm</i>		31.0	47.2	86.5	74.9	59.1	32.5	21.3
roots ≥1.5 cm		12.2	19.9	36.5	30.9	23.7	15.5	8.2
<1.5 cm		32.5	52.7	97.7	70.8	57.3	40.0	—
Oregon Coast Range, S								
CH 082.25 (4.4) ⁴								
TGC budburst, <i>pct</i>		—	0.0	20.0	90.0	100.0	100.0	—
shoot length, <i>cm</i>		—	.0	.0	1.6	4.5	6.8	—
RGC root length, <i>cm</i>		—	28.3	53.0	91.8	74.7	30.3	18.7
roots ≥1.5 cm		—	12.9	22.7	35.7	27.0	14.1	6.9
<1.5 cm		—	44.2	75.5	67.8	59.5	36.8	—
Klamath Mtns, W								
GQ 301.30 (4.4) ⁴								
TGC budburst, <i>pct</i>		0.0	0.0	23.3	83.3	100.0	100.0	—
shoot length, <i>cm</i>		.0	.0	.0	1.3	6.4	8.6	—
RGC root length, <i>cm</i>		68.0	29.4	91.8	76.7	64.4	49.4	20.8
roots ≥1.5 cm		25.1	12.2	37.2	30.1	24.4	22.1	7.6
<1.5 cm		54.7	45.8	88.8	68.2	61.7	46.3	—
Klamath Mtns, central								
HC 301.30 (4.2) ⁴								
TGC budburst, <i>pct</i>		0.0	0.0	50.0	83.3	100.0	100.0	—
shoot length, <i>cm</i>		.0	.0	.4	1.8	7.1	8.6	—
RGC root length, <i>cm</i>		43.1	33.4	62.4	70.2	91.2	35.5	22.2
roots ≥1.5 cm		17.3	13.7	27.4	28.6	32.9	15.1	8.3
<1.5 cm		47.2	30.5	66.8	63.0	55.0	36.5	—
Klamath Mtns, E								
OK 321.40 (4.4) ⁴								
TGC budburst, <i>pct</i>		—	0.0	20.0	76.7	100.0	100.0	—
shoot length, <i>cm</i>		—	.0	.2	1.6	6.8	8.5	—
RGC root length, <i>cm</i>		—	17.7	70.4	74.4	79.8	35.9	19.2
roots ≥1.5 cm		—	8.0	29.2	28.1	29.1	17.3	7.7
<1.5 cm		—	29.3	70.0	61.3	68.2	45.0	—
Klamath Mtns, S								
BI 312.30 (4.4)								
TGC budburst, <i>pct</i>		0.0	0.0	20.0	90.0	100.0	100.0	—
shoot length, <i>cm</i>		.0	.0	.2	1.3	5.2	10.5	—
RGC root length, <i>cm</i>		43.2	24.2	89.2	131.7	95.7	23.0	22.9
roots ≥1.5 cm		20.0	10.7	36.5	51.8	36.8	11.9	9.2
<1.5 cm		52.2	29.3	108.5	110.2	70.8	47.7	—
HA 312.25 (4.5)								
TGC budburst, <i>pct</i>		0.0	0.0	56.7	93.3	100.0	100.0	—
shoot length, <i>cm</i>		.0	.0	.5	3.4	7.8	7.5	—
RGC root length, <i>cm</i>		54.2	22.1	70.1	56.4	43.1	53.8	20.7
roots ≥1.5 cm		21.3	9.7	28.8	25.1	18.3	22.3	7.9
<1.5 cm		70.5	30.5	71.8	75.3	63.0	59.	—

¹ See Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 2—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)		TGC and RGC, by nursery lifting date				
1977-78		Nov 14	Dec 12	Jan 9	Feb 6	Mar 6
Klamath Mtns, N						
IL 512.35 (4.5)						
TGC budburst, <i>pct</i>		0.0	13.3	66.7	96.7	100.0
shoot length, <i>cm</i>		.0	.0	.6	3.2	5.8
RGC root length, <i>cm</i>		42.6	110.0	112.6	74.2	43.8
roots ≥1.5 cm		18.8	48.1	49.4	33.0	19.7
<1.5 cm		67.0	157.2	116.3	101.0	57.3
Klamath Mtns, central						
SA 311.40 (4.2)						
TGC budburst, <i>pct</i>		0.0	33.3	96.7	100.0	100.0
shoot length, <i>cm</i>		.0	.3	2.5	8.0	8.8
RGC root length, <i>cm</i>		29.0	74.6	74.8	44.1	10.4
roots ≥1.5 cm		12.2	29.4	32.3	18.7	4.7
<1.5 cm		35.2	71.2	58.7	55.0	27.2
Klamath Mtns, E						
SC 322.40 (4.5)						
TGC budburst, <i>pct</i>		0.0	10.0	66.7	96.7	100.0
shoot length, <i>cm</i>		.0	.0	.7	4.4	8.3
RGC root length, <i>cm</i>		77.0	144.3	127.3	79.5	25.4
roots ≥1.5 cm		31.8	60.7	50.2	31.6	11.5
<1.5 cm		80.8	117.7	85.0	63.5	30.3
Klamath Mtns, S						
YO 371.45 (4.5)						
TGC budburst, <i>pct</i>		0.0	13.3	93.3	96.7	100.0
shoot length, <i>cm</i>		.0	.1	2.3	3.9	7.1
RGC root length, <i>cm</i>		17.6	73.0	98.0	43.8	35.6
roots ≥1.5 cm		8.5	32.2	43.2	19.0	14.7
<1.5 cm		49.2	81.3	100.5	60.2	47.3
N Coast Range, coastal						
RE 093.25 (4.4)						
TGC budburst, <i>pct</i>		0.0	3.3	93.3	100.0	100.0
shoot length, <i>cm</i>		.0	.0	1.1	6.7	10.9
RGC root length, <i>cm</i>		52.0	156.6	179.3	121.4	95.8
roots ≥1.5 cm		20.5	54.8	62.8	44.6	37.3
<1.5 cm		60.2	108.2	121.2	102.8	57.0
N Coast Range, inland						
MR 340.36 (4.8)						
TGC budburst, <i>pct</i>		0.0	6.7	70.0	96.7	100.0
shoot length, <i>cm</i>		.0	.0	.4	4.7	7.5
RGC root length, <i>cm</i>		37.4	54.7	88.8	70.5	48.4
roots ≥1.5 cm		14.3	20.3	38.0	28.6	20.7
<1.5 cm		49.7	72.7	79.7	79.0	44.5

Table 3— Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested at spring planting time, after cold storage at Humboldt Nursery¹

Seed source ² (testing date)	TGC and RGC, by nursery lifting date					LSD ³
1975-76	Nov 6	Dec 10	Jan 6	Feb 10	Mar 16	
Oregon Coast Range, S						
CH 082.25 (Apr 20) ⁴						
TGC budburst, <i>pct</i>	0.0	16.7	70.0	95.0	70.0	19.0
RGC root length, <i>cm</i>	.0	40.7	151.1	192.7	49.5	41.6
roots ≥1.5 cm	.0	14.3	45.1	67.0	20.6	13.5
<1.5 cm	.0	26.2	58.8	111.0	61.3	20.9
Klamath Mtns, S						
HA 312.25 (Apr 20) ⁴						
TGC budburst, <i>pct</i>	0.0	53.3	100.0	93.3	100.0	15.7
RGC root length, <i>cm</i>	.0	54.5	20.3	88.4	75.1	29.6
roots ≥1.5 cm	.0	21.9	46.0	32.6	27.7	11.1
<1.5 cm	.0	58.3	122.2	91.5	76.7	25.8
1976-77	Nov 8	Dec 13	Jan 10	Feb 7	Mar 7	
Oregon Coast Range, N						
WA 061.10 (May 2)						
TGC budburst, <i>pct</i>	23.3	100.0	100.0	100.0	96.7	10.6
shoot length, <i>cm</i>	.5	5.3	5.7	5.7	4.0	1.1
RGC root length, <i>cm</i>	14.3	69.4	89.6	89.8	65.0	22.0
roots ≥1.5 cm	5.2	25.6	32.1	31.8	23.3	7.4
<1.5 cm	9.5	41.5	57.0	58.8	47.0	11.4
AL 252.10 (Apr 11)						
TGC budburst, <i>pct</i>	30.0	90.0	100.0	100.0	100.0	12.6
shoot length, <i>cm</i>	.7	3.7	4.9	4.4	4.8	1.1
RGC root length, <i>cm</i>	33.6	63.8	87.2	89.0	52.5	27.4
roots ≥1.5 cm	13.0	23.8	30.2	35.9	20.8	9.5
<1.5 cm	27.7	42.2	59.2	82.5	44.2	17.2
Oregon Coast Range, S						
CH 082.25 (Mar 28) ⁴						
TGC budburst, <i>pct</i>	6.7	100.0	86.7	96.7	95.0	12.1
shoot length, <i>cm</i>	.1	3.5	2.4	3.5	3.5	1.0
RGC root length, <i>cm</i>	4.8	116.2	87.2	75.0	62.2	24.7
roots ≥1.5 cm	1.5	41.7	33.5	30.8	28.0	9.1
<1.5 cm	2.7	57.8	54.2	46.2	45.2	11.6
Klamath Mtns, W						
GQ 301.30 (Apr 25) ⁴						
TGC budburst, <i>pct</i>	30.0	93.3	90.0	90.0	100.0	15.3
shoot length, <i>cm</i>	.7	4.2	4.4	3.2	3.0	1.2
RGC root length, <i>cm</i>	57.0	90.5	79.5	68.0	91.1	29.9
roots ≥1.5 cm	23.0	33.7	30.5	27.2	35.7	11.3
<1.5 cm	35.8	64.3	82.5	64.2	68.3	17.0
Klamath Mtns, central						
HC 301.30 (Mar 28) ⁴						
TGC budburst, <i>pct</i>	30.0	73.3	100.0	100.0	100.0	16.9
shoot length, <i>cm</i>	.8	2.3	4.7	4.2	5.3	1.1
RGC root length, <i>cm</i>	24.2	57.1	51.9	66.8	33.0	20.2
roots ≥1.5 cm	6.6	21.0	19.3	22.7	13.8	6.4
<1.5 cm	16.0	35.5	43.2	33.5	51.0	10.8
N Coast Range, inland						
UP 372.30 (Apr 4)						
TGC budburst, <i>pct</i>	0.0	16.7	40.0	70.0	80.0	19.9
shoot length, <i>cm</i>	.0	.3	1.4	2.1	3.9	1.1
RGC root length, <i>cm</i>	.9	88.1	132.8	154.4	102.4	43.7
roots ≥1.5 cm	.5	29.6	42.3	45.6	32.7	14.0
<1.5 cm	2.5	45.2	59.0	59.8	52.3	16.2

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 3—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested at spring planting time, after cold storage at Humboldt Nursery—continued ¹

Seed source ² (testing date)	TGC and RGC, by nursery lifting date					LSD ³
1976-77	Nov 8	Dec 13	Jan 10	Feb 7	Mar 7	
Oregon Cascades, W						
BL 472.30 (May 2)						
TGC budburst, <i>pct</i>	73.3	100.0	100.0	100.0	100.0	10.2
shoot length, <i>cm</i>	2.9	6.9	6.6	6.4	6.6	1.1
RGC root length, <i>cm</i>	45.9	45.1	57.0	61.5	63.5	23.5
roots ≥1.5 cm	19.3	19.3	23.5	25.1	26.5	9.0
<1.5 cm	38.2	36.0	47.8	43.7	47.5	12.4
1976-77	Nov 1	Dec 7	Jan 3	Feb 1	Mar 1	
N Coast Range, coastal						
KI 390.25 (Apr 4)						
TGC budburst, <i>pct</i>	0.0	40.0	63.3	70.0	70.0	22.4
shoot length, <i>cm</i>	.0	.2	1.6	2.1	2.8	1.0
RGC root length, <i>cm</i>	.0	72.9	114.9	94.8	71.2	33.8
roots ≥1.5 cm	.0	22.6	37.1	32.9	22.9	11.8
<1.5 cm	.0	40.3	42.3	42.7	32.8	15.3
Klamath OK Mtns, E						
OK 321.40 (May 23) ⁴						
TGC budburst, <i>pct</i>	16.7	96.7	100.0	100.0	100.0	9.5
shoot length, <i>cm</i>	.4	5.0	6.3	6.0	6.0	.8
RGC root length, <i>cm</i>	6.1	36.3	42.4	73.9	53.6	14.6
roots ≥1.5 cm	2.3	14.7	18.0	29.3	19.1	5.5
<1.5 cm	8.2	22.8	36.0	46.5	32.2	9.5
Klamath Mtns, S						
BI 312.40 (May 9)						
TGC budburst, <i>pct</i>	36.7	96.7	96.7	93.3	100.0	14.8
shoot length, <i>cm</i>	1.0	5.2	5.7	5.4	5.2	1.2
RGC root length, <i>cm</i>	15.2	58.3	29.1	49.6	33.4	16.0
roots ≥1.5 cm	6.0	22.9	11.6	19.6	14.4	5.9
<1.5 cm	16.3	39.7	27.3	34.8	32.0	10.5
California Cascades						
SH 516.30 (May 9)						
TGC budburst, <i>pct</i>	6.7	66.7	93.3	100.0	100.0	13.5
shoot length, <i>cm</i>	.1	3.2	3.6	4.5	4.5	1.0
RGC root length, <i>cm</i>	5.3	70.6	55.2	79.8	41.8	23.2
roots ≥1.5 cm	2.4	28.6	22.8	32.3	18.4	9.5
<1.5 cm	6.3	50.5	47.0	70.0	48.3	12.9
Sierra Nevada, N						
GR 523.45 (Apr 13)						
TGC budburst, <i>pct</i>	33.3	96.7	96.7	100.0	100.0	12.3
shoot length, <i>cm</i>	1.0	5.3	5.4	6.7	5.6	1.0
RGC root length, <i>cm</i>	20.9	93.3	131.1	120.4	90.9	31.3
roots ≥1.5 cm	6.6	26.1	34.0	35.3	27.0	8.1
<1.5 cm	13.5	34.0	52.5	72.8	48.7	14.9
Sierra Nevada, W						
PL 526.40 (Apr 13)						
TGC budburst, <i>pct</i>	0.0	96.7	100.0	96.7	100.0	5.8
shoot length, <i>cm</i>	.0	4.9	5.9	5.3	5.6	.8
RGC root length, <i>cm</i>	.0	55.8	43.8	88.7	48.1	25.3
roots ≥1.5 cm	.0	17.2	15.7	26.8	15.0	7.3
<1.5 cm	.0	22.0	21.7	32.5	27.8	6.6
MI 531.40 (Apr 13)						
TGC budburst, <i>pct</i>	73.3	96.7	100.0	100.0	100.0	11.0
shoot length, <i>cm</i>	3.3	5.2	7.2	6.3	6.3	1.1
RGC root length, <i>cm</i>	46.6	63.2	58.4	122.6	48.5	27.9
roots ≥1.5 cm	17.6	20.5	19.2	37.7	16.6	8.0
<1.5 cm	24.3	35.8	39.0	55.7	34.0	9.4

Table 3—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested at spring planting time, after cold storage at Humboldt Nursery—continued ¹

Seed source ² (testing date)		TGC and RGC, by nursery lifting date					LSD ³
1977-78		Nov 21	Dec 19	Jan 16	Feb 13	Mar 13	
Oregon Coast Range, N							
AL 252.05 (Jun 22)							
TGC budburst, <i>pct</i>		45.0	100.0	100.0	100.0	96.7	11.0
shoot length, <i>cm</i>		2.2	6.6	9.2	9.0	7.8	1.4
RGC root length, <i>cm</i>		12.8	28.9	18.6	45.2	33.5	16.0
roots ≥1.5 cm		6.2	12.2	8.6	18.9	14.0	6.5
<1.5 cm		14.0	27.0	20.5	37.8	25.5	10.4
Oregon Coast Range, S							
CH 082.25 (Apr 10) ⁴							
TGC budburst, <i>pct</i>		86.7	100.0	90.0	100.0	100.0	10.4
shoot length, <i>cm</i>		3.5	3.7	3.8	5.7	7.0	1.0
RGC root length, <i>cm</i>		56.4	74.5	50.9	48.4	27.5	18.4
roots ≥1.5 cm		22.5	25.4	19.4	19.1	10.3	6.7
<1.5 cm		40.8	61.3	49.7	51.7	39.5	14.4
Klamath Mtns, W							
GQ 301.30 (May 1) ⁴							
TGC budburst, <i>pct</i>		76.7	100.0	96.7	100.0	100.0	10.6
shoot length, <i>cm</i>		3.9	6.3	7.7	6.8	7.5	1.2
RGC root length, <i>cm</i>		31.7	54.4	52.2	63.6	78.8	22.8
roots ≥1.5 cm		12.3	20.6	20.1	23.8	31.8	8.2
<1.5 cm		31.5	34.3	37.8	56.5	43.8	10.7
Klamath Mtns, central							
HA 301.30 (May 1) ⁴							
TGC budburst, <i>pct</i>		86.7	96.7	100.0	96.7	100.0	9.8
shoot length, <i>cm</i>		3.7	6.8	8.0	7.4	7.7	1.2
RGC root length, <i>cm</i>		23.4	21.5	59.3	47.0	39.1	15.5
roots ≥1.5 cm		9.2	9.2	22.6	17.2	15.1	5.8
<1.5 cm		21.3	23.8	36.5	29.7	31.7	8.9
Klamath Mtns, E							
OK 321.40 (Apr 18) ⁴							
TGC budburst, <i>pct</i>		100.0	100.0	100.0	100.0	100.0	—
shoot length, <i>cm</i>		5.6	6.3	6.9	6.4	7.5	1.1
RGC root length, <i>cm</i>		22.8	30.1	31.9	41.5	39.4	15.3
roots ≥1.5 cm		9.2	11.3	13.1	15.7	16.4	5.7
<1.5 cm		21.0	33.2	25.3	35.5	37.7	8.8
Klamath Mtns, S							
BI 312.30 (Jun 27)							
TGC budburst, <i>pct</i>		80.0	96.7	100.0	100.0	100.0	10.1
shoot length, <i>cm</i>		3.6	7.8	8.7	8.4	9.0	1.2
RGC root length, <i>cm</i>		26.6	35.6	47.6	68.6	40.0	23.3
roots ≥1.5 cm		10.6	13.4	19.0	27.6	17.3	8.8
<1.5 cm		22.2	26.0	32.7	50.2	47.5	12.7
HA 312.25 (Apr 3) ⁴							
TGC budburst, <i>pct</i>		86.7	93.3	100.0	96.7	100.0	10.5
shoot length, <i>cm</i>		4.2	4.7	7.2	6.9	8.0	1.2
RGC root length, <i>cm</i>		31.6	39.6	60.7	55.8	36.1	16.4
roots ≥1.5 cm		12.4	16.0	23.9	22.1	15.5	6.3
<1.5 cm		28.7	38.3	58.7	55.5	31.7	12.5

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 11*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 3—Top and root growth capacity (TGC, RGC) of 2-0 Douglas-fir tested at spring planting time, after cold storage at Humboldt Nursery—continued ¹

Seed source ² (testing date)		TGC and RGC, by nursery lifting date					LSD ³
1977-78		Nov 14	Dec 12	Jan 9	Feb 6	Mar 6	
Klamath Mtns, N							
IL 512.35 (May 30)							
TGC budburst, <i>pct</i>		70.0	100.0	100.0	100.0	100.0	10.5
shoot length, <i>cm</i>		3.0	7.9	6.3	6.0	6.3	1.1
RGC root length, <i>cm</i>		25.4	69.8	27.0	32.6	45.6	21.0
roots ≥1.5 cm		10.7	30.3	12.2	14.2	21.9	8.6
<1.5 cm		21.0	52.2	26.7	33.7	52.0	13.7
Klamath Mtns, central							
SA 311.40 (Jun 12)							
TGC budburst, <i>pct</i>		76.7	90.0	100.0	96.7	100.0	12.6
shoot length, <i>cm</i>		3.1	6.6	8.9	7.7	8.9	1.2
RGC root length, <i>cm</i>		15.0	1.5	9.5	7.2	21.2	8.9
roots ≥1.5 cm		6.0	0.7	4.1	3.4	8.7	3.5
<1.5 cm		19.7	7.8	14.2	9.8	26.5	8.2
Klamath Mtns, E							
SC 322.40 (Jun 5)							
TGC budburst, <i>pct</i>		60.0	100.0	100.0	96.7	96.7	12.7
shoot length, <i>cm</i>		2.5	7.0	8.6	7.6	7.9	1.3
RGC root length, <i>cm</i>		27.0	27.7	47.7	25.4	51.7	18.1
roots ≥1.5 cm		10.0	12.2	18.1	11.0	21.6	6.7
<1.5 cm		16.2	33.5	30.3	24.7	36.7	10.2
Klamath Mtns, S							
YO 371.45 (May 8)							
TGC budburst, <i>pct</i>		86.7	100.0	100.0	100.0	100.0	7.8
shoot length, <i>cm</i>		3.8	7.7	6.2	7.1	7.1	1.1
RGC root length, <i>cm</i>		45.8	55.6	41.6	55.6	82.2	20.5
roots ≥1.5 cm		17.5	21.5	17.4	24.2	31.5	7.7
<1.5 cm		37.0	41.8	27.2	58.5	64.5	13.6
N Coast Range, coastal							
RE 093.25 (Apr 3)							
TGC budburst, <i>pct</i>		30.0	76.7	96.7	93.3	100.0	16.0
shoot length, <i>cm</i>			2.7	4.4	4.7	8.4	1.1
RGC root length, <i>cm</i>		13.0	86.0	80.4	79.6	129.3	29.8
roots ≥1.5 cm		4.9	32.8	30.0	29.7	48.9	10.7
<1.5 cm		15.8	52.2	62.8	57.0	82.2	18.3
N Coast Range, inland							
MR 340.36 (May 1)							
TGC budburst, <i>pct</i>		66.7	90.0	100.0	100.0	100.0	12.9
shoot length, <i>cm</i>		2.5	5.7	4.8	8.0	8.8	1.3
RGC root length, <i>cm</i>		25.1	24.6	20.5	19.2	50.1	16.8
roots ≥1.5 cm		9.7	9.5	8.8	8.4	18.8	6.4
<1.5 cm		22.5	18.3	22.0	15.0	34.8	11.0

Table 4— Top and root growth capacity (TGC, RGC) of minor conifers tested just after lifting at Humboldt Nursery¹

Seed source ² (stem diam, mm)	TGC and RGC, by nursery lifting date					LSD ³
1976-77	Nov 15	Dec 20	Jan 17	Feb 14	Mar 14	
Shasta red fir						
OK 321.60 (4.0)						
TGC budburst, <i>pct</i>	3.1	16.7	83.3	100.0	100.0	16.3
RGC root length, <i>cm</i>	86.9	165.6	111.9	103.7	74.5	29.3
roots ≥1.5 cm	39.4	73.8	55.8	54.5	38.7	12.8
<1.5 cm	83.7	107.0	76.8	96.3	77.7	17.8
GN 741.65 (4.0)						
TGC budburst, <i>pct</i>	6.7	20.0	90.0	100.0	100.0	12.9
RGC root length, <i>cm</i>	101.8	75.4	121.5	78.0	62.1	27.5
roots ≥1.5 cm	47.7	36.8	58.9	40.8	32.8	13.2
<1.5 cm	102.3	72.2	83.2	76.4	61.5	16.6
White fir						
OK321.60 (4.4)						
TGC budburst, <i>pct</i>	—	13.3	96.7	100.0	100.0	9.9
RGC root length, <i>cm</i>	—	119.0	127.9	85.5	55.7	23.2
roots ≥1.5 cm	—	48.6	57.6	43.8	28.9	10.3
<1.5 cm	—	121.3	143.0	166.3	86.8	28.2
1982-83	Nov 29	Dec 27	Jan 24	Feb 22		
Noble fir						
AL 252.40 (4.2)						
TGC budburst, <i>pct</i>	6.7	70.0	93.3	100.0		15.0
shoot length, <i>cm</i>	.0	.0	.0	1.6		.3
RGC root length, <i>cm</i>	75.3	114.0	97.1	129.2		39.0
roots ≥1.5 cm	35.5	56.9	50.6	66.8		18.3
<1.5 cm	135.0	208.0	169.0	147.3		36.0
Grand fir						
MA 062.20 (4.3)						
TGC budburst, <i>pct</i>	46.7	73.3	80.0	93.3		21.2
shoot length, <i>cm</i>	.1	.0	.2	1.8		.4
RGC root length, <i>cm</i>	116.0	226.8	139.0	105.6		52.2
roots ≥1.5 cm	52.5	103.3	66.5	49.5		24.3
<1.5 cm	129.9	181.4	144.3	112.3		34.1
Western redcedar						
AL 061.10 (3.7) ⁴						
TGC shoots active, <i>pct</i>	100.0	100.0	100.0	100.0		—
RGC root length, <i>cm</i>	225.3	433.0	283.0	388.5		121.4
roots ≥1.5 cm	106.1	201.3	134.1	177.5		70.9
<1.5 cm	144.3	249.3	206.0	210.7		52.8
Incense-cedar						
AP 511.40 (4.3)						
TGC shoots active, <i>pct</i>	83.3	96.7	100.0	100.0		10.8
RGC root length, <i>cm</i>	344.6	396.3	336.9	356.1		89.2
roots ≥1.5 cm	131.4	148.2	131.6	129.7		29.0
<1.5 cm	116.5	149.3	142.2	134.5		32.0

¹ See Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 4—Top and root growth capacity (TGC, RGC) of minor conifers tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)		TGC and RGC, by nursery lifting date					LSD ³
1982-83		Nov 9	Dec 7	Jan 4	Feb 1	Mar 1	
Sitka spruce							
HE 053.10 (4.0)							
TGC budburst, <i>pct</i>		0.0	30.0	93.3	100.0	100.0	12.0
shoot length, <i>cm</i>		.0	.0	.2	.9	2.9	.5
RGC root length, <i>cm</i>		176.5	177.7	125.3	144.3	126.6	49.8
roots ≥1.5 cm		70.9	71.6	54.5	62.0	59.5	20.2
<1.5 cm		208.2	184.0	141.8	135.7	124.0	44.8
WA 061.10 (4.3) ⁴							
TGC budburst, <i>pct</i>		0.0	6.7	46.7	100.0	100.0	12.8
shoot length, <i>cm</i>		.0	.0	.0	.6	2.9	.4
RGC root length, <i>cm</i>		155.0	225.5	145.5	154.8	150.4	49.2
roots ≥1.5 cm		60.0	87.6	58.6	63.5	68.8	18.3
<1.5 cm		158.8	158.2	137.8	154.0	134.0	32.7
AL 061.05 (4.0)							
TGC budburst, <i>pct</i>		0.0	0.0	10.0	83.3	100.0	11.0
shoot length, <i>cm</i>		.0	.0	.0	.3	1.7	.3
RGC root length, <i>cm</i>		92.0	121.6	106.9	122.5	110.1	28.1
roots ≥1.5 cm		38.1	48.8	43.2	48.1	48.8	11.7
<1.5 cm		140.5	184.7	121.8	117.5	102.3	33.7
MA 062.10 (3.8) ⁴							
TGC budburst, <i>pct</i>		0.0	0.0	10.0	86.7	96.7	11.2
shoot length, <i>cm</i>		.0	.0	.0	.2	1.9	.4
RGC root length, <i>cm</i>		114.4	130.7	145.4	193.4	154.0	36.9
roots ≥1.5 cm		46.9	50.7	56.1	70.7	62.5	14.3
<1.5 cm		135.3	154.5	140.3	139.8	102.0	29.8
1983-84		Nov 21	Dec 19	Jan 16	Feb 13	Mar 12	
Sitka spruce							
WA 061.10 (4.7) ⁴							
TGC budburst, <i>pct</i>		0.0	80.0	100.0	100.0	100.0	14.0
shoot length, <i>cm</i>		.0	.3	.7	2.0	6.1	1.0
RGC root length, <i>cm</i>		190.0	245.6	244.8	123.9	102.5	81.0
roots ≥1.5 cm		80.4	101.9	104.5	53.3	49.1	34.5
<1.5 cm		174.0	172.3	229.0	112.0	137.0	57.6
MA 062.10 (4.8) ⁴							
TGC budburst, <i>pct</i>		0.0	13.3	93.3	100.0	100.0	14.3
shoot length, <i>cm</i>		.0	.0	.3	2.0	3.4	.7
RGC root length, <i>cm</i>		202.8	298.7	294.3	274.4	289.0	87.7
roots ≥1.5 cm		86.9	122.7	103.7	100.5	112.4	29.0
<1.5 cm		165.7	232.3	168.3	147.0	181.0	49.8
Western hemlock							
HE 053.20 (4.3)							
TGC budburst, <i>pct</i>		20.0	100.0	100.0	100.0	100.0	13.5
shoot length, <i>cm</i>		.0	.9	1.4	2.2	4.6	.7
RGC root length, <i>cm</i>		195.5	317.7	362.9	239.7	217.1	96.9
roots ≥1.5 cm		81.1	131.0	162.3	106.2	101.1	40.8
<1.5 cm		132.7	190.0	229.0	180.3	162.0	53.7
AL 061.10 (4.5)							
TGC budburst, <i>pct</i>		20.0	100.0	100.0	93.3	100.0	15.9
shoot length, <i>cm</i>		.0	.5	2.6	1.7	4.3	.7
RGC root length, <i>cm</i>		237.4	366.9	289.5	232.8	103.7	106.3
roots ≥1.5 cm		106.9	160.7	136.3	114.6	50.7	44.7
<1.5 cm		153.7	186.3	190.0	189.7	122.3	55.5

Table 4— Top and root growth capacity (TGC, RGC) of minor conifers tested just after lifting at Humboldt Nursery—continued¹

Seed source ² (stem diam, mm)	TGC and RGC, by nursery lifting date					LSD ³
1983-84	Nov 21	Dec 19	Jan 16	Feb 13	Mar 12	
Western hemlock						
MA 062.10 (4.4)						
TGC budburst, <i>pct</i>	0.0	93.3	100.0	86.7	93.3	16.6
shoot length, <i>cm</i>	.0	.4	1.7	.8	4.3	1.0
RGC root length, <i>cm</i>	26.7	355.8	427.0	216.9	174.6	128.3
roots ≥1.5 cm	14.4	153.4	185.1	95.1	78.9	54.6
<1.5 cm	30.3	140.7	234.7	103.0	121.0	65.8
Western redcedar						
HE 053.10 (4.3)						
TGC shoots active, <i>pct</i>	93.3	100.0	100.0	100.0	100.0	8.4
RGC root length, <i>cm</i>	234.8	393.6	526.2	546.2	556.6	177.1
roots ≥1.5 cm	108.6	153.7	194.4	219.4	224.9	64.7
<1.5 cm	127.0	97.3	143.4	156.3	152.0	41.4
AL 061.10 (4.3) ⁴						
TGC shoots active, <i>pct</i>	100.0	93.3	80.0	93.3	93.3	19.9
RGC root length, <i>cm</i>	224.2	433.3	571.1	607.8	496.2	199.4
roots ≥1.5 cm	104.2	180.3	229.1	240.7	216.6	78.4
<1.5 cm	133.7	134.0	183.7	189.3	203.6	62.0
MA 062.10 (4.1)						
TGC shoots active, <i>pct</i>	100.0	93.3	80.0	93.3	86.7	22.2
RGC root length, <i>cm</i>	184.2	233.8	500.0	432.5	388.7	194.4
roots ≥1.5 cm	89.6	100.2	199.5	176.3	161.4	75.2
<1.5 cm	131.5	86.0	155.0	137.7	137.0	46.8
1984-85	Nov 19	Dec 17	Jan 14	Feb 11	Mar 11	
Western hemlock						
HE 053.15 (4.2)						
TGC budburst, <i>pct</i>	6.7	100.0	100.0	93.3	93.3	14.6
shoot length, <i>cm</i>	.0	.0	1.1	1.9	3.2	.7
RGC root length, <i>cm</i>	164.0	261.4	253.0	344.7	219.9	107.0
roots ≥1.5 cm	79.4	134.2	119.3	162.9	104.8	50.4
<1.5 cm	103.7	157.7	180.0	193.3	158.3	56.2
AL 061.15 (4.1)						
TGC budburst, <i>pct</i>	0.0	53.3	100.0	80.0	90.0	29.6
shoot length, <i>cm</i>	.0	.0	.3	.8	1.6	.5
RGC root length, <i>cm</i>	95.5	166.0	286.2	197.3	184.3	103.2
roots ≥1.5 cm	46.9	81.1	122.2	89.9	86.0	47.3
<1.5 cm	54.0	74.0	94.0	69.0	83.5	37.3
AL 252.25 (4.1)						
TGC budburst, <i>pct</i>	66.7	93.3	100.0	100.0	100.0	18.4
shoot length, <i>cm</i>	.0	.9	.7	2.3	2.0	.8
RGC root length, <i>cm</i>	200.4	267.3	471.6	425.4	251.9	139.0
roots ≥1.5 cm	97.9	133.6	212.9	206.9	109.2	65.2
<1.5 cm	131.9	158.0	237.7	184.7	80.0	63.4

¹ See Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 5—*Top and root growth capacity (TGC, RGC) of minor conifers tested after cold storage at Humboldt Nursery*¹

Seed source ² (testing date)		TGC and RGC, by nursery lifting date					LSD ³
1975-76		Nov 6	Dec 10	Jan 6	Feb 10	Mar 16	
Shasta red fir							
OK 321.60 (May 24)							
TGC budburst, <i>pct</i>		96.7	100.0	100.0	100.0	100.0	4.1
RGC root length, <i>cm</i>		131.7	111.6	117.5	121.6	107.5	32.7
roots ≥1.5 cm		60.9	52.0	54.1	60.9	53.2	14.6
<1.5 cm		91.0	88.7	94.8	97.0	118.8	20.6
1976-77		Nov 15	Dec 20	Jan 17	Feb 14	Mar 14	
Shasta red fir							
OK 321.60 (May 31)							
TGC budburst, <i>pct</i>		100.0	100.0	100.0	100.0	100.0	—
shoot length, <i>cm</i>		4.4	4.1	4.2	3.8	4.4	0.6
RGC root length, <i>cm</i>		29.5	77.1	75.3	67.1	51.3	20.0
roots ≥1.5 cm		15.3	38.2	36.8	34.0	27.9	10.3
<1.5 cm		30.5	46.7	57.5	50.0	58.3	11.2
GN 741.65 (May 31)							
TGC budburst, <i>pct</i>		90.0	100.0	100.0	100.0	100.0	6.9
shoot length, <i>cm</i>		3.2	3.8	3.3	3.2	3.7	.6
RGC root length, <i>cm</i>		16.3	44.3	40.5	29.7	44.6	11.4
roots ≥1.5 cm		9.4	22.8	21.6	15.7	22.6	5.9
<1.5 cm		25.5	49.7	48.0	37.8	44.5	9.0
White fir							
OK 321.60 (Jun 6)							
TGC budburst, <i>pct</i>		—	100.0	100.0	100.0	100.0	—
shoot length, <i>cm</i>		—	3.7	4.0	3.8	4.0	0.8
RGC root length, <i>cm</i>		—	26.5	30.6	33.3	29.6	11.2
roots ≥1.5 cm		—	12.8	14.2	16.9	14.6	5.0
<1.5 cm		—	41.8	39.5	59.5	63.0	11.8
1977-78		Nov 28	Dec 27	Jan 23	Feb 21	Mar 20	
Shasta red fir							
OK 321.60 (Jul 5)							
TGC budburst, <i>pct</i>		90.0	96.7	100.0	100.0	100.0	8.0
shoot length, <i>cm</i>		4.0	3.2	4.9	5.3	4.4	.8
RGC root length, <i>cm</i>		4.5	4.2	11.4	18.5	12.1	4.7
roots ≥1.5 cm		2.7	2.4	5.9	10.4	6.6	2.6
<1.5 cm		13.0	13.7	25.5	37.8	25.8	6.8

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See *fig. 22*.

³ Least significant difference ($p = 0.05$).

⁴ Seedlot repeated in another nursery year.

Table 5—Top and root growth capacity (TGC, RGC) of minor conifers tested after cold storage at Humboldt Nursery—continued¹

Seed source ² (testing date)		TGC and RGC, by nursery lifting date				LSD ³
1982-83		Nov 29	Dec 27	Jan 24	Feb 22	
Noble fir						
AL 252.40 (Apr 25)						
TGC budburst, <i>pct</i>		100.0	100.0	100.0	100.0	—
shoot length, <i>cm</i>		2.9	2.8	2.3	2.8	0.5
RGC root length, <i>cm</i>		260.6	320.0	275.5	221.8	111.7
roots ≥1.5 cm		112.9	135.3	133.1	101.5	41.0
<1.5 cm		116.7	178.0	184.0	135.3	47.7
Grand fir						
MA 062.20 (Apr 25)						
TGC budburst, <i>pct</i>		70.0	90.0	96.7	96.7	15.7
shoot length, <i>cm</i>		2.0	3.5	3.3	3.8	1.0
RGC root length, <i>cm</i>		123.0	202.8	197.8	163.9	61.6
roots ≥1.5 cm		56.6	81.6	76.3	71.7	25.3
<1.5 cm		90.7	114.3	96.0	98.3	33.8
Western redcedar						
AL 061.10 (May 23)						
TGC shoots active, <i>pct</i>		96.7	100.0	100.0	100.0	4.7
RGC root length, <i>cm</i>		276.4	268.6	375.9	255.2	144.8
roots ≥1.5 cm		133.7	125.1	166.4	119.9	61.6
<1.5 cm		122.0	100.7	116.0	159.7	44.3
Incense-cedar						
AP 511.40 (May 31)						
TGC shoots active, <i>pct</i>		60.0	93.3	90.0	93.3	17.5
RGC root length, <i>cm</i>		56.6	257.5	138.7	178.5	90.1
roots ≥1.5 cm		23.0	93.8	55.5	66.2	33.4
<1.5 cm		22.8	77.8	77.7	80.0	29.4
1982-83		Nov 9	Dec 7	Jan 4	Feb 1	Mar 1
Sitka spruce						
HE 053.10 (Apr 4)						
TGC budburst, <i>pct</i>		83.3	100.0	100.0	100.0	100.0
shoot length, <i>cm</i>		1.6	2.7	2.2	2.2	1.9
RGC root length, <i>cm</i>		73.2	100.1	127.5	181.2	128.5
roots ≥1.5 cm		33.5	46.3	52.0	80.4	57.1
<1.5 cm		57.3	81.7	79.0	119.3	85.0
WA 061.10 (Mar 28) ⁴						
TGC budburst, <i>pct</i>		76.7	90.0	100.0	100.0	100.0
shoot length, <i>cm</i>		1.1	1.0	1.2	1.6	3.0
RGC root length, <i>cm</i>		122.0	156.9	150.7	149.5	174.0
roots ≥1.5 cm		58.6	69.1	58.9	57.9	71.7
<1.5 cm		86.7	122.0	91.7	80.7	119.3
AL 061.05 (Mar 28)						
TGC budburst, <i>pct</i>		70.0	93.3	96.7	100.0	93.3
shoot length, <i>cm</i>		.7	.7	.6	1.1	1.4
RGC root length, <i>cm</i>		121.2	152.1	126.7	157.5	117.6
roots ≥1.5 cm		61.3	63.5	58.0	62.1	49.2
<1.5 cm		114.7	98.0	97.7	137.7	97.7
MA 062.10 (Apr 4) ⁴						
TGC budburst, <i>pct</i>		43.3	80.0	76.7	93.3	96.7
shoot length, <i>cm</i>		.3	.5	.3	.7	1.8
RGC root length, <i>cm</i>		58.6	139.0	141.6	160.0	184.7
roots ≥1.5 cm		26.9	61.7	60.3	70.9	77.9
<1.5 cm		35.7	97.7	96.7	97.7	79.0

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures.

² See fig. 22.

³ Least significant difference (p = 0.05).

⁴ Seedlot repeated in another nursery year.

Table 5—Top and root growth capacity (TGC, RGC) of minor conifers tested after cold storage at Humboldt Nursery—continued¹

Seed source ² (testing date)		TGC and RGC, by nursery lifting date					LSD ³
1983-84		Nov 21	Dec 19	Jan 16	Feb 13	Mar 12	
Sitka spruce							
WA 061.10 (Apr 23) ⁴							
TGC budburst, <i>pct</i>		66.7	93.3	100.0	100.0	100.0	18.0
shoot length, <i>cm</i>		1.5	2.8	4.0	3.7	4.8	1.2
RGC root length, <i>cm</i>		84.3	227.8	304.9	198.4	209.1	85.6
roots ≥1.5 cm		38.7	89.2	123.7	84.0	81.9	32.4
<1.5 cm		68.7	117.0	161.3	103.3	104.3	33.5
MA 062.10 (Apr 23) ⁴							
TGC budburst, <i>pct</i>		6.7	66.7	100.0	93.3	93.3	21.6
shoot length, <i>cm</i>		.0	1.4	2.3	2.3	3.1	1.0
RGC root length, <i>cm</i>		36.7	172.8	260.2	280.1	292.5	123.9
roots ≥1.5 cm		15.4	65.2	103.6	100.7	111.4	46.4
<1.5 cm		14.0	88.3	126.7	136.3	127.0	47.3
Western hemlock							
HE 053.20 (Mar 26)							
TGC budburst, <i>pct</i>		53.3	93.3	93.3	100.0	100.0	20.7
shoot length, <i>cm</i>		1.7	2.6	1.7	4.0	3.7	1.4
RGC root length, <i>cm</i>		183.8	509.1	332.7	495.4	366.8	187.3
roots ≥1.5 cm		75.1	226.8	148.0	201.1	147.5	79.7
<1.5 cm		88.3	226.3	177.7	194.7	162.7	76.6
MA 062.10 (Mar 26)							
TGC budburst, <i>pct</i>		0.0	6.7	93.3	26.7	86.7	22.3
shoot length, <i>cm</i>		.0	.3	1.4	.2	2.0	1.0
RGC root length, <i>cm</i>		.0	55.2	396.8	78.7	256.0	157.0
roots ≥1.5 cm		.0	22.8	171.1	37.1	106.7	66.3
<1.5 cm		.0	12.0	191.0	28.0	95.0	46.3
Western redcedar							
HE 053.10 (Apr 9)							
TGC shoots active, <i>pct</i>		0.0	100.0	100.0	93.3	93.3	11.9
RGC root length, <i>cm</i>		.0	322.2	525.5	167.4	106.3	209.2
roots ≥1.5 cm		.0	144.5	202.3	80.8	51.8	82.8
<1.5 cm		.0	122.7	162.0	98.0	73.5	53.3
MA 062.10 (Apr 9)							
TGC shoots active, <i>pct</i>		0.0	73.3	100.0	73.3	60.0	26.9
RGC root length, <i>cm</i>		.0	129.6	447.2	241.3	234.1	184.1
roots ≥1.5 cm		.0	61.5	201.2	108.0	111.7	78.2
<1.5 cm		.0	85.0	141.0	116.7	109.7	59.4
1984-85		Nov 19	Dec 17	Jan 14	Feb 11	Mar 11	
Western hemlock							
HE 053.15 (Mar 25)							
TGC budburst, <i>pct</i>		53.3	86.7	100.0	100.0	93.3	22.9
shoot length, <i>cm</i>		.1	1.1	2.0	1.8	2.2	1.1
RGC root length, <i>cm</i>		130.9	236.4	433.7	503.5	394.1	131.0
roots ≥1.5 cm		56.7	105.1	199.9	218.7	177.2	57.7
<1.5 cm		48.0	119.7	238.7	176.0	170.7	56.7
AL 061.15 (Mar 25)							
TGC budburst, <i>pct</i>		0.0	33.3	86.7	86.7	53.3	28.3
shoot length, <i>cm</i>		.0	.2	.6	.4	.4	.5
RGC root length, <i>cm</i>		.0	106.6	413.2	287.7	118.8	140.8
roots ≥1.5 cm		.0	39.1	165.5	123.1	47.7	55.3
<1.5 cm		.0	24.3	106.7	78.3	28.0	34.1

Table 6—Top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir from April sowings tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² and testing date	TGC and RGC, by nursery lifting date					LSD ³
1983-84	Nov 28	Dec 27	Jan 23	Feb 21	Mar 19	
Oregon Coast Range, S; CO 072.10						
At lifting						
TGC budburst, <i>pct</i>	4.4	60.0	96.7	100.0	100.0	7.2
shoot length, <i>cm</i>	.0	.3	2.5	4.1	7.6	.6
RGC root length, <i>cm</i>	58.9	145.8	129.7	105.4	88.5	31.6
roots ≥1.5 cm	23.1	58.0	48.2	44.2	42.1	12.2
<1.5 cm	55.6	121.6	131.3	119.8	117.9	29.0
After storage (May 7)						
TGC budburst, <i>pct</i>	15.0	92.5	100.0	100.0	100.0	10.3
shoot length, <i>cm</i>	.9	7.4	9.2	8.8	7.4	1.3
RGC root length, <i>cm</i>	12.8	61.1	92.1	81.0	72.8	23.1
roots ≥1.5 cm	5.4	26.5	35.9	32.8	31.2	9.6
<1.5 cm	7.5	52.1	72.2	66.2	66.3	13.7
Klamath Mtns, N; RO 270.20						
At lifting						
TGC budburst, <i>pct</i>	3.3	53.3	98.9	100.0	100.0	7.2
shoot length, <i>cm</i>	.0	.4	3.0	4.7	7.4	.6
RGC root length, <i>cm</i>	32.7	132.2	93.9	93.9	56.9	31.6
roots ≥1.5 cm	14.1	52.3	36.8	38.7	25.7	12.2
<1.5 cm	41.5	113.5	107.9	94.4	97.5	29.0
After storage (May 7)						
TGC budburst, <i>pct</i>	58.3	93.3	98.3	100.0	100.0	8.8
shoot length, <i>cm</i>	3.1	7.2	8.9	8.7	7.8	1.1
RGC root length, <i>cm</i>	23.6	32.2	34.8	24.6	39.5	18.3
roots ≥1.5 cm	9.8	14.0	15.3	12.0	16.7	7.8
<1.5 cm	17.0	32.2	44.4	42.0	42.0	14.9

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures. Means are for the check and 2N treatments; see Assessing Nursery Culture Alternatives, *tables 24, 25*.

² See *fig. 10*.

³ Least significant difference ($p = 0.05$).

Table 7—Significance of seed source, sowing date, and lifting date effects on top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir tested just after lifting and after cold storage at Humboldt Nursery¹

Winter season, seed sources, ² testing date, and source of variation	Degrees freedom	Variance (mean square) for...				
		Budburst (pct)	Shoot length (cm)	Root length (cm)	Roots elongated	
					≥1.5 cm	<1.5 cm
1985-86						
GQ 091.25, SA 311.40						
After storage (Apr 21)						
Seed source, S	1	0.0001	3.294	9905**	1939.6**	3744**
Sowing date, D	3	.0020	1.185	420	106.8	381
Lifting date, L	2	.0335**	23.926**	6516**	1478.0**	3330**
SD	3	.0035	.418	689	133.6	272
SL	2	.0001	.483	928	213.2	674
DL	6	.0031	.756	522	99.7	268
SDL	6	.0024	.675	1560	207.3	319
Error	48	.0053	1.385	725	114.2	257
1986-87						
GQ 091.25, SA 311.40						
At lifting						
Seed source, S	1	0.3063**	10.845**	10011*	3117.0**	2560
Sowing date, D	3	.0385	.540	4672	842.2*	4795*
Lifting date, L	4	3.3872**	64.897**	16995**	2077.8**	37628**
SD	3	.0106	.131	3086	338.9	2476
SL	4	.0431	3.476**	2977	474.2	6926**
DL	12	.0209	.433	2742	406.4	1835
SDL	12	.0079	.131	2008	246.6	1898
Error	79	.0181	.277	2062	293.4	1196
After storage (May 11)						
Seed source, S	1	0.3756**	53.561 **	9341 *	1412.5**	1034**
Sowing date, D	3	.0426	7.466	1064	139.2	172
Lifting date, L	2	1.2693**	73.738**	10683**	1657.7**	2487**
SD	3	.0241	1.163	144	13.0	34
SL	2	.4610**	9.118	5964**	886.0**	1476**
DL	6	.0286	1.113	554	74.2	130
SDL	6	.0062	2.087	46	10.7	47
Error	48	.0376	3.589	1112	142.1	113
1987-88						
GQ 091.25, SA 311.40,						
HE 053.10, MK 472.45						
At lifting						
Seed source, S	3	1.1047**	160.95**	172762**	16163**	62866**
Sowing date, D	3	.3936**	31.73**	29462**	2671	3863
Lifting date, L	3	86.9922**	3368.94**	263822**	33433**	112585**
SD	9	.2593**	4.40*	15489*	2092*	6468**
SL	9	.4079**	40.42**	92526**	10488**	32796**
DL	9	.0876	9.06**	35794**	3692**	6458**
SDL	27	.1274	2.43	19464**	2484**	5397**
Error	1856	.1009	2.30	7773	1028	1658

*,** Significant at $p < 0.05$, $p < 0.01$.

¹ Seedlings were lifted monthly in winter and stored at 1° C (34° F) until spring planting time; see Assessing Planting Stock Quality, Standard Testing Procedures. See *table 8*, and Assessing Nursery Culture Alternatives, *tables 28, 31*.

² See *fig. 10*.

Table 8—Top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir from the February-May, 1985 and January-April, 1986 and 1987 sowings tested just after lifting and after cold storage at Humboldt Nursery¹

Seed source ² and testing date	TGC and RGC, by nursery lifting date					LSD ³
1985-86	Dec 16	Jan 13	Feb 10			
N Coast Range, coastal; GQ 091.25						
After storage (Apr 21)						
TGC budburst, <i>pct</i>	93.3	100.0	99.2			5.6
shoot length, <i>cm</i>	5.22	7.33	6.88			1.06
RGC root length, <i>cm</i>	41.8	84.3	74.7			25.1
roots ≥1.5 cm	16.6	36.7	33.0			10.0
<1.5 cm	20.1	50.8	48.4			15.4
Klamath Mtns, central; SA 311.40						
After storage (Apr 21)						
TGC budburst, <i>pct</i>	93.3	100.0	100.0			6.6
shoot length, <i>cm</i>	6.62	7.44	7.41			.92
RGC root length, <i>cm</i>	30.8	48.4	51.4			20.0
roots ≥1.5 cm	12.5	20.6	22.0			7.9
<1.5 cm	17.9	29.2	29.0			11.4
1986-87	Nov 10	Dec 8	Jan 5	Feb 2	Mar 2	
N Coast Range, coastal; GQ 091.25						
At lifting						
TGC budburst, <i>pct</i>	0.0	5.0	13.3	36.7	90.8	9.9
shoot length, <i>cm</i>	.00	.00	.12	.32	2.96	.42
RGC root length, <i>cm</i>	97.1	183.3	134.7	127.4	170.9	37.6
roots ≥1.5 cm	43.0	75.9	54.7	48.2	62.5	14.8
<1.5 cm	47.5	192.2	116.6	99.2	84.2	27.7
After storage (May 11)						
TGC budburst, <i>pct</i>	—	26.7	88.3	91.7	—	14.3
shoot length, <i>cm</i>	—	1.14	4.89	5.52	—	1.48
RGC root length, <i>cm</i>	—	16.4	77.3	81.4	—	31.1
roots ≥1.5 cm	—	6.4	29.9	31.6	—	11.3
<1.5 cm	—	6.3	33.3	38.2	—	9.5
Klamath Mtns, central; SA 311.40						
At lifting						
TGC budburst, <i>pct</i>	0.0	10.8	35.	052.5	98.4	12.2
shoot length, <i>cm</i>	.00	.12	.37	1.12	4.82	.45
RGC root length, <i>cm</i>	89.6	132.4	142.5	114.5	142.5	37.4
roots ≥1.5 cm	37.4	52.0	53.7	41.1	48.7	13.5
<1.5 cm	62.7	125.2	127.2	107.6	70.4	29.4
After storage (May 11)						
TGC budburst, <i>pct</i>	—	72.5	92.5	85.0	—	8.2
shoot length, <i>cm</i>	—	4.28	6.09	6.37	—	1.70
RGC root length, <i>cm</i>	—	29.7	32.6	44.4	—	24.8
roots ≥1.5 cm	—	11.3	11.9	18.0	—	8.6
<1.5 cm	—	16.4	13.7	25.0	—	8.4

¹ Seedlings were stored at 1° C (34° F); see Assessing Planting Stock Quality, Standard Testing Procedures. See *table 7*, and Assessing Nursery Culture Alternatives, *tables 28, 31*.

² See *fig. 10*.

³ Least significant difference ($p = 0.05$).

Table 8—*Top and root growth capacity (TGC, RGC) of 1-0 Douglas-fir from the February-May, 1985 and January-April, 1986 and 1987 sowings tested just after lifting and after cold storage at Humboldt Nursery—continued*¹

Seed source ² and testing date	TGC and RGC, by nursery lifting date				LSD ³
1987-88	Dec 14	Jan 11	Feb 8	Mar 7	
N Coast Range, coastal; GQ 091.25					
At lifting					
TGC budburst, <i>pct</i>	0.00	42.5	80.0	96.7	8.3
shoot length, <i>cm</i>	.00	.33	1.64	4.92	.38
RGC root length, <i>cm</i>	94.9	201.8	166.3	175.3	26.0
roots ≥1.5 cm	37.4	75.5	55.2	67.4	9.3
<1.5 cm	62.6	100.4	98.1	103.5	11.0
Klamath Mtns, central; SA 311.40					
At lifting					
TGC budburst, <i>pct</i>	5.8	60.0	90.8	100.0	7.8
shoot length, <i>cm</i>	.06	.95	2.84	7.60	.45
RGC root length, <i>cm</i>	140.5	157.3	165.5	97.6	21.1
roots ≥1.5 cm	52.3	57.6	55.5	40.6	7.6
<1.5 cm	63.5	70.3	78.2	71.9	8.8
1987-88	Dec 7	Jan 4	Feb 1	Feb 29	
Oregon Coast Range, N; HE 053.10					
At lifting					
TGC budburst, <i>pct</i>	6.7	32.5	84.2	100.0	8.2
shoot length, <i>cm</i>	.02	.14	1.81	4.80	.34
RGC root length, <i>cm</i>	109.5	153.5	152.9	80.7	22.6
roots ≥1.5 cm	43.7	59.1	53.4	65.2	8.1
<1.5 cm	67.4	102.1	100.3	103.2	11.3
Oregon Cascades, W; MK 472.45					
At lifting					
TGC budburst, <i>pct</i>	6.6	54.2	91.7	99.2	7.8
shoot length, <i>cm</i>	.10	.62	3.07	6.20	.36
RGC root length, <i>cm</i>	96.9	149.8	118.4	95.6	18.9
roots ≥1.5 cm	39.3	61.8	42.6	37.6	7.2
<1.5 cm	53.8	122.6	59.5	60.6	9.9

C. GROWTH CAPACITY TEST INSTRUCTIONS

These instructions are provided for the benefit of those who wish to test seedling top and root growth capacity (TGC and RGC; Stone and Jenkinson 1970, 1971) before spring planting. It is assumed that the seedlings have been properly shipped from the nursery and properly handled on arrival. For any seedlot, the test should be carried out after cold storage and finished within 4 weeks of planting, to give a reliable estimate of field performance. The test takes 28 days.

The method described was adopted because it provides safeguards against equipment failures that if not immediately detected would destroy integrity of the standard environment and compromise growth results. With the seedling roots planted in soil and the containers held in a large volume of water, some time could elapse before the temperature changed enough to affect root growth. The roots are not at risk to oxygen deficiency, as when an aerator fails in a hydroponic system, or to desiccation, as when a root-misting system fails. The security obtained more than offsets any price paid for inconvenience.

Equipment needed—To duplicate the test carried out at Humboldt Nursery, an airconditioned greenhouse is required. A polypropylene screen can be installed over the top to reduce incident sunlight and maintain effective air temperature control, depending on the month. Self-ballasted mercury-phosphor lights or their equivalent should be positioned 1 m (3.3 ft) above the water baths. Each bath is equipped with a thermostat and the water is circulated continuously. The baths are stainless steel, and hold up to six stainless steel containers, or trays. Each tray is 7.5 by 37.5 by 30 cm deep (3 by 15 by 12 in), and has a drain hole (#2 rubber stopper) covered inside with a brass, 6-mm (0.25-in) mesh screen to retain the planting mix. Ballast weights may be needed to stabilize the trays in the baths, depending on the mix used. A power blender for preparing a standard soil mix, water tanks for flooding the trays, and a sloped drain table for emptying them are required.

Sampling seedlings—The ability to predict field survival from the test results critically depends on whether the seedling sample truly represents the seedlot, that is, the seedlings to be planted in the field. For each lot to be tested, obtain a random sample of 75 to 100 seedlings (total) from two to four

randomly chosen packing bags. Randomly draw 30 seedlings from the sample and label each set of 10 with a waterproof tag indicating the seedlot, nursery lifting date, and sampling date. Do not select the largest or smallest seedlings. Never jeopardize the test by careless handling. Protect the seedlings at all times by keeping the tops and roots covered and moist until they are planted in the trays.

Planting seedlings—Use a planting mix consisting of equal volumes of river sand, perlite, shredded redwood conditioner, and sandy loam forest soil. Prepare the tray for planting by filling the bottom 5 to 8 cm (2 to 3 in) with the moist soil mix. Leave enough space to accommodate seedlings with roots pruned at 22 to 25 cm (9 to 10 in). Set the tray at an angle so that you can place soil mix on the lower side and firm it in place. When the tray is ready, place the sample seedlings in a tub of the moist soil mix, carefully covering the roots. Place the largest seedling in one end of the tray, making sure the roots are hanging straight. Draw the next seedling at random, and place it beside the first seedling in the tray. Continue placing seedlings until you have ten (or five, if exceptionally large) equally spaced in the tray. Once the seedlings are in, fill the upper side of the tray with the soil mix, firming it so that the roots will not sag and bend when the tray is set upright. When the tray is full, stand it up and rap it gently on the counter twice to settle the soil about the roots. If the soil has been firmed properly, settling will be minimal. Add soil until the tray is full, then set it aside and continue to plant the other trays with the balance of the test seedlings.

Watering seedlings—After all seedlings have been planted, move the trays onto a drain table in the airconditioned greenhouse. Irrigate them evenly until water flows freely from the drainholes. Use a series of small waterings to avoid washing soil from the tray. Let the trays drain overnight. Weigh each tray to obtain its initial gross weight to the nearest 0.1 kg (0.25 lb). Insert the stopper firmly in the drainhole to make the tray watertight. After all trays have been weighed and stoppered, immerse them to just below the rim in the constant-temperature baths. The trays should be set on two lengths of plastic pipe in the bottom of the bath to clear the stoppers and permit water circulation beneath. Use ballast weights as needed to stabilize the trays. Be careful not to upset or flood the trays as they are placed in the baths, as added water reduces soil aeration and necessitates replanting. Each of the three trays of a particular seedlot should be placed in a different bath, so that if any problem occurs in the operation of a bath, only one tray of the seedlot will be lost.

The test environment—Maintain the seedlings in the greenhouse for 4 weeks. Check the water bath levels and temperatures morning and evening and add water to the baths as needed. Hold the bath temperature at 20° C (68° F). Keep air temperatures above 17° C (63° F) at night and below 26° C (78° F) during the day. Circulate air constantly by using a turbulator or comparable circulation system to prevent temperature gradients in the greenhouse. Set the photoperiod at 16 hours by operating the lights morning and evening, from 6 to 8 A.M. and 6 to 10 P.M.

Rewatering seedlings—Irrigate all seedlings weekly. Take the trays out of the baths and remove the stoppers to prevent airblocks and insure even watering. Place each tray on the scale, record its current weight, and add water slowly and evenly to the soil surface until the tray is restored to its initial gross weight. Transfer it gently to the drain table and allow 20 minutes for the added water to percolate before replacing the stopper. Place the restoppered trays back in their respective baths.

Terminating tests—After 4 weeks, lift the trays from the baths, remove the stoppers, and place the trays in a tank of water to flood the soil mix from below. This procedure prevents the breakage of new roots by easing removal of the root-soil mass from the trays. Gently empty the tray onto a sloped drain table, and wash all soil from the roots with a spray of water from a waterbreak. After each set is washed free and clean, wrap it in wet paper towels to keep the roots moist. Store the labelled, wrapped sets of seedlings in a polyethylene bag at 1° C (34° F).

Counting new roots—Evaluate the new white root growth within 3 days, before it turns brown. For each seedling, record the number of roots that elongated 1.5 cm or more. If most seedlings do not have at least 10 such roots, then count the roots that grew less than 1.5 cm as well, to assess marginal seed lots.

Summarizing and using test results—For each seedlot, determine the percentage of seedlings having 10 or more roots that grew at least 1.5 cm during the test. Determine the percentage having 20 or more, 30 or more, 40 or more, and 50 or more. Survival potential of the seedlot may be estimated from a knowledge of the critical root growth capacity typical of the sites to be planted. Remember that critical values depend not only on the regional climate, soil type, and topographic position of the planting site, but on quality of the planting job and protection against competing vegetation and browsing mammals.

D. PLANTING SITE DESCRIPTIONS

The planting sites described here were used to test field survival and growth of 2-0 Douglas-fir, Shasta red fir, and white fir in the seed zones of origin in western Oregon and northern California.

Douglas-fir sites

Oregon Coast Range, N

WA 061.10 77

Douglas-fir/western hemlock forest, Waldport Ranger District (RD), Siuslaw National Forest (NF); Lincoln Co., T14S, R11 W, S12; 44.37° N, 123.95° W

Unit: 87-acre clearcut, logged 1974, sprayed with 2,4-D and 2,4,5-T May 1975, broadcast-burned September 1975

Site: 3 mi south of Alsea River, 8 mi from the Pacific Ocean; altitude 900 ft, slope NW 5 pct, Bohannon gravelly loam

Planted: April 15, using planting bars

Rain (in): Mar, 8.9; Apr, 0.8; May, 5.8; Jun, 1.6; Aug, 2.9

AL 252.10 77

Douglas-fir/western hemlock/vinemaple forest, Alsea RD, Siuslaw NF; Lincoln Co., T14S, R9W, S3; 44.38° N, 123.76° W

Unit: 40-acre clearcut, high-lead logged 1975, broadcast-burned May 1976

Site: just north of Alsea River, 16 mi from the Pacific Ocean; altitude 750 ft, slope SW-SE 20-75 pct, site III, Bohannon gravelly loam

Planted: April 22, using powered soil auger; seedlings were protected by 30-inch vexar tubes, and were cleared of tansey ragwort

Rain (in): Mar, 9.8; Apr, 0.9; May, 5; Jun, 1.2; late Aug, 2.1

AL 252.05 78

Douglas-fir/salal forest, Alsea RD, Siuslaw NF; Lincoln Co., T14S, R10W, S11; 44.36° N, 123.86° W

Unit: 80-acre clearcut, logged 1976, broadcast-burned October 1977

Site: near Meadow Fork Creek 2 mi west of Alsea River, 12 mi from the Pacific Ocean; altitude 500 ft, slope S 30 pct, site II, Slickrock gravelly loam

Planted: April 13, using planting hoes; seedlings were protected by 30-inch vexar tubes

Rain (in): Mar, 3; Apr, 7.2; May, 4.2; Jun, 0.9; Jul, 0.5; Aug, 2; Sep, 3.8; Oct, 1.3; Nov, 6

*Douglas-fir timberlands,
Gasquet Ranger District:
View of Jones Ridge and
Muslatt Mountain skyline
from Fox Ridge unit 6*



Oregon Coast Range, S

CH 082.25 76

Douglas-fir forest, Chetco RD, Siskiyou NF; Curry Co., T38S, R12W, S18; 42.26° N, 124.17° W
Unit: 93-acre clearcut, logged November 1974, broadcast-burned February 1976

Site: north fork headwaters of Eagle Creek, 3 mi north of confluence with Chetco River, 13 mi from the Pacific Ocean; altitude 1600 ft, slope NW-SW 5-50 pct, clay loam on schists with high erosion potential

Planted: April 23, using powered soil auger; test blocks were set along an 0.5-mi transect

Rain (in): below normal to Aug; air temperature ranged up to 95° F

CH 082.25 77

Tanoak brushfield, Chetco RD, Siskiyou NF; Curry Co., T38S, R11W, S30; 42.23° N, 124.03° W

Unit: 65-acre conversion, thickets 20 ft tall after wildfire, cut June 1975, broadcast-burned June 1976

Site: ridge near Quail Prairie Lookout, 1 7 mi from the Pacific Ocean; altitude 2700 ft, slope S-SW 30 pct, shallow gravelly loam on sandstone and mudstone

Planted: March 17, using powered soil auger

Rain (in): Mar-Jun, 10; late Aug, 2.3; Sep, 11.2; air temperature ranged up to 95° F, and relative humidity, down to 17 pct

CH 082.25 78

Tanoak brushfield, Chetco RD, Siskiyou NF; Curry Co., T38S, R12W, S23; 42.25° N, 124.08° W

Unit: 13-acre conversion, thickets 20 ft tall after wildfire, cut and stump-treated with tordon May 1976, broadcast-burned October 1976

Site: Long Ridge in Quail Prairie Creek drainage of Chetco River, 16 mi from the Pacific Ocean; altitude 2300 ft, slope S 20 pct, shallow loam on sandstone and mudstone

Planted: April 10, using powered soil auger

Rain (in): above normal; May, 1.91- Jun, 2.2; Jul, 0.3; Aug, 5.9; Sep, 1 2.1

Klamath Mountains, W

GQ 301.30 77, 78

Knobcone pine/tanoak brushfield, Gasquet RD, Six Rivers NF; Del Norte Co., T16N, R1E, S2, NE1/4; 41.81° N, 124.02° W

Unit: 28-acre conversion, was Douglas-fir/sugar pine forest before 1918 wildfire; tractor-cleared and windrowed June 1976; brush included salal, rhododendron, huckleberry, chinquapin, and manzanita

Site: ridge between Middle and South Forks Smith River, 9 mi from the Pacific Ocean; altitude 1700 ft, slope S 15 pct, site IV, clay loam

Planted: monthly in October-March, and April 25, 1977 or May 1, 1978 using powered soil auger

Rain (in) 1976-77: Oct, 2.3; Nov, 2.3; Dec, 1.1; Jan, 4.8; Feb, 7.3; Mar, 10; Apr, 1.6; May, 4.5; late Aug, 1.1



North Coast Range, coastal

KI 390.25 77
Douglas-fir/evergreen hardwood forest, Ukiah Resource Area (RA), BLM; Humboldt Co., T4S, R1E, S1, SW1/4; 40.14° N, 124.02° W
Unit: wildfire 1973, tractor-logged 1976
Site: King Range, on spur ridge in Noonung Creek drainage of Mattole River, 2 to 3 mi from the Pacific Ocean; altitude 2000 ft, slopes NE-SW 50 pct, Hugo loam on Cretaceous marine rock
Planted: March 18, using powered soil auger; seedlings were cleared of manzanita, tanoak, madrone, and huckleberry
Rain (in): Jan-Feb, 3.9; Mar, 12.1; Apr, 2.1; May, 4.8; Sep, substantial

RE 093.25 78
Mixed conifer forest, Ukiah RA, BLM; Mendocino Co., T24 N, R17W, S3, SE1/4 of SW 1/4; 39.95° N, 123.72° W
Unit: clearcut
Site: ridge in Red Mountain Creek watershed of South Fork Eel River, 4 mi east of Piercy; altitude 1800 ft, slope S 30 pct, Hugo loam on Cretaceous marine rock
Planted: April 6, using planting hoes

North Coast Range, inland

MR 340.36 78
Douglas-fir forest, Mad River RD, Six Rivers NF; Trinity Co., T3S, R8E, S29, SW1/4; 40.17° N, 123.30° W
Unit: clearcut, tractor-piled and burned
Site: divide between Mad and Eel Rivers, in Tub Creek headwaters of North Fork Eel River; altitude 3700 ft, exposure WSW
Planted: April 24, using planting hoes
Rain (in): Apr, abundant; May, 1.6; Nov, 2

UP 372.30 77
Ponderosa pine/Douglas-fir forest, Upper Lake RD, Mendocino NF; Lake Co., T17N, R10W, S14, SE1/4 of SE1/4; 39.32° N, 122.95° W
Unit: Round Fire Burn 1966; stands included sugar pine, incense-cedar, California black oak, madrone, deerbrush, and hoary manzanita
Site: west of North Coast Range crest, at headwaters of Bucknell Creek between Lake Pillsbury and Clear Lake; altitude 3400 ft, site II, Josephine loam on consolidated sedimentary rock
Planted: March 10, using powered soil auger
Rain (in): Jan, 2.7; Feb, 2.7; Mar, 2.7; May, 2.1; Aug, 0.4; Sep, 4.9; site had 10 freezing days in March and hot, dry winds in summer

Klamath Mountains, N

IL 512.35 78
Mixed conifer forest, Illinois Valley RD, Siskiyou NF; Josephine Co., T40S, R7W, S31; 42.04° N, 123.56° W
Unit: 5-acre clearcut, logged 1975, tractor-piled and burned 1976
Site: Elder Creek drainage of East Fork Illinois River; altitude 3500 ft, slope W 10-25 pct, clay loam
Planted: May 16, using planting hoes

Klamath Mountains, central

HC 301.30 77, 78
Douglas-fir/tanoak/madrone forest, Happy Camp RD, Klamath NF; Siskiyou Co., T15N, R7E, S6, NE 1/4 of NW1/4; 41.73° N, 123.46° W
Unit: 10-acre clearcut, logged 1968, tractor-piled and burned 1971, planted October 1972, release-sprayed with 2, 4, 5-T 1974.
Site: Wingate Creek drainage of Klamath River; altitude 2100 ft, slope E 20 pct, site III, Josephine gravelly loam
Planted: March 11, 1977 or May 3, 1978 using powered soil auger; seedlings were cleared of snowbrush, deerbrush, bracken, poison oak, and grasses
Rain (in) 1977: Feb, 4; Mar, 3.7; May, 1.7; Jun, 0.8; late Aug, 1

Klamath Mountains, S

BI 312.40 77
Mixed conifer/evergreen hardwood forest, Big Bar RD, Shasta-Trinity NF; Trinity Co., T34N, R7E, S25, SE1/4; 40.69° N, 123.33° W
Unit: clearcut, tractor-logged 1965 and 1974, piled and burned 1974
Site: 1 mi northeast of Pattison Peak, in Corral Creek drainage of Trinity River; altitude 3250 ft, slope NW 10 pct, gravelly loam on pre-Cretaceous metamorphic rock
Planted: March 17, using powered soil auger; seedlings were cleared of canyon liveoak, tanoak, madrone, chinquapin, poison oak, whitethorn, deerbrush, snowberry, western raspberry, and thistle
Rain (in): Jan-Feb, 5.8; Mar, 2.5; Apr, 0.4; May, 1.8; Jul, 0.4; Aug, 0.3; Sep, substantial

BI 312.30 78
Mixed conifer forest, Big Bar RD, Shasta-Trinity NF; Trinity Co., T33N, R7E, S36; 40.68° N, 123.33° W
Unit: clearcut
Site: spur ridge 1 mi east of Pattison Peak, in Corral Bottom watershed of Hayfork Creek; altitude 3000 ft
Planted: May 17, using planting hoes
Rain (in): Mar-Apr, 9.3; May, 0.8; Jun, 1.6; Sep, 2

HA 312.25 78
Mixed conifer forest, Hayfork RD, Shasta-Trinity NF; Trinity Co.
Unit: clearcut; E block of Drinkwater sale
Planted: April 27, using planting hoes

YO 371.45 78
Mixed conifer forest, Yolla Bolla RD, Shasta-Trinity NF; Tehama Co., T26N, R8W, S4, NW1/4 of NW1/4; 40.14° N, 122.78° W
Unit: Skinner Mill Burn 1976
Site: Nuisance Ridge in Maple Creek watershed, 2 mi east of Tom head Mtn; altitude 4500 ft, slope N 50 pct, site III, Sheetiron clay loam
Planted: May 2, using shovels and planting hoes; seedlings were cleared of grasses and forbs
Rain (in): Feb-Mar, 9.6; Apr, 3.4; Jun, 2.4; Sep, 2.4

Klamath Mountains, E

OK 321.40 77

Mixed conifer/Jeffrey pine forest, Oak Knoll RD, Klamath NF; Siskiyou Co., T47N, R8W, S6; 41.95° N, 122.82° W

Unit: 20-acre clearcut, tractor-logged and cleared 1975

Site: Little Soda Creek drainage of West Fork Beaver Creek; altitude 4000 ft, slope S 10 pct, shallow clay loam on serpentinite

Planted: May 5, using powered soil auger

Rain (in): Jan-Mar, 5.7; May, 1.3; Jun, 0.8; Aug, 0.3; Sep, 2.5

OK 321.40 78

Mixed conifer forest, Oak Knoll RD, Klamath NF; Siskiyou Co., T46N, R10W, S2, NW1/4 of SE1/4; 41.86° N, 122.97° W

Unit: Buckhorn Burn wildfire, salvage-logged and tractor-piled 1977

Site: Buckhorn Ridge in Kohl Creek drainage of Klamath River, north of Horse Creek; altitude 3500 ft, slope SE 15 pct, deep clay loam on Condrey Mtn schist

Planted: April 11, using planting hoes; seedlings were cleared of grasses, forbs, and regrowth of deerbrush and manzanita

Rain (in): Mar, 2.7; Apr, 1.6; May, 0.4; Jun, 1.5; Jul, 0.3; Aug, 0.9; Sep, 2

SC 322.40 78

Mixed conifer forest, Scott River RD, Klamath NF; Siskiyou Co., T45N, R9W, S6, SE1/4 of SE1/4; 41.77° N, 122.92° W

Unit: clearcut

Site: divide separating headwaters of Mill and McKinney Creeks, 7 mi east of confluence of Scott and Klamath Rivers; altitude 4400 ft

Planted: May 3, using planting hoes

Oregon Cascades, W

BL 472.30 77

Douglas-fir/western redcedar/hemlock forest, Blue River RD, Willamette NF; Lane Co., T16S, R5E, S29; 44.15° N, 122.23° W

Unit: 28-acre clearcut, high-lead logged 1970, broadcast-burned 1976

Site: Cougar Creek drainage of South Fork McKenzie River; altitude 2300 ft, slope SW 35 pct, site III, gravelly loam on volcanic rock

Planted: April 8, using shovels; seedlings were cleared of shrubs, vines, bracken, grasses, thistles, and forbs

Rain (in): Mar, 11; Apr, 2.3; May, 7.4; Jun, 0.9; Aug, 3.5

California Cascades

SH 516.30 77

White fir/ponderosa pine forest, Mt Shasta RD, Shasta-Trinity NF; Siskiyou Co., T40N, R3W, S1 7; 41.31° N, 122.22° W

Unit: clearcut, tractor-logged 1976, brush-raked to clear manzanita

Site: Big Canyon Creek drainage, south side Mt Shasta; altitude 5200 ft, slope SW 3 pct, Shasta loamy sand on pyroclastic alluvium

Planted: May 10, using powered soil auger

Rain (in): about half normal; Jan-Jun, 19; Aug, 0.6

Sierra Nevada, N

GR 523.45 77

Mixed conifer forest, Greenville RD, Plumas NF; Plumas Co., T27N, R7E, S21, SE1/4 of SE1/4; 40.18° N, 121.19° W

Unit: 11-acre understocked, tractor-bladed and piled 1976, to clear manzanita, whitethorn, and bitter cherry between clumps of white fir, ponderosa pine, and incense-cedar poles

Site: North Fork Feather River drainage, between Lake Al manor and Butt Valley Reservoir; altitude 4300 ft, slope W 10 pct, sandy loam on Pliocene basalt

Planted: April 25, using powered soil auger

Rain (in): April, heavy; May, 1.5; Sep, 1.5; Oct, 2

Sierra Nevada, W

PL 526.40 77

Mixed conifer forest, Placerville RD, Eldorado NF; Eldorado Co., T1 ON, R1 4E, S6, NW1/4 of NE1/4; 38.75° N, 120.46° W

Unit: 5-acre clearcut, tractor-logged, piled and burned 1974

Site: Ogilby Canyon drainage of South Fork American River; altitude 4600 ft, slope NE 30 pct, Cohasset sandy clay loam on andesite

Planted: April 1, using planting hoes; prickly sowthistle covered unit in July-November

Rain (in): Mar, 1.8; Apr, 1.9; May, 2.1; Sep, 0.2; Oct, 0.1; Nov, 3.5

MI 531.40 77

Mixed conifer forest, Mi-Wok RD, Stanislaus NF; Tuolumne Co., T3N, R17E, S33; 38.07° N, 120.11° W

Unit: Wrights Creek Burn; torched November 1976 to clear whitethorn and chokecherry

Site: Wrights Creek watershed in North Fork Tuolumne River drainage; altitude 5000 ft, slope W 25-40 pct, Chaix sandy loam on granitic rock

Planted: April 1-14, using planting hoes

Snowpack: 6 ft

Rain (in): Feb-Mar, 13.5; Apr, 0.2; May, 3.9; Jun, 0.3; Oct, substantial

Shasta red fir sites

Klamath Mountains, E

OK 321.60 76

Mixed conifer/true fir forest, Oak Knoll RD, Klamath NF; Siskiyou Co., T45N, R12W, S13; 41.75° N, 123.18° W

Unit: clearcut, tractor-terraced 1975

Site: Marble Mtns, 7 mi south of Seiad Valley, 1.5 mi west of Lake Mtn Lookout; altitude 5700 ft, slope NW 100 pct, site II, loam on metamorphic rock

Planted: May 24, using planting hoes

Rain (in): Jun-Aug, nil

OK 321.60 77

Red fir/white fir forest, Oak Knoll RD, Klamath NF; Jackson Co., T40S, R1E, S21, NW1/4 of SE 1/4; 42.07° N, 122.72° W

Unit: clearcut

Site: Eastern Siskiyou Mtns, on Mt Ashland; altitude 6200 ft, slope SE 10 pct, fine sandy loam on granitic rock

Planted: May 17, using powered soil auger

Rain (in): Jan-Mar, 5.7; Apr-May, 1.5; Jun, 0.8; Jul-Aug, 0.3; Sep, 2.5

OK 321.60 78

Red fir/white fir forest, Oak Knoll RD, Klamath NF; Jackson Co., T40S, R1E, S20, SE1/4 of NW1/4; 42.07° N, 122.73° W

Unit: logged to create small scattered openings, yumyarded 1975

Site: Eastern Siskiyou Mtns, on Mt Ashland; altitude 6300 ft, slope E 26 pct, fine sandy loam on granitic rock

Planted: June 2, using planting hoes

Snowpack: melted by late May

California Cascades

GN 741.65 77

Red fir forest, Goosenest RD, Klamath NF; Siskiyou Co., T46N, R2W, S30, SW1/4 of NW1/4; 41.80° N, 122.15° W

Unit: 15-acre clearcut, tractor-logged, windrowed, and burned 1966; cross-plowed 16 inches deep with two-gang Towner disc to control grasses, sedges, and gophers October 1976

Site: Shasta Cascades, on Ball Mtn; altitude 6800 ft, slope NE 10 pct, sandy loam on volcanic rock

Planted: June 13, using powered soil auger

Snowpack: melted by late May

Rain (in): Jun, 2; Sep, 2

White fir sites

Klamath Mountains, E

OK 321.60 77

White fir/Douglas-fir forest, Oak Knoll RD, Klamath NF; Jackson Co., T40S, R1E, S31; 42.04° N, 122.75° W

Unit: clearcut; stand included scattered Jeffrey pine, incense-cedar

Site: Eastern Siskiyou Mtns, near west branch of Grouse Creek; altitude 5700 ft, slope SE 10 pct, gravelly loam on granitic rock

Planted: May 18, using powered soil auger

Rain (in): Jan-Mar, 5.7; Apr-May, 1.5; Jun, 0.8; Jul-Aug, 0.3; Sep, 2.5

OK 321.60 78

White fir/Douglas-fir forest, Oak Knoll RD, Klamath NF; Jackson Co., T41S, R1W, S1, NW1/4 of SE1/4; 42.02° N, 122.86° W

Unit: logged by group selection, tractor-piled, and burned 1977; stand contained scattered sugar pine, ponderosa pine

Site: Eastern Siskiyou Mtns, in eastern watershed of Long John Creek; altitude 4800 ft, slope W 14 pct, sandy loam on granitic rock

Planted: April 13, using planting hoes



Douglas-fir plantation at age 18, 2 years after thinning: View of Jones Ridge unit 4 from Fox Ridge unit 6, with Muslatt Mountain in distance, and closer view of unit 4 from Jones Creek



E. FIELD TEST DATA FORMS

Standard forms were used to map seedlings and record survival and growth in the field performance tests. Each form mapped seedlings in randomized complete blocks of lifting date plots (A), or lifting date plots split for cultural treatment (B).

A. Form for tests to determine seed source lifting windows

Humboldt Nursery Study RF 431A02 _____

(test and year)

Seed source _____

Lifting date A = Nov _____

B = Dec _____

Date planted _____

C = Jan _____

Date scored _____

D = Feb _____

E = Mar _____

Block # _____

Block # _____

Lifting date

Seedling 1

2

3

4

5

6

7

8

9

10

Seedling codes: o = dead, m = missing, + = healthy, - = weak, b = budbreak, f = shoot elongating

Remarks: freezing weather, rain, browse damage, gopher kill, grass or other vegetative competition, etc.

B. Form for tests to assess nursery cultural treatments

Humboldt Nursery Study RF 431A02 _____

(test and year)

Seed source _____

Lifting date

Cultural treatment

Date planted _____

B = Dec _____

1 = _____

Date scored _____

D = Feb

3 = _____

E = Mar _____

Block # _____

Lifting date and cultural treatment

[illegible]

Seedling codes: o = dead, m = missing, + = healthy, - = weak, b = budbreak, f = shoot elongating

Remarks: freezing weather, rain, browse damage, gopher kill, grass or other vegetative competition, etc.



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- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

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- Represents the research branch of the Forest Service in California, Hawaii, American Samoa, and the western Pacific.
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Forest Service

IMPROVING PLANTING STOCK QUALITY—THE HUMBOLDT EXPERIENCE

**Pacific Southwest
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