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
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, 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. 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.

- 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 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.

- 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 precolder 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 precolder, 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 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 sources 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 shingletow 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° ± 0.5° C (68° ± 1° 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/m² at seeding 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 mm
- Shoot extension, the length of the longest new shoot >1 cm, per seedling

**RGC**
- Root elongation, the new length of roots elongated ≥1.5 cm, per seedling
- Roots elongated, including the number ≥1.5 cm and the number >2 mm but <1.5 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.
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).
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

\[
\text{LSD} = \frac{q \cdot \text{ems}}{r^{1/2}},
\]

where ems is error mean square from program P8V 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

\[
\text{LSD} = \frac{q \cdot \text{ems}}{r^{1/2}},
\]

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 $Z = bY$, 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 $\geq 5, 10, 20, ...100$ 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