Winter Sowing for Production of 1.0 Douglas-fir Planting Stock[1]

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Abstract.--Effects of early sowing on emergence and growth of Douglas-fir were examined in the Humboldt Nursery on California's north coast. In a 1979 study, seeds from coastal and inland regions of western Oregon and northern California were chilled 30 or 90 days at 1^{0}C and sown in March and May. Chilling seeds for 90 days resulted in greater speed and amount of seedling emergence in cool soil (March) and greater speed of emergence in warm soil (May). March sowing captured at least six additional weeks early in the potential growing season and resulted in 1-0 seedlings that were large enough to outplant. Top dry weight was increased by 63 to 106 percent and root dry weight after pruning, by 24 to 82 percent, depending on seed source. In a 1985 study, seeds of coastal and inland sources were chilled 90 days and sown in January, February. March. April, and May. Sizes of the resulting 1-0 seedlings defined sowing windows that were wide open in February and closed in late April. Relative stem volumes in the February through May sowings were 7.5. 4.2, 2.9. and 1.0, and the cull percentages, 14, 21, 38, and 82. respectively. Humboldt Nursery can efficiently produce 1-0 Douglas-fir for the Pacific slope by sowing fully chilled seeds in winter and early spring.

INTRODUCTION

Planting 1-0 seedlings of Pacific Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) is an attractive option for reforestation programs in the Pacific slope regions of western Oregon and northern California. Advantages for forest management include shorter lead times and greater silvicultural flexibility for regenerating harvested stands and forests burned by wildfire. Advantages for nursery management include more frequent cover cropping or fallow years and ripping or chisel plowing to improve soil aeration and drainage. Compared with 2-0 seedlings, 1-0 seedlings take less water, fertilizer, weeding, and inventory effort, require neither undercutting nor vertical pruning of roots in the nursery, and cost less to lift, grade, pack, store, ship, and plant. They are more easily lifted and separated without mechanical damage to the roots, and standard root pruning removes less of the lifted root system. Up to three times as many 1-0 as 2-0 seedlings can fit in the standard packing bag. tripling the capacity of premium cold storage. Because 1-0 seedlings are easier to plant with proper root placement and easier to protect against depredation by animals, their use may enhance early plantation establishment.

The biological basis for growing 1-0 Douglas-fir partly rests on knowledge of the physiological ecology of conifer seeds and seedlings. Seeds of most conifers in the wild. including those of Douglas-fir on the Pacific slope, are shed in autumn, undergo moist overwinter chilling, and germinate in early spring. Research on Douglas-fir. sugar pine (Pinus lambertiana Dougl.). ponderosa pine (P. ponderosa Dougl. ex Laws.). loblolly pine (P. taeda L.), lodgepole pine (P. contorta Dougl.). Engelmann spruce (Picea engelmannii [Parry]

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Engelm.), and Fraser fir (Abies fraseri [Pursh] Poir.) has shown that prolonged chilling may enable rapid germination, seedling emergence, and early growth in cool conditions (Adkins and others 1984. Allen 1960, Danielson and Tanaka 1978, Dunlap and Barnett 1982, Jenkinson and others 1982. McLemore 1969. Sorensen 1978, Tanaka and others 1986). Moreover, cool soils may restrict the lethal activity of damping-off and Fusarium root disease (Bloomberg 1973, Filer and Peterson 1975, Jenkinson and others 1982. Smith 1975) and promote the early mycorrhizal development and protection of young seedling roots (Parke and others 1983. Sinclair 1974, Sinclair and others 1982. Sylvia 1983).

Nursery and field experience with three widespread pines in California encouraged our work on Douglas-fir. By sowing in May, nurseries in the western Sierra Nevada readily produce successful 1-0 seedlings of ponderosa and Jeffrey pines (Pinus jeffreyi Grev. & Balf.) for many different seed sources (Jenkinson 1980). In these same nurseries, the traditional May sowings always take 2 years to grow acceptable crops of sugar pine. A recent April sowing of sugar pine at the Placerville Nursery nevertheless produced successful 1-0 seedlings for a number of different seed sources in the North Coast Range and Sierra Nevada (U.S. Dep. Agric.. Forest Service 1982). In the nearby Institute of Forest Genetics nursery, February and March sowings of sugar pine from an elevational transect of the western Sierra consistently produced large and healthy 1-0 seedlings, whereas seedlings in May sowings were highly susceptible to Fusarium disease and too small to outplant (Jenkinson and others 1982).

Situated on the Pacific Coast near McKinleyville, the Humboldt Nursery is historically free of winter snow and frozen soil. but traditionally has sown in May to avoid the rainy season. Seedlings of all conifers in these late spring sowings require 2 years to reach acceptable planting sizes. By contrast, trial sowings of Douglas-fir in March and April have commonly produced 1-0 seedlings that were big enough to outplant. No other treatment was needed.

To evaluate the survival and growth potential of its 1-0 Douglas-fir. Humboldt Nursery and its clientele established a series of field tests in the Oregon Coast and Cascade Ranges, the Klamath Mountains, and the North Coast Range of California. Seedlings were planted in spring on cleared sites in the seed zone of origin for a total of 11 different seed sources. Results were encouraging. For seedlings dug within the seed source lifting window (Jenkinson and Nelson 1978). field survival averaged 81 to 99 percent. depending on planting site, and tree heights often doubled in the first and second years (Jenkinson 1984; Jenkinson and Nelson 1983. 1985; Turpin and others 1985).

It seems evident that by sowing early. bareroot nurseries in California might easily produce 1-0 planting stock for sugar pine and Douglas-fir. Yet responsible nursery people hesitate to shift from the traditional sowing schedules, and for valid reasons (Owston and Stein 1974). Seed treatment and soil preparations for early sowing will necessarily invade the nursery lifting season, and the usual winter and spring rains will typically obstruct any calendar for seedling harvest, nursery bed formation, and early sowing. In such circumstances, work plans must be highly flexible if harvest and sowing schedules are to be coordinated effectively. The greatest deterrent to sowing early is the occasional torrential rain that can cause severe soil erosion, destroy newly sown beds, and force another sowing with summer imminent.

This paper reports two studies of early sowing in the Humboldt Nursery and offers guides for the production of large. 1-0 planting stock for Pacific Douglas-fir. In 1979, we explored the effects of seed chilling period and nursery sowing date on the speed and amount of seed germination. seedling emergence and growth for seed sources from coastal and inland regions of western Oregon and northern California. Seedlings from this study were successfully tested for field survival and growth (Jenkinson and Nelson 1983). In 1985, we investigated the nursery sowing windows--that is. the earliest and latest safe times to sow coastal and inland seed sources for the production of 1-0 stock--and explored ways to control erosion in the seed beds. Field tests of seedlings from this study are in progress.

MATERIALS AND METHODS

For the 1979 study, seed sources were chosen in the Oregon Coast Range and western Cascade Range. and in the North Coast Range and eastern Klamath Mountains of California (table 1). These sources represent the diversity of coastal and inland regions supplied with planting stock from Humboldt Nursery.

Seed Germination Test

Seed$ were soaked 36 hours in aerated water at 22°C (72 F), chilled 0, 20. 40. or 60 days at 1°C (34°F) to bracket Humboldt's traditional 30 days, and germinated at 22°C on moist filter paper in 11-cm Petri dishes. Each dish contained 100 seeds of a particular source and chilling treatment, and each combination was replicated four times. Filter papers were kept moist with a dilute suspension of captan fungicide. Germinated seeds were counted and removed at 7, 14. and 21 days. A seed was considered germinated once the radicle had extended 2 mm beyond the seedcoat and showed positive geotropic response.

The effects of seed source and chilling period on germination were assessed by analysis of variance using BMD P2V (Jennrich and others 1981).

Table 1. Seed sources used to investigate early spring and winter sowing for the production of 1-0 Douglas-fir at Humboldt Nursery

Forest region and seed source code	Ranger District or Resource Unit	Tree seed zone[2]	Seed parent elevations (ft)[3]
	March and May sowings, 1979		
Oregon Coast Range AL 252.15	Alsea	252	1000-1500
Cascade Range, western MK 472.30	McKenzie	472	2500-3000
North Coast Range KR 390.20	King Range[1]	390	1500-2000
Klamath Mtns, eastern OK 321.30	Oak Knoll	321	2500-3000
	January through May sowings, 1985		
North Coast Range GQ 091.25	Gasquet	091	2000-2500
Klamath Mtns, central SA 311.40	Salmon River	311	3500-4000

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[1] Bureau of Land Management.

[2] U.S. Dep. of Agric., Forest Service 1969, 1973.

[3] 1 m = 3.28 ft.

Seedling Emergence and Growth Test

Seeds were soaked 36 hours in aerated water at 22^0 C, chilled 30 or 90 days at 1^{0}C. and sown in the nursery on March 14 and May 15. Adjacent beds were prepared by the standard chisel plow and power harrow method in early March. Monoammonium phosphate (11-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation, according to traditional practice (200 lb and 50 lb material/acre, respectively). To facilitate plot installation and cultural treatments, one bed was necessarily assigned the March sowing and the other, the May sowing. A Love-Oyjord seeder was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m^2).

The design of the test consisted of five replications of a randomized complete block of split plots. The bed pair was divided into five blocks of seed source plots. The blocks were 80 ft long, the source plots. 20 ft. and the treatment plots. 10 ft (1 ft = 30.5 cm). The source plots were split across the beds for chilling treatment and between the beds for sowing dates. The five replications extended 400 ft. sampling most of the width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to moisten the soil surface during emergence, and once or twice weekly to irrigate the soil profile through the growing season. The seedlings were not fertilized.

To track seedling emergence. four sample plots were randomly located in seed rows 2 to 7 of the middle 5 ft of each chilling treatment plot. Each sample plot consisted of 1 ft of seed row and was permanently marked with parallin stakes. New germinants were counted three times weekly after emergence began, and less frequently as emergence neared completion. A germinant was counted after its hypocotyl penetrated the bed surface.

In December, seedlings were dug from the sample plots, combined by treatment plot, carefully washed free of soil, root-pruned 23 cm (9 in) below the cotyledon node, and graded to eliminate any damaged individuals. Ten randomly selected seedlings per treatment plot were evaluated for shoot height above the cotyledon node, stem diameter 1 cm below the node, and oven dry weights (65°C or 140°F) of the top and roots separated at the node.

The effects of seed source and chilling period on seedling emergence were assessed for the March and May sowings separately, by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split plot design, with seed sources and chilling periods considered fixed and the blocks, random.

The effects of seed source, chilling period, and sowing date on seedling growth were also assessed by BMD P8V. The data were analyzed as a split-split plot design with seed sources. chilling periods, and sowing dates considered fixed and the blocks, random.

Determining Nursery Sowing Windows

For the 1985 study, seed sources representing coastal and inland regions were chosen in the North Coast Range and the central Klamath Mountains of California (table 1).

Seeds were soaked 24 hours in aerated water at 22°C. chilled 90 days at 1°C, and sown in the nursery on January 15, February 19, March 21, April 23, and May 17. One full bed was prepared by the chisel plow and power harrow method in early January. when soil conditions were favorable. Triple super phosphate (0-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation (440 lb and 200 lb material/acre, respectively). The shaped bed was protected against erosion by covering the soil surface with a 1/4-inch-mesh net made of polypropylene. The net was removed as the plots were sown. A Love-Oyjord seeder again was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m^2).

The design of the test consisted of three replications of a randomized complete block of split plots. Sowing date was split for seed source and seed source was split for a check and three erosion control methods, that is, a woven tissue paper mat, hydromulch (Landis and others 1984), and a 30-percent shade polypropylene cloth stretched 20 cm (8 in) above the soil surface. The sowing-date plots were 40 ft long, the source plots, 20 ft. and the treatment plots, 5 ft (1 ft = 30.5 cm). The three replications extended 600 ft, sampling the full width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to keep the soil surface moist during emergence and twice a week to irrigate the soil profile as seedlings grew and summer progressed. Seedlings of each sowing were fertilized with nitrogen within 2 months of emergence (100 lb N/acre). The soil surface was scarified between seedling rows and top-dressed with granular ammonium phosphate sulfate (NPS 16-20-13, 625 lb material/acre). Time of application varied with the sowing date, which largely determined time of emergence.

Initial emergence was recorded for each sowing. Seedling height was measured in July. August. September. and October, and stem diameter, in October. A standard nursery inventory frame (0.5 by 4 ft or 15 x 122 cm long) was set across the bed in each of two randomly located positions per plot. Seedlings within the frame were counted and measured separately for rows 1 to 4 and 5 to 8.

Effects of seed source, sowing date, and erosion control on seedling growth and stocking were assessed by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split-split plot design with seed sources, sowing dates, and erosion control considered fixed and the blocks, random.

For each source, coefficients of determination were calculated to assess the relations of seedling height and stem volume to sowing date and time of emergence (Ryan and others 1981). The frequency distributions of stem diameter were determined for each sowing, using BMD P5D (Chasen 1981).

RESULTS

Seed sources from both coastal and inland regions required prolonged chilling and early sowing to produce 1-0 seedlings efficiently.

Seed Chilling and Germination

In the 1979 study, germination was significantly affected by seed source and chilling period (0, 20, 40. or 60 days) and their interaction after 7. 14, and 21 days at room temperature (table 2).

Both the speed and amount of germination were greatest with 60 days of chilling for three of the four sources tested (fig. 1. table 3). The 20-day chill sacrificed speed in every source and enabled complete germination of only the North Coast, or King Range. source. After 7 days, germination was highest with the 60-day chill for sources from the Oregon Coast Range (AL), Cascade Range (MK), and Klamath Mountains (OK), and with the 40- and 60-day chills for the King Range (KR). After 21 days. germination was highest with the 60-day chill for source MK, nearly as high with the 40as the 60-day chill for sources AL and OK, and about equally high with the 20-, 40-. and 60-day chills for source KR.

Seedling Emergence in March and May Sowings

Emergence was significantly affected by the seed source and chilling period (30 versus 90

Table 2. Significance of effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds [1]

Source of variation	Degrees freedom	Variance (mean square) for germination (percent), by day		
		7	14	21
Seed source, S	3	1453.9**	491.2**	380.1**
Chilling period, T	3	19444.1**	21978.9**	15367.6**
ST	9	529.8**	433.3**	469.4**
Error	48	37.8	28.9	29.8

[1] Seeds from coastal and inland regions in Oregon and California were chilled for 0, 20, 40, or 60 days.

** Statistically significant at the 1 percent level.

days) in both the March and May sowings, and by their interaction in the March sowing (table 4).

For the March sowing, emergence began on March 29. 15 days after sowing, and was essentially completed by May 7. 54 days after sowing (fig. 2, table 5). The 90-day chill resulted in faster and greater emergence than did the 30-day chill. At 28 days. emergence for the 90-day chill was greater by factors of 4.3, 2.0. 1.4. and 1.7 in sources AL, MK, KR, and OK, respectively. The 90-day chill, compared to the 30-day, increased total emergence by an absolute 46 percent in source AL, 16 percent in source MK, and 29 percent in source OK.

For the May sowing, emergence began on May 25. 10 days after sowing, and was finished by June 14. 30 days after sowing. The 90-day chill again resulted in faster emergence but did not increase total emergence. At 15 days. emergence for the 90-day chill exceeded that for the 30-day by factors of 4.2, 1.8, 1.6. and 1.4 in sources AL. MK, KR, and OK, respectively.

Seedling Growth in March and May Sowings

Sowing date significantly affected seedling height, stem diameter, top dry weight and root dry weight after pruning, but not top/root ratio (table 6). The seed source significantly affected seedling height, stem diameter, top weight and top/root ratio, but not root weight. The chilling period significantly affected seedling height, but no other size trait.

Seedling height and top dry weight decreased with increase in source latitude and distance inland from the Pacific Coast (table 7). The coastal sources. Al and KR, were taller than their inland counterparts MK and OK, and the California

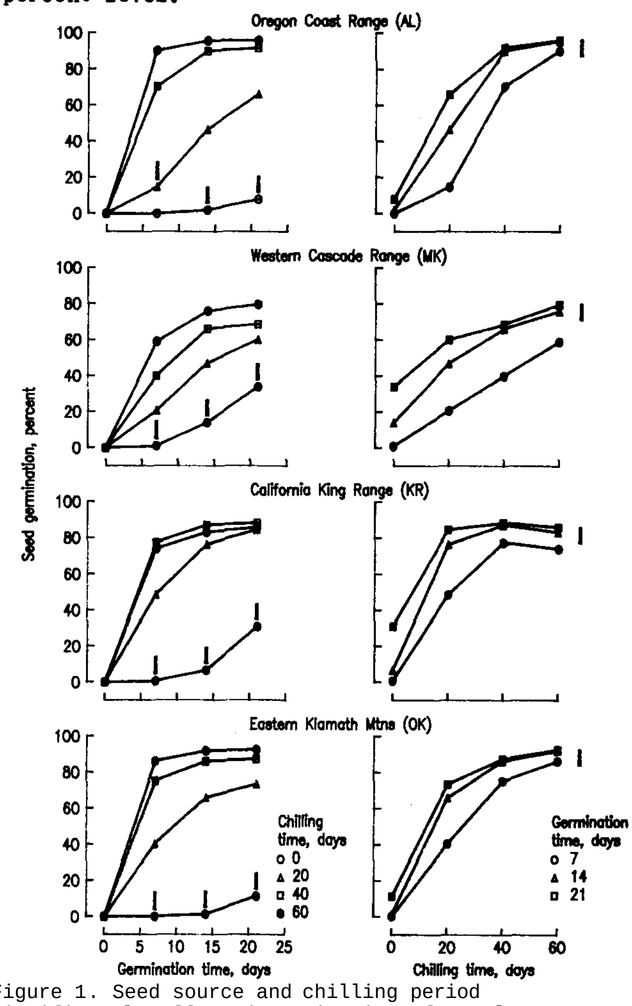

Figure 1. Seed source and chilling period significantly affected germination of Douglas-fir seed. Curves are for chilling periods of 0, 20, 40, and 60 days at 1°C (left panel) and germination periods of 7. 14, and 21 days at 22°C (right panel).

Bars indicate least significant difference at the 5 percent level.

Table 3. Effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds

Seed source and germination time (days)	Germination (percent), by **chilling period (days)** [1]				LSD [2]
	0	20	40	60	
Oregon Coast Range (AL)					
7	0.0	14.7	70.5	90.2	8.8
14	2.0	46.7	90.0	95.7	7.7
21	8.0	66.2	91.7	96.0	7.8
Cascade Range, Western (MK)					
7	1.0	20.7	40.0	59.0	8.8
14	14.0	47.0	66.2	76.0	7.7
21	34.0	60.2	68.7	79.7	7.8
North Coast Range (KR)					
7	0.7	48.7	77.5	74.0	8.8
14	6.7	76.5	87.2	83.2	7.7
21	31.0	84.7	88.5	86.0	7.8
Klamath Mtns, eastern (OK)					
7	0.2	40.5	75.2	86.2	8.8
14	1.5	66.0	86.2	92.0	7.7
21	11.5	73.5	87.5	92.7	7.8

[1] Values are the means of four replications of 100 seeds each.

[2] Least significant difference at the 5 percent level.

Table 4. Significance of effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for emergence (percent)					
			March sowing, by day			May sowing, by day		
			28	37	44	15	21	28
Seed source, S	SB	3	250.8**	142.5	102.3	1391.6**	1867.8**	1729.3**
Chilling period, T	TB	1	1452.0**	1404.2*	1113.0*	1322.5**	1081.6**	483.0*
Block, B	[2]	4	68.6	28.9	34.6	101.1	297.5	182.9
ST	STB	3	58.1	156.2*	158.3*	118.5	126.5	230.6
SB	STB	12	39.3	82.5	76.3	41.5	107.6	104.9
TB	STB	4	54.7	124.9*	138.2*	29.6	9.0	39.2
STB		12	29.1	37.8	40.8	55.6	120.3	210.1

[1] Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days.

[2] SB + TB - STB for March dates; STB for May dates. F-Tests with the Satterthwaite approximation using only the variance components with positive method of moments estimates.

*, ** Statistically significant at the 5, 1 percent levels.

sources, KR and OK. were taller than their Oregon counterparts AK and MK.

Seedlings from the March sowing were taller and stouter and had greater top and root dry weights than seedlings from the May sowing (fig. 3). Seedlings of sources AL, MK, KR. and OK were respectively 21, 27, 24, and 35 percent taller and had 26, 31, 31. and 44 percent greater stem diameter. They had 63. 68. 92. and 106 percent greater top weight, and 24, 45. 82. and 61 percent more root weight. Increases in top/root ratio were not significant.

Nursery Sowing Windows

In the 1985 study, several problems related to sowing time and seedling emergence required solution. The January sowing was necessarily -dropped from the analyses because a flock of juncos partially harvested the plots soon after emergence began. Depredation of the February and later sowings was forestalled by spraying the newly sown plots with a bird repellant containing the fungicide thiram.

The nursery soil was crusted by February and needed scarification to shatter the crust and enable a uniform sowing depth and density. Thus the February. March, April, and May sowings were done after first raking the plots with steel tines.

The woven paper mat treatment was discontinued after it badly entangled emerging seedlings in the February sowing. In every sowing, the shade cloth in the shade cloth treatment was permanently removed after emergence was well underway, to permit drying of the soil surface to inhibit damping-off disease.

Seedling height, stem diameter, and stocking in October were significantly affected by sowing date and replication (table 8). In addition, seedling stocking was significantly affected by seed source and erosion control. All traits were significantly affected by various interactions. Results of the analyses of seedling height and stocking in July. August. and September (not presented) were mostly like those in October. at the close of the growing season.

Seedling Growth.--Throughout the growing season, seedlings of both the coastal and inland seed sources were consistently taller with earlier sowing (table 9). At the end of the growing season, stem height and diameter for the coastal seedlings were 106 and 82 percent greater in the February than in the May sowing, and for the inland seedlings, 115 and 95 percent greater.

In July. the inland seedlings were taller than the coastal seedlings and they remained so through August for all sowing dates. In September. inland seedlings were still slightly taller in the March. April. and May sowings. but coastal seedlings were

Table 5. Effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) [1]

Seed source and chilling period (days)	Emergence (percent)															
	March sowing, by day								May sowing, by day							
	21	23	26	28	30	37	44	54	11	15	17	21	23	25	28	30
Oregon Coast Range (AL)																
30	1.9	2.8	6.9	13.0	24.1	37.5	49.1	53.7	0.0	6.3	16.8	70.2	82.1	89.5	98.6	100.0
90	4.6	14.8	33.3	56.5	69.0	88.4	95.8	100.0	0.0	26.4	46.8	85.6	90.8	93.3	97.9	100.0
Cascade Range, western (MK)																
30	6.4	9.6	28.8	30.4	43.3	64.1	76.3	84.0	0.0	8.7	25.5	66.4	80.5	88.6	96.0	100.0
90	12.2	21.8	38.5	59.6	75.0	91.7	97.4	100.0	0.0	16.1	35.5	73.7	79.6	88.2	98.4	100.0
North Coast Range (KR)																
30	13.0	21.2	43.5	56.5	67.4	89.7	97.8	100.0	0.7	31.7	53.0	82.2	90.7	92.2	98.6	100.0
90	20.0	33.7	60.0	77.7	83.4	97.7	99.4	100.0	3.0	51.1	70.2	89.8	93.8	96.0	98.4	100.0
Klamath Mtns, eastern (OK)																
30	13.6	23.8	30.2	42.6	49.0	60.9	66.3	70.8	0.8	41.5	63.1	86.4	91.9	95.8	98.3	100.0
90	28.2	44.6	62.4	72.8	82.2	94.1	99.5	100.0	9.5	57.3	69.7	91.2	93.8	96.7	98.5	100.0

[1] Values are expressed as percent of maximum for the seed source.

taller in the February sowing. In October, coastal seedlings were taller and stouter than inland seedlings, regardless of the sowing date (table 9).

For seedlings of both sources, the seasonal pattern of height growth varied with sowing date (fig. 4). Through September. growth rates were higher in the February than in the May sowing. From September to October. growth rates decreased in the February sowing and increased in the May sowing. Intermediate patterns were found in the intervening March and April sowings.

Seedling Stocking.--Seedling stocking decreased with earlier sowing and the rate of reduction was greater for the coastal than for the inland seed source (fig. 5, table 9). Averaged over all sample dates, stocking for coastal seedlings in the February. March, and April sowings was 63. 71. and 87 percent of that in the May sowing, and for inland seedlings, 83. 89. and 92 percent. These differential trends in stocking explain the highly significant interaction of seed source and sowing date (table 8).

Erosion Control.--Use of hydromulch and shade cloth improved stocking for seedlings of the coastal but not inland seed source (table 10). Stocking for coastal seedlings in the hydromulch and shade cloth plots respectively was 24 and 41 percent greater than in the check plots, and for inland seedlings, zero and 5 percent. The interaction of seed source and erosion control was significant in the inventories for July and August, but not September and October.

Humboldt Nursery received an average number of heavy rainstorms in the January-March period of 1985 (fig. 6). Each of four storms delivered 2 inches (5.1 cm) or more within 48 hours. The January sowing got all of these rains and the February and March sowings, two of them. The seed beds were saturated each time, but there was no visible evidence of soil erosion nor of any washing of seed or germinants. even in the check plots.

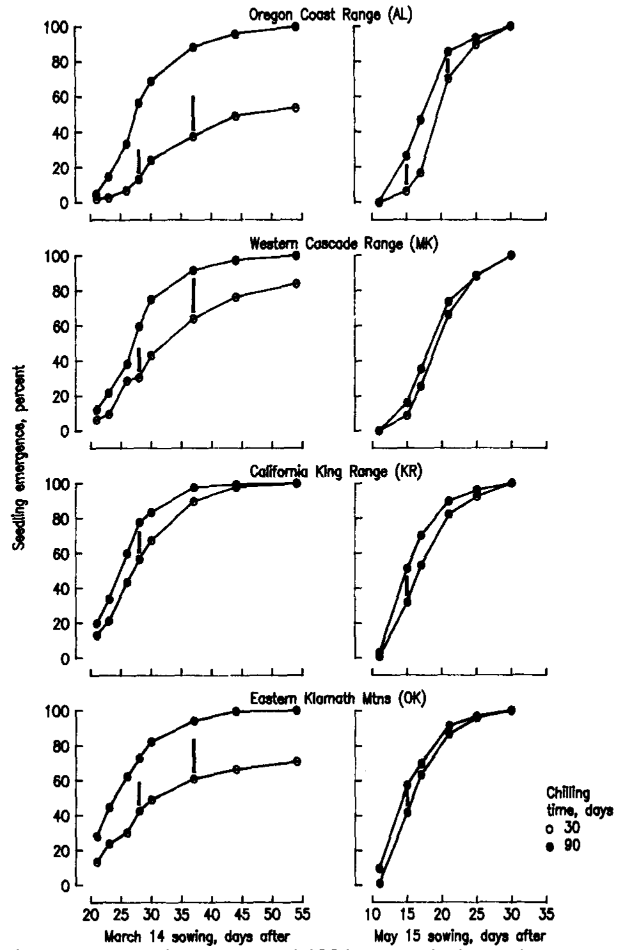

Figure 2. Seed source, chilling period, and sowing date markedly affected emergence of Douglas-fir in Humboldt Nursery. Curves are for chilling periods of 30 and 90 *days* for sowings on March 14 (left panel) and May 15 (right panel). Bars indicate least significant difference at the 5 percent level.

DISCUSSION

Whatever the seed source, the size of 1-0 seedlings in Humboldt Nursery largely depends on how early the seed is sown. Sowing early captures valuable weeks and months at the front end of the growing season, even though the prevailing cool soil conditions slow germination and prolong emergence. In 1979 at Humboldt. the usual cool soil of early spring stretched emergence of the March sowing to the first of May, and the typically warm soil of late spring enabled complete emergence of the May sowing by the middle of June. But by the time emergence was complete in the May sowing, most seedlings in the March sowing had been elongating roots and expanding shoots for more than 6 weeks.

Similar patterns of emergence and growth held at Humboldt in 1985. Emergence of the January sowing started in the middle of February and emergence of the February sowing was just underway when the March sowing was installed. Germinants in the March, April, and May sowings began to emerge within 18, 9, and 6 days of seeding, respectively. By early April. all seedlings in the January sowing were expanding shoots, and all seedlings in the February sowing had shed their seedcoats. The winter sowings were clearly up and growing more than 3 weeks before emergence began in the April sowing and 6 weeks before it began in the May sowing.

Emergence and Growth in Cool Conditions

Full benefit of early sowing can only be achieved by a seed treatment that effectively substitutes for overwinter chilling in the wild. To insure maximum rates and amounts of emergence in the cool soils that prevail in winter and early

Table 6. Significance of effects of seed source, chilling period, and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for... Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Sowing date, D	DB	1	235.709**	12.8480**	13.0411**	3.2321**	0.4961
Seed source, S	SB	3	104.367**	2.9942*	1.7454**	.0401	1.9338**
Chilling period, T	TB	1	8.179*	.0130	.1280	.0054	.0858
Block, B	[2]	4	3.232	.0615	.1104	.0352	.2488
DS	DSB	3	2.412	.1224	.3370	.1141	.0801
DT	DTB	1	2.513	.0106	.0442	.0353	.1514
ST	STB	3	1.704	.1178	.1639	.0369	.0307
DB	[3]	4	.652	.2568	.1375	.0252	.1197
SB	[4]	12	4.025	.5519	.1177	.0611	.1089
TB	[5]	4	.816	.0782	.0244	.0308	.0389
DST	DSTB	3	1.438	.0971	.0580	.0389	.0126
DSB	DSTB	12	5.126	.1609	.1440	.0463	.0688
DTB	DSTB	4	1.177	.1809	.0220	.0626	.0827
STB	DSTB	12	2.505	.0757	.0733	.0163	.0607
DSTB		12	1.368	.0852	.0976	.0458	.0243

[1] Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days and sown in March and May.

[2] DB + SB + TB - DSB - DTB - STB + DSTB (See table 6A for denominators

[3] DSB + DTB - DSTB. [4] DSB + STB - DSTB. [5] DTB + STB - DSTB.

*, ** Statistically significant at the 5, 1 percent levels.

Table 6A. Denominators for F-Tests for Table 6.[1]

Source of variation	Seedling height	Stem diam	Top weight	Root weight	Top/root ratio
B	DSB+STB-DSTB	DB+SB-DSB	DSB	SB+DTB-DSTB	SB+DTB-DSTB
DB	DSB	DTB+DSB-DSTB	DSB	DTB+DSB-DSTB	DTB+DSB-DSTB
SB	DSB+STB-DSTB	DSB	DSB	DSB	DSB+Stb-DSTB
TB	STB	DTB	DSTB	DTB	DTB+STB-DSTB

[1]F-tests with the Satterthwaite approximation using only the variance components with positive method of moments estimated

Table 7. Effects of seed source and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979)

Seed source and sowing date [1]	Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Oregon Coast Range (AL)					
March 14	16.0	2.82	1.58	1.14	1.44
May 15	13.2	2.24	0.97	0.92	1.13
Cascade Range, western (MK)					
March 14	13.6	3.36	1.48	1.19	1.27
May 15	10.7	2.57	0.88	0.82	1.16
North Coast Range (KR)					
March 14	19.5	3.80	2.40	1.29	1.91
May 15	15.7	2.89	1.25	0.71	1.90
Klamath Mtns, eastern (OK)					
March 14	16.2	3.02	1.69	1.14	1.51
May 15	12.0	2.09	0.82	0.71	1.31

[1] Within source, values of all traits except top/root ratio were significantly greater for the March sowing. See table 6.

spring, stored seeds must be properly soaked and then chilled for at least 60 and preferably 90 days before sowing. Sources like those from the Oregon Coast Range. Cascade Range. and Klamath Mountains (AL. MK. OK), which typify much of the Pacific slope forests of Douglas-fir in Oregon and California, will require 60 to 90 days of chilling for most rapid and complete germination and emergence (fig. 1. 2). Although certain sources like that of California's north coast King Range (KR) may germinate completely with a 20-day chill and show maximum emergence with a 30-day chill, they will germinate and emerge most rapidly with prolonged chilling.

Early growth in cool conditions may be just as essential for the health of 1-0 Douglas-fir as it is for 1-0 sugar pine (Jenkinson and others 1982). For coastal and inland seed sources. seedlings in our February. March. and April sowings mostly escaped disease, had abundant mycorrhizae and associated mycelium (Laccaria laccata and Thelephora terrestris are common in Humboldt Nursery), and grew uniformly. By contrast, seedlings in our May sowings had incipient problems with Fusarium or other damping-off fungi (Kliejunas and Allison 1982) and exhibited stunting in the classic mosaic pattern

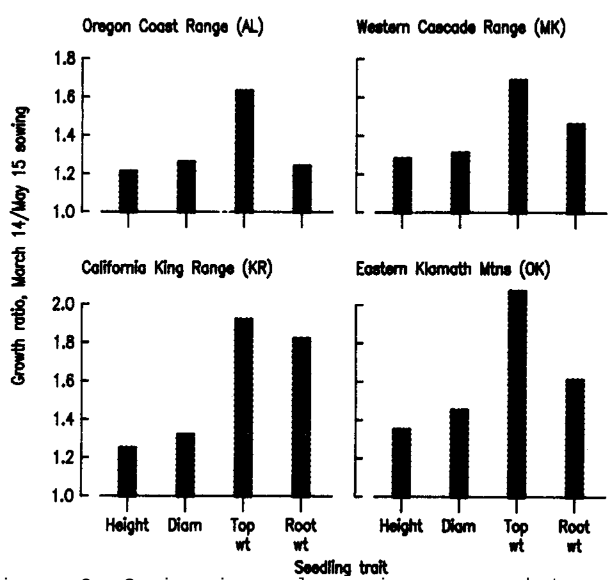

Figure 3. Sowing in early spring compared to late spring resulted in substantial gains in .the size and *dry* weight of 1-0 Douglas-fir in Humboldt Nursery.

Table 8. Significance of effects of seed source, sowing date, and soil erosion control on the growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for: Seedling height (cm)	Stem diam (mm)	Seedlings per ft^2
Sowing date, D	DB	3	1511.28**	32.670**	741.1**
Seed source, S	SB	1	349.80	2.000	803.3*
Erosion control, T	TB	2	1.58	.241	759.8*
Block, B	P	2	262.50**	7.094**	176.3*
DS	DSB	3	5.28	.058	185.1**
DT	DTB	6	26.91**	.097	199.9
ST	STB	2	31.72	.029	149.0
DB	P	6	9.27*	.152	72.9
SB	P	2	37.74**	1.214**	12.9
TB	P	4	34.87**	.731**	62.5
DST	DSTB	6	13.17*	.862*	179.8
DSB	P	6	18.77**	.207	15.7
DTB	P	12	5.26	.230	142.0**
STB	P	4	10.78*	.233	132.6*
DSTB	P	12	4.14	.201	159.8**
P(DSTB)		216	4.15	.162	48.1

[1] Seeds from coastal and inland regions in northern California were chilled for 90 days and sown in February, March, April, and May.

*, ** Statistically significant at the 5, 1 percent levels.

that is symptomatic of poor or spotty mycorrhizal development (Molina and Trappe 1984).

Early sowing obviously has specific advantages. In fact, the disease and stunting problems that have plagued past seedling crops in the Humboldt Nursery might largely be avoided by simply shifting to a sowing schedule that captures the natural germination environment.

Growth Gains with Early Sowing

Any assessment of the amount of growth gained by sowing early is determined partly by the trait measured and partly by the seed source examined (fig. 3). Thus, gains of 20 to 35 percent in seedling height were accompanied by gains of 30 to 45 percent in stem diameter. 65 to 110 percent in top dry weight, and 25 to 85 percent in root dry weight after pruning. Growth gains for inland sources MK and OK were much alike while those for coastal sources AL and KR differed. Top weight showed the greatest gain in all sources, and root weight kept pace in one coastal source (KR) but trailed notably in the other (AL).

Seed Source Lifting Windows

Early sowing may be essential if seed source lifting windows for 1-0 seedlings at Humboldt Hursery are to correspond approximately to those already determined for the standard 2-0 seedlings (Jenkinson 1984). Winter and early spring sowings (February. March) may capture enough of the potential growing season to allow 1-0 seedlings to approach dormancy in early autumn. The seasonal course of height growth in Humboldt Nursery suggests a sigmoid pattern in the winter sowings (February) and an exponential pattern in the late spring sowings (May). Exponential patterns seemed to characterize even the early and midspring sowings of the coastal GQ source, but not of the inland SA source (fig. 4). In early autumn, however, growth of both sources was slowing in the February sowing and accelerating in the May sowing. Such divergent rates suggest

Table 9. Effects of seed source and sowing date on the seasonal growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source and sowing date	Seedling height (cm)				Stem diam	Seedlings
	Jul 22	Aug 19	Sep 16	Oct 21	(mm)	per ft^2
North Coast Range (GQ)						
Feb 19	6.82	11.12	17.48	22.47	3.49	18.6
Mar 21	4.85	8.39	12.70	18.20	2.94	21.7
Apr 23	4.32	7.13	11.32	16.49	2.65	25.9
May 17	2.88	4.62	6.24	10.92	1.92	29.3
Klamath Mtns, central (SA)						
Feb 19	7.72	12.68	16.92	19.50	3.40	24.6
Mar 21	5.08	8.88	13.00	16.42	2.77	27.8
Apr 23	4.41	7.36	11.35	14.28	2.42	27.2
May 17	3.37	4.83	6.41	9.07	1.74	29.2

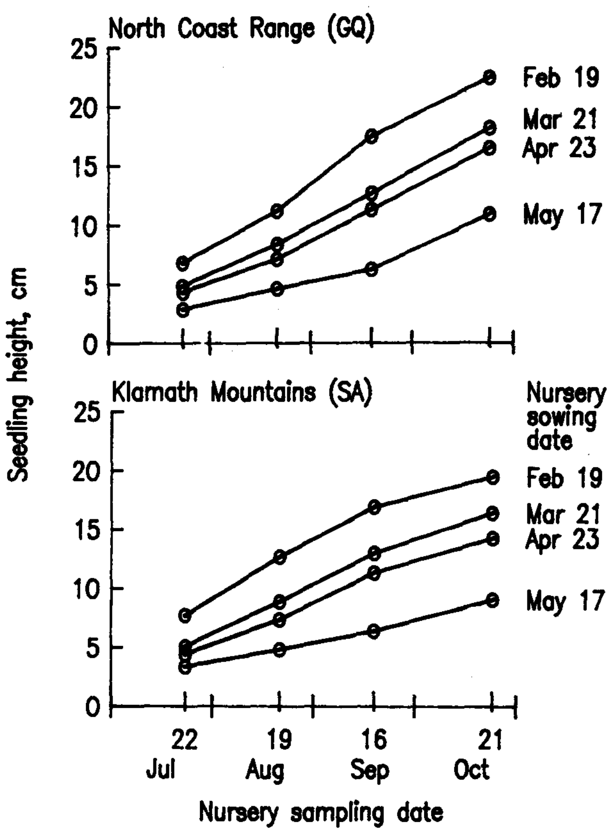

Figure 4. Sowing in winter compared to late in spring resulted in sigmoid rather than exponential patterns in the seasonal height growth of 1-0 Douglas-fir in Humboldt Nursery.

physiological states that respectively enhance and delay the autumn development of seedling dormancy. cold hardiness, and readiness for cold storage.

Winter sowing probably is essential if every source lifting window is to open at the same time for 1-0 as for 2-0 seedlings. Field survivals of 1-0 seedlings from April sowings have shown lifting windows that open later than those of 2-0 seedlings for nearby seed zones (Turpin and others 1985). And survivals of 1-0 seedlings from March sowings have shown windows that open as soon as. shortly after, or later than those of 2-0 seedlings planted in the same or nearby zones (Jenkinson 1984). Winter sowings are thus indicated if 1-0 seedlings are to achieve the physiological conditioning that is necessary to allow lifting and cold storage on the first safe date for 2-0 seedlings.

Seedling Size

Besides their physiological condition and storability, the size of 1-0 seedlings is a vital concern. No nursery wants to lift, and no forester wants to plant, thin-stemmed or whippy seedlings. Field experience suggests that 1-0 planting stock should be culled to a stem diameter of about 2.5 mm. In our March sowings. most seedlings of every seed source exceeded that standard. In 1979, stem diameters for Sources AL. MK. KR. and OK averaged 2.8. 3.3. 3.8. and 3.0 mm. respectively, compared to 2.2, 2.6. 2.9. and 2.1 mm for the May sowing (table 7). In 1985. stem diameters for sources GQ and SA averaged 2.9 and

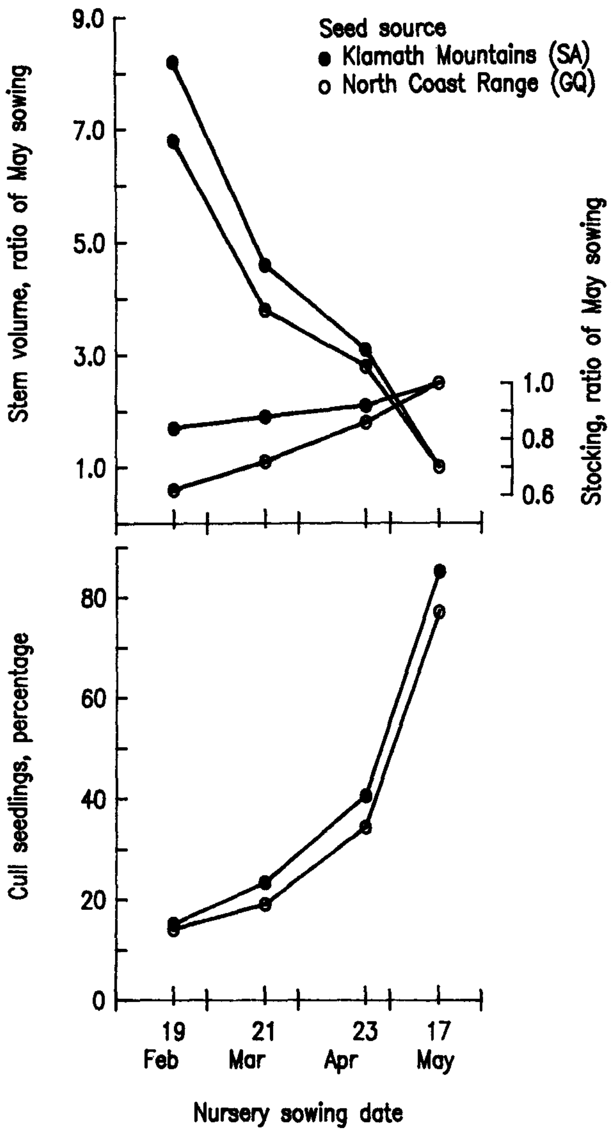

Figure 5. Sowing in winter compared to late in spring lowered seedling stocking by 18 or 34 percent, depending on seed source, but increased stem volumes seven- to eightfold and reduced cull percentages more than fivefold for 1-0 Douglas-fir in Humboldt Nursery.

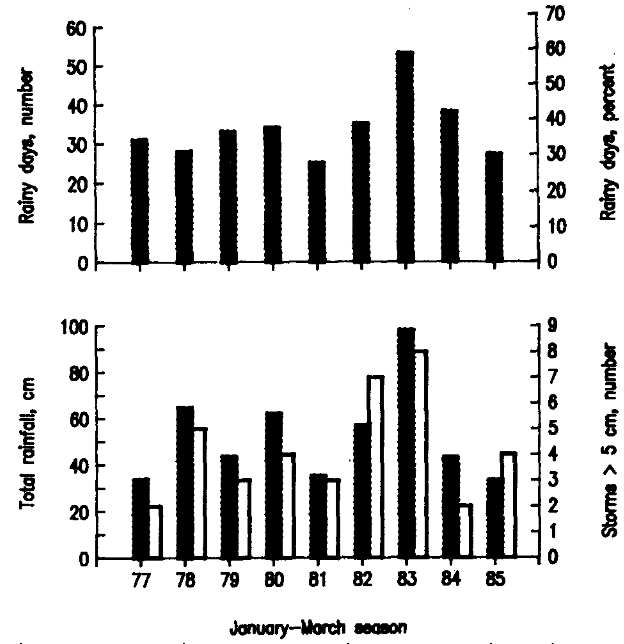

Figure 6. Weather patterns in January through March at Humboldt Nursery usually bring two to five heavy rainstorms and 50 to 65 clear days. The wettest period on record (1983) had eight heavy storms and 36 clear days.

Table 10. Effects of seed source and soil erosion control on the stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source	Seedlings per ft², by erosion control method [1]			
	None	Hydromulch	Shade cloth	Mean [2]
North Coast Range (GQ)	19.4	24.1	27.4	23.6 b
Klamath Mtns, central (SA)	27.5	27.6	29.0	28.0 a
Mean [2]	23.4 b	25.8 ab	28.2 a	

[1] Values are grand means of inventories in July, August, September, and October.

[2] Means followed by different letters differ significantly at the 5 percent level.

2.8 mm, compared to 1.9 and 1.7 in the May sowing (table 9). Even modest increases in stem thickness mean substantial gains in the total dry matter of root-pruned seedlings, for example. 44. 57. 88. and 85 percent respectively in sources AL. MK, KR. and OK.

Early spring sowings (March) in Humboldt Nursery can produce large 1-0 seedlings that have wide seed source lifting windows and high potentials for plantation establishment (Jenkinson and Nelson 1983). Our 1985 test suggests that winter sowings may prove to be even better. however, because seedlings of both coastal and inland sources were about 75 percent larger in the February than in the March sowing (fig. 5).

Nursery Sowing Windows

With an improved capability for winter sowing. Humboldt Nursery might safely sow in January to produce 1-0 planting stock. The potential sowing window may span up to 3 months, from midwinter to midspring. The number of seedlings produced per hundred viable seeds will determine when the window opens, and the size of the seedlings produced will determine when the window closes. The last safe sowing date will usually fall in early April. assuming that 75 percent of the seedlings must have a minimum stem diameter of 2.5 mm (fig. 5).

The first safe sowing date will depend on the effects of early sowing and soil erosion control on seedling stocking. Sowing in February reduced the stocking of inland seedlings by one-sixth, and of coastal seedlings, by one-third, compared to sowing in May (fig. 5). Erosion control substantially improved stocking for the coastal source but not the inland source, with shade cloth increasing stocking by 41 percent in source GQ but by only 5 percent in source SA (table 10). Thus. any choice of a first safe date may have to balance the tradeoffs of lower stocking and larger seedlings that accompany earlier sowing. The date chosen should be one for which the possible reduction in stocking is slightly less than an accepted cull percentage, assuming that most seedlings in the earliest sowing will be large enough to outplant.

The greater effects of early sowing and erosion control on the stocking of coastal seedlings may be explained by the significantly smaller seeds of coastal sources. Air dry seeds were 23 percent smaller for the North Coast Range than for the central Klamath Mountains source (12.2 mg/seed, or 37.100 seeds/lb against 15.0 mg/seed, or 30.200 seeds/lb). Sowing depth is critical for the successful germination and emergence of Douglas-fir (Minore 1985). and the precise sowing and uniform maintenance of smaller seeds at 3 mm below the surface may be more difficult and less likely under winter conditions.

The smaller size of the coastal seeds may also explain why the coastal seedlings were consistently smaller than inland seedlings during the summer (table 9). By late autumn, however, coastal seedlings were larger than inland seedlings, reflecting their adaptation to length of growing season at seed origin.

CONCLUSION

Early spring and winter sowings of Douglas-fir over two separate years at the Humboldt Nursery have consistently resulted in plantable 1-0 seedlings for diverse seed sources in coastal and inland regions of western Oregon and northern California. We conclude that Humboldt Nursery can readily produce 1-0 Douglas-fir planting stock for most forest sites on the Pacific slope. To produce 1-0 stock efficiently, we recommend three practices:

- Chill seeds at least 60 to 90 *days* to insure rapid and complete emergence in cool soil conditions.
- Sow in winter and early spring to utilize all or most of the potential growing season.
- Protect newly sown beds with hydromulch or shade cloth to control soil erosion and limit seed losses.

Studies are being repeated to determine the stability of nursery sowing windows for 1-0 stock and to firmly establish procedures that can preclude soil and seed losses. With the proper sowing schedule, seed source lifting windows can be as wide for 1-0 as for the highest quality 2-0 stock. Continued aggressive field evaluation of 1-0 stock is warranted because of its potential payoff in high survival and growth for less than the costs of 2-0 stock.

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