1-0 DOUGLAS-FIR: A BARE-ROOT PLANTING OPTION

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ABSTRACT: 1-0 seedlings of Douglas-fir from five physiographic regions in northern California and western Oregon were lifted monthly in winter in Humboldt Nursery, stored at 1° C, and planted in spring in the region of seed origin. Field survival indicated that the calendar periods for safe lifting span 2 or 3 months, and closely match those determined for 2-0 seedlings of similar sources in earlier trials. After one summer, survival of 1-0 seedlings was 90 percent in the southern Klamath Mountains, 94 and 99 percent in the King and Oregon Coast Ranges, and 84 and 88 percent in the Eastern Siskiyou Mountains and Oregon Cascade Range. Browsing mammals and competing vegetation reduced seedling survival and growth. Mortality the second summer ranged from 3 percent in the Coast Range to 17 percent in the Eastern Siskiyous. Increase in height ranged from zero in the Klamath Mountains to about fourfold in the Coast Range. With protection, successful plantation establishment with 1-0 Douglas-fir is attainable in all five regions.

ADDITIONAL KEY WORDS: *Pseudotsuga menziesii,* artificial regeneration, root growth capacity, field survival, seedling growth, geographic variation.

INTRODUCTION

In 1978, the Humboldt Nursery produced 1-0 seedlings of Douglasfir that were large enough to plant in the field. The seedlings, from seed sources in the Klamath Mountains of northern California (seed zones 312.25 and 312.50), averaged 20 cm (8 inches) tall and 3 mm (0.12 inch) in stem diameter. Obtained with 4 months of stratification and a March sowing, they were triple the size of seedlings in the traditional May sowings. If their survival potentials were high enough, 1-0 Douglas-fir could be a viable reforestation option.

Planting 1-0 seedlings would increase flexibility and decrease lead time in the regeneration of harvested or burned stands. Obvious advantages for nursery soil management would include more deep ripping, cover crops, and fallow years. Compared with 2-0 seedlings, 1-0 seedlings take less water, fertilizer, weeding, and inventory effort. They do not require vertical pruning and undercutting of the roots. They cost less to lift, grade, pack, store, ship and plant. Three times as many 1-0 as 2-0 seedlings fit in the standard packing bag, tripling the capacity of premium cold storage. Because they are easier to plant with proper root placement and easier to protect against mammals, 1-0 seedlings could even favor early plantation establishment.

This paper reports a study of the field survival and growth of 1-0 seedlings of Douglas-fir from sources that typify five of the various physiographic regions that the Humboldt Nursery serves. It compares the performances of 1-0 seedlings with those of 2-0 in the same regions, and examines their implications for successful plantation establishment.

MATERIALS AND METHODS

To evaluate the performance of 1-0 seedlings, two trials were set up in 1978-79. In the first, 1-0 and 2-0 seedlings from a single seedlot (source 312.25) were lifted on five dates in winter, root-pruned 23 cm (9 inches) below the foliage, and stored in standard, polyethylene-lined packing bags at 1° C (34° F, in the bag).

The seedlings were planted April 1, 1979, on a cleared site in the southern Klamath Mountains (Table 1). The design of the planting consisted of 10 replications of a randomized complete block of split plots, with lifting dates split for seedling class (1-0, 2-0). The seedlings were spaced 0.6 m apart in parallel, 10-seedling rows. Competing vegetation was periodically removed through the first summer, but browsing by deer and cattle was chronic.

Seedling survival was monitored through two summers. Seedling height, stem diameter, and browse damage were evaluated in late summer of the second year. The effects of nursery lifting date and seedling class on field survival and seedling size were assessed by analysis of variance, with date and class fixed and blocks random (Table 2).

In the second trial, seed sources were chosen to represent coastal and interior regions in both western Oregon and northern California (Table 1). Seeds of the four sources were soaked 24 hours in aerated water at 25° C (77° F), chilled 90 days in polyethylene bags at 1° C (34° F), and sown in standard nursery beds in late March. The design of the sowing consisted of five replications of a randomized complete block, with 3 m of bed per plot. The beds were surface-watered as needed until emergence was complete. Through summer, the seedlings were deep-watered each time their predawn water stress increased to 5 bars. On five dates in winter, samples of seedlings in each plot were lifted, pooled by source, root-pruned 23 cm (9 inches) below the foliage, and stored in standard packing bags at 1° C. Root and top growth capacities were evaluated from subsamples of the rootpruned seedlings just after lifting and after cold storage, at the time of planting (Jenkinson and Nelson 1978).

The seedlings were planted in spring, 1980, on a cleared site in the region of origin (Table 1). The coastal sources were planted March 31 (source 252.15) and April 11 (source 390.20); and the interior sources, April 3 (source 321.30) and May 19 (source 472.30). The planting design was 10 replications of a randomized complete block of lifting-date plots. Each plot was a 10-seedling row, with seedlings spaced 0.6 or 1 m apart, depending on the site. Seedlings in the King and Oregon Coast Range plantings were shielded with vexar tubes, to protect against deer and elk. The King Range planting was continually scalped free of ground cover. Herbaceous vegetation quickly invaded the Coast and Cascade Range plantings; it was cleared from the Coast Range planting after the first summer, but not from the Cascade planting. The Siskiyou planting remained free the first summer, but was swamped by grass the following spring. Seedling survival and growth were determined in fall of the first and second years, after rains ended the summer drought.

The effects of nursery lifting date on seedling root growth capacity (RGC), field survival, and growth were assessed by analyses of variance. RGC at the time of lifting was assessed by a single analysis encompassing all liftings and sources. RGC at planting time was assessed for each source separately, because the planting times differed. Survival and growth were analyzed at 1 and 2 years (Table 3), and means were contrasted by Keuls' method (Steel and Torrie 1960). Coefficients of determination were calculated to assess the relation of RGC at planting time to RGC at lifting (r^2 for $Y = a + bX$), and of field survival to RGC at planting time (R^2 for $Z = b\ln(Y + 1) + c[\ln(Y + 1)]^2$).

To assess severity of the post-planting environment, the critical RGC--here termed the minimum number of elongating roots associated with individual seedling survival--was estimated for each planting. Coefficients of determination were calculated for the relation $Z = bY'$, with Y' the percentage of seedlings having RGC greater than N, for N = 10, 20,..., 90. The critical RGC was identified as the value of N yielding the highest r^2 and slope, b, closest to 1.

RESULTS

Seedling class did not affect the lifting window (Jenkinson and Nelson 1978) of Douglas-fir from the southern Klamath Mountains (Table 4). Within the window, field survival averaged 90 percent for 1-0 seedlings and 94 percent for 2-0 seedlings after 1 year, and 86 and 92 percent at 2 years (class difference significant at 5 percent level). Deer and cattle destroyed the 1979 and 1980 leaders, cutting 5 cm off the initial height of 1-0 and maintaining that of 2-0 seedlings. Stem diameters of the resulting bushes were 5.5 and 8.9 mm.

Lifting windows for the Oregon sources were at least 3 months (Table 5, Fig. 1). Within the window, field survival after one summer was 99 percent in the coastal planting (source 252.15) and 87 percent in the interior planting (source 472.30). Lifting windows for the California sources were 2 months. Survival within the window was 94 percent in the coastal planting (source 390.20) and 84 percent in the interior planting (source 321.30).

Nursery lifting date affected seedling root growth capacity (RGC) at lifting (significant at 0.1 percent level) and after cold storage (significant at 10 to 0.1 percent level, depending on seed source). RGC always changed in cold storage, so that RGC at lifting was no guide to RGC at planting time. With RGC expressed as the number of roots able to elongate 2 mm or more, RGC at lifting explained just 7 percent (r^2 = 0.07) of the variation in RGC at the time of planting.

RGC at planting time explained 99 percent of the variation in 1year survival of seedlings planted in the Oregon Coast and Cascade Ranges, and 98 percent in the King Range and Eastern Siskiyou Mountains (R^2 significant at 1 percent level). The estimated critical values of RGC were about 10 and 20 actively elongating roots for seedlings in the Coast and Cascade plantings, and nearly 30 and 60 active roots in the King and Siskiyou plantings (Fig. 1). The critical value increased from north to south and from coastal to interior areas, reflecting the longer summer drought on southern sites and higher evapotranspiration on inland sites.

Within the specified lifting window (Table 4), leader growth the first summer ranged from 6 cm in the King Range and 7 cm in the Siskiyous to 11 cm in the Coast Range. Respective stem diameters averaged 6, 5, and 3.5 mm, the reverse of the ranking for height growth. In the Cascade Range, Phomopsis canker (Smith 1975) or similar fungal disease killed many of the new leaders, but stem diameter still averaged 5.2 mm.

In the second summer, vegetative competition for soil water caused substantial mortality in the California plantings. Root competition from six old Douglas-firs and tanoaks was apparently lethal for 17 percent of the seedlings in the King Range. The trees were scattered along the northern perimeter of the planting site, and had diameters (dbh) ranging from 86 to 122 cm (34 to 48 inches). Only four seedlings survived in block 9, 4 m (13 ft) south of a large Douglas-fir. In the Siskiyou planting, a dense stand of grasses probably caused lethal water stress in 16 percent of the seedlings. In the Oregon Coast and Cascade Range plantings, mortality the second summer was 3 and 4 percent.

Competing vegetation and mammals largely determined seedling growth the second year. In the King Range planting, seedling height increased markedly with distance from the nearest residual large tree (Fig. 2). Distance alone accounted for 87 percent of the variation in height among the nine stocked blocks (r^2 = 0.87, significant at 0.1 percent level). Seedlings in the four blocks that were more than 17 m (56 ft) from any tree averaged 45 cm tall. The best grew 65 cm in 1981, and measured 89 cm in height and 19 mm in diameter. In the Siskiyou planting, the survivors of grass competition averaged 12 cm of new leader growth, 31 cm in height, and 8.7 mm in diameter. A spring freeze, browsing deer, and grazing cattle caused leader and stem injuries on at least 70 percent of the seedlings. About 13 percent still were 40 to 60 cm tall and up to 16 mm in diameter. Seedlings in the Coast Range planting, protected against mammals and freed of competition, doubled in height to 54 cm and in diameter to 7 mm. About 31 percent were 60 to 105 cm tall and 8 to 16 mm in diameter. The tallest grew 73 cm in 1981, measuring 107 cm in total height. Seedlings in the Cascade planting, recovering from Phomopsis injury and competing with heavy ground cover, averaged 9 cm of leader growth, 28 cm in height, and 6.7 mm in diameter.

DISCUSSION

At the Humboldt Nursery, chilling presoaked seeds 2 to 3 months at 1° C (34^{0} F) promotes uniformly rapid and complete germination of Douglas-fir from every source. Sowing in March, when the nursery soil first warms enough for radicle elongation and seedling emergence, effectively adds 2 months to the growing season, compared with traditional sowings in May. March and April probably are the most important months in the local growing season, because they encompass the environmental conditions associated with the start of new growth in native populations: mild temperature, high moisture, low evaporative stress, low pathogen activity, and high activities of soil bacteria and mycorrhizal fungi. To ensure that water is available for rapid seedling growth through summer, the soil profile is irrigated each time the seedlings' predawn water stress reaches 5 bars (Zaerr and others 1981).

Their high survivals in the field show that 1-0 seedlings do not have a dormancy problem, even though their predawn stress is held below 5 bars in the nursery. When lifted within the appropriate winter period (Tables 4, 5)and stored at -1^{0} C (34° F, in the bag), 1-0 seedlings are dormant and have high root growth capacities at planting time (Table 6). Planted on typical Douglas-fir sites (Table 1), they survive as well as 1-0 ponderosa and Jeffrey pines on pine sites (Jenkinson 1980).

For any particular seed zone, 1-0 seedlings have the same lifting window and high field survival as 2-0 seedlings (Jenkinson and Nelson 1978, Knight and others 1980). In all six of the seed zones investigated to date, the survival of 1-0 seedlings was clearly adequate, and even the equal of 2-0 seedlings (Table 7); field survival ranged from 84 to 99 percent for 1-0 seedlings, and from 86 to 98 percent for 2-0 seedlings. Differences in mortality between classes reflect differences in site environment, whether seedlings were protected against invading vegetation or mammals, and the greater ability of 2-0 seedlings to endure browse damage (Table 4). Overall survivals of the two classes are practically the same.

Field survival is the best guide to the calendar period in which seedlings may be safely lifted and stored for spring planting (Jenkinson and Nelson 1978, Knight and others 1980). For 1-0 as for 2-0 seedlings, growth through two seasons on the planting site essentially the lifting window indicated by 1-year survival. Our 1-0 trials provided no evidence that field growth might be used to refine or narrow the window (Table 5). For each source, seedlings lifted within the window had similar heights and diameters after 2 years on the planting site--even when free of competing vegetation and browsing mammals.

In all regions, the survival and growth of 1-0 seedlings consistently demonstrates the possibility of successful plantation establishment in just 2 years. Because vegetative competition and mammals reduce growth, few seedlings ever attain their free-growth potential. In our trials, new growth was limited or eaten on every site in one or both years, yet the potential for growth was still apparent. Through two summers in the southern Klamath Mountains, 1-0 seedlings grew 83 percent in diameter, even though mammals precluded growth in height (Table 4). After one summer in the King Range, Eastern Siskiyous, and Oregon Cascades, stem diameters of 1-0 seedlings averaged 5 to 6 mm (Table 5), values common for 2-0 seedlings from May sowings in Humboldt Nursery. In two summers in the King, Siskiyou, Cascade, and Oregon Coast Range plantings, stem diameters increased 103, 124, 86, and 100 percent. In the same plantings, seedling heights increased 102, 123, 75, and 297 percent.

Excepting the fourfold gain in height for seedlings in the Coast Range, the potential gains in height were much greater than the percentages noted. In the King Range, seedlings in blocks that were free of root competition averaged 49 cm tall (Fig. 2, blocks 4 and 5)--a gain of 163 percent. In the Siskiyou planting, which was invaded by both grass and cattle, 13 percent of the seedlings still topped 40 cm--a gain of 183 percent. Such gains suggest that 1-0 Douglas-fir has the potential to triple its height in two field seasons, even in northern California where the typical summer drought is 5 to 6 months. In the Coast Range, where the normal summer drought is 3 months, height may quadruple in two seasons--if mammals and competing vegetation are excluded.

CONCLUSION

By sowing stratified seeds in March, Humboldt Nursery is able to produce 1-0 seedlings of Douglas-fir of acceptable size and survival potential. Their high survivals and good growth in the field show that 1-0 seedlings are a viable option for reforestation of Douglas-fir in western Oregon and northern California.

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Table 1--Seed sources and planting sites for tests of field survival and growth of Douglas-fir from Humboldt Nursery

Region	Seed source[1]	Site, aspect, and slope (%)	Elev (m)[2]	Planting location		
				Watershed	Lat (° N)	Long (° W)
California						
S Klamath Mtns	312.25	Ridge, SW, 5	915	Trinity	40.38	123.27
King Range	390.20	Ridge, S, 5	520	Mattole	40.10	124.02
E Siskiyou Mtns	321.30	Bench, SE, 10	1070	Klamath	41.88	123.05
Oregon						
Coast Range	252.15	Slope, E, 30	460	Alsea	44.37	123.70
W Cascade Range	472.30	Slope, NW, 60	855	McKenzie	44.18	122.02

[1] First 3 digits identify seed zone; last 2 digits indicate upper limit of 500-ft elevational band, in hundred ft (Buck and others 1970).

[2] 1 m = 3.28 ft

Table 2--Variance (mean square) associated with effects of nursery lifting date and seedling class (1-0, 2-0) on field survival and growth of Douglas-fir in the southern Klamath Mountains

Source of variation	Error term	Degrees freedom	1 year survival (percent)	2 years		
				Survival (percent)	Diam (mm)	Height (cm)
Block, B	BD	9	2.899 o	4.343 o	2.191 **	10.63 ns
Date, D	BD	4	22.760 **	21.835 **	2.407 **	15.26 o
Class, C	BC	1	7.290 *	10.890 *	275.892 **	5547.27 **
BD	a	36	1.493	2.313	.619	6.58
BC	BDC	9	.934 ns	1.979 ns	.734 ns	9.08 ns
DC	BDC	4	1.240 ns	.915 ns	.209 ns	9.32 ns
BDC	b	36	.773	1.282	.555	7.48

o, *, and ** = F significant at 10, 5, and 1 percent levels; ns = not significant.

Table 3--Variance (mean square) associated with effects of nursery lifting date on field survival and growth of 1-0 Douglas-fir, by physiographic region

Region and source of variation [1]	1 year				2 years			
	Survival (percent)	Diam (mm)	Height (cm)	Leader (cm)	Survival (percent)	Diam (mm)	Height (cm)	Leader (cm)
California King Range								
Block, B	1.43 ns	--	0.429 ns	0.244 ns	22.27 **	9.982 **	244.6 **	212.93 **
Date, D	152.67 **	--	.111 ns	.200 ns	102.08 **	4.413 **	32.2 ns	9.41 ns
BD	1.09	--	.737	.133	3.72	.935	24.2	12.66
E Siskiyou Mtns								
B	1.37 ns	--	7.14 o	0.288 ns	4.64 ns	10.408 **	16.2 ns	9.33 ns
D	15.88 **	--	23.01 **	5.053 **	11.37 *	2.604 ns	33.4 ns	6.50 ns
BD	2.34	--	3.74	1.319	3.06	1.725	16.5	7.70
Oregon Coast Range								
B	1.68 ns	0.082 ns	10.06 ns	11.74 **	1.37 ns	3.544 **	50.9 ns	28.68 ns
D	14.58 **	.186 *	24.28 *	11.81 *	14.83 **	1.993 o	202.0 **	115.60 **
BD	1.17	.059	8.54	3.61	1.51	.830	37.9	19.17
W Cascade Range								
B	3.10 ns	0.253 ns	10.18 **	--	3.15 ns	0.396 ns	16.0 ns	6.35 *
D	31.28 **	1.308 **	52.96 **	--	29.43 **	2.330 **	93.7 **	5.95 o
BD	2.69	.191	3.43	--	3.23	.310	14.2	2.78

1 Degrees freedom = 9, 4, and 36 for B, D, and BD, except 9, 3, and 27 for growth traits in King Range.

o, *, and ** = F significant at 10, 5, and 1 percent levels; ns = not significant.

Table 4--Field survival and growth of Douglas-fir (source 312.25) lifted in Humboldt Nursery, stored at 1° C, and planted in spring in the southern Klamath Mountains

Seedling class [1] and trait	Nursery lifting date [2] Nov 20 1978	Dec 18	Jan 15	Feb 12	Mar 12 1979	W [3]
1-0						
1-year survival (%)	64	87	93	85	94	11.1
2-year survival (%)	62	85	89	81	87	13.8
diam (mm)	4.9	5.6	5.6	5.5	5.4	0.71
height (cm)	14.5	15.4	15.7	14.3	15.5	2.33
2-0						
1-year survival (%)	73	96	93	94	95	11.1
2-year survival (%)	69	94	90	93	91	13.8
diam (mm)	8.0	8.8	8.8	8.9	9.1	0.71
height (cm)	28.2	28.7	31.5	30.8	30.5	2.33

[1] 1-0 initially averaged 20 cm tall and 3 mm in diameter, and 2-0, 30 cm and 5 mm. Deer and cattle ate new leaders of all seedlings, and 5 cm of the 1-0 stem.

[2] Bars indicate nursery lifting window.

[3] W = difference significant at 5 percent level.

Table 5--Field survival and growth of 1-0 Douglas-fir lifted in Humboldt Nursery, stored at 1° C, and planted in spring in the region of seed origin

Seed source and seedling traits	Nursery lifting date[1] Nov 26 1979	Dec 26	Jan 21	Feb 19	Mar 17 1980	W[2]
California King Range, 390.20						
1-year survival (%)	4	81	93	94	94	9.48
diam (mm)	6.0	6.0	6.0	6.0	6.0	
height (cm)	20.3	25.0	24.9	25.3	24.7	
leader (cm)	4.3	5.8	6.6	6.5	6.2	
2-year survival (%)	4	68	74	77	80	17.5
diam (mm)	6.5	7.5	7.4	8.7	8.9	0.88
height (cm)	34.5	36.2	35.4	39.5	37.3	
leader (cm)	13.3	12.7	12.1	14.3	13.5	
Eastern Siskiyou Mtns, 321.30						
1-year survival (%)	58	73	88	84	79	13.9
diam (mm)	5.0	5.0	5.0	5.0	5.0	
height (cm)	20.8	20.8	22.2	23.2	19.2	1.76
leader (cm)	7.0	7.2	8.0	7.9	6.3	1.04
2-year survival (%)	45	61	70	72	61	15.9
diam (mm)	8.2	8.9	8.6	9.4	8.1	
height (cm)	28.8	30.9	32.3	33.0	29.3	
leader (cm)	10.4	11.8	12.6	12.2	11.6	
Oregon Coast Range, 252.15						
1-year survival (%)	72	99	99	99	99	9.81
diam (mm)	3.2	3.5	3.4	3.5	3.5	0.22
height (cm)	21.8	24.6	24.8	26.1	24.4	2.65
leader (cm)	8.9	10.9	11.5	11.5	10.8	1.72
2-year survival (%)	69	92	98	97	96	11.1
diam (mm)	6.0	7.0	6.8	7.1	7.0	0.83
height (cm)	46.0	53.6	51.7	56.8	56.8	5.59
leader (cm)	25.0	30.3	29.4	31.9	34.1	3.97
Western Cascade Range, 472.30						
1-year survival (%)	48	88	86	88	88	14.9
diam (mm)	4.5	5.0	5.2	5.1	5.5	0.40
height (cm)	18.6	23.3	21.5	24.2	23.9	1.68
leader (cm)	--	--	--	--	--	
2-year survival (%)	45	85	82	84	82	16.3
diam (mm)	5.7	6.7	6.4	6.7	7.0	0.51
height (cm)	22.2	28.5	26.5	29.1	29.8	3.42
leader (cm)	7.8	9.4	8.9	9.0	9.9	1.51

[1] Bars indicate nursery lifting windows.

[2] W = difference significant at 5 percent level.

Table 6--Growth capacities of 1-0 Douglas-fir lifted within the window at Humboldt Nursery, stored at 1° C, and planted in April or May in a standard greenhouse environment [1]

Seed source	Root elongation (cm)	Roots elongating (number)	Shoot extension (cm)	Stem diam [2] (mm)
California (n = 90)				
King Range	80	108	7.3	4.0
E Siskiyou Mtns	83	109	7.2	3.9
Oregon (n = 120)				
Coast Range	64	109	5.9	3.5
W Cascade Range	40	80	7.4	3.6

[1] Growth per seedling after 28 days in soil at 20° C: new length of roots elongated 1.5 cm or more, root tips elongated 2 mm or more, and length of longest flush.

[2] Size at end of test.

Table 7-- Field survival of 1-0 and 2-0 Douglas-fir lifted within the window at Humboldt Nursery and planted in spring in the zone of seed origin

Region	Seed source	Seedling survival (percent) 1-0	2-0
California			
King Range	390.20	94	87
S Klamath Mtns	312.25	90	94
E Siskiyou Mtns	321.30-40	84	96
W Cascade Range	521.40	89	--
Oregon			
Coast Range	252.10-15	99	98
W Cascade Range	472.30	87	86
	Mean:	90.5	92.2

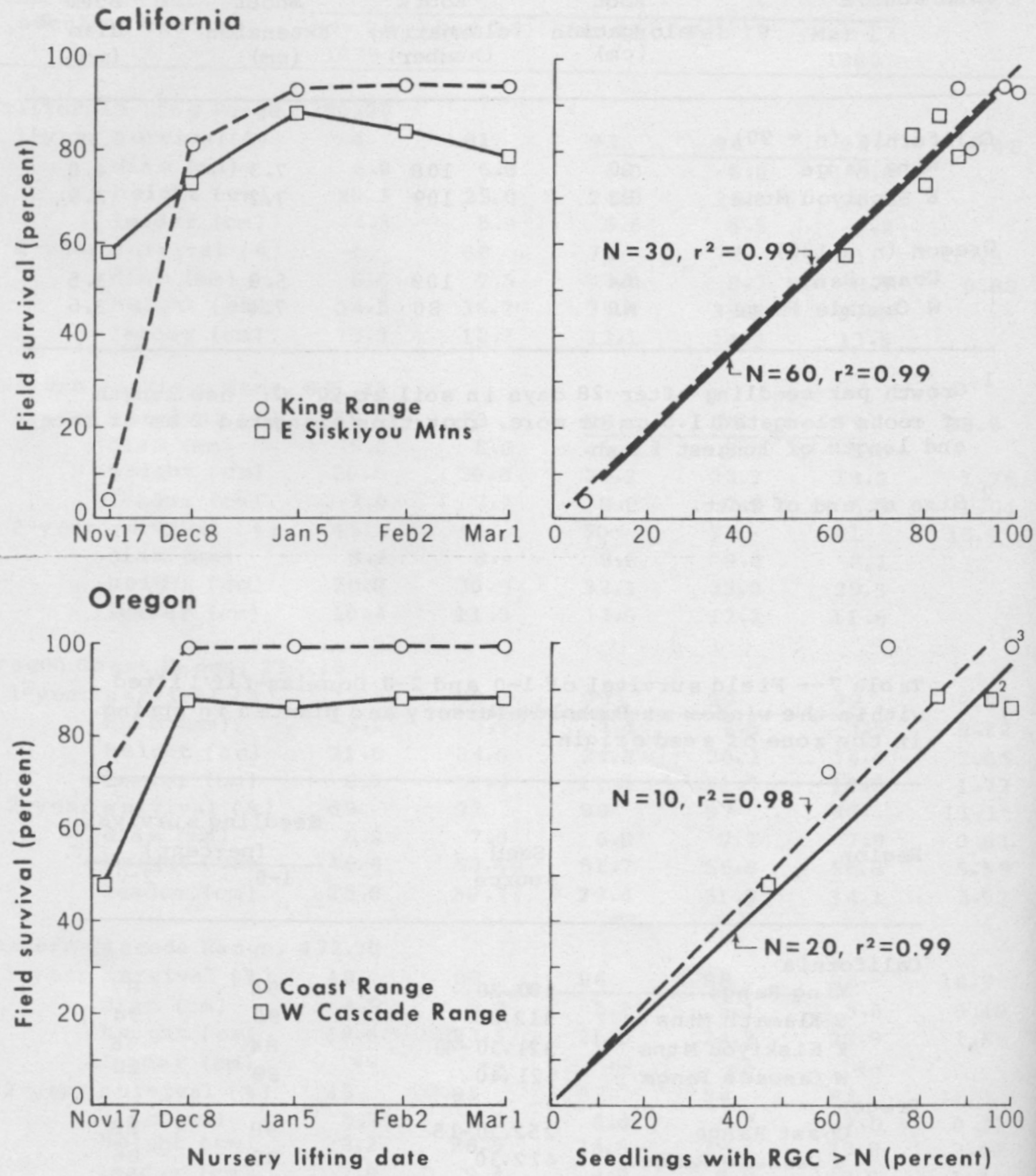

Figure 1. Field survival of 1-0 seedlings of Douglas-fir varied with the time of lifting (left panel), and with the percentage of seedlings that had root growth capacities (RGC) greater than some critical value (N = roots able to elongate) fixed by the post-planting environment (right panel).

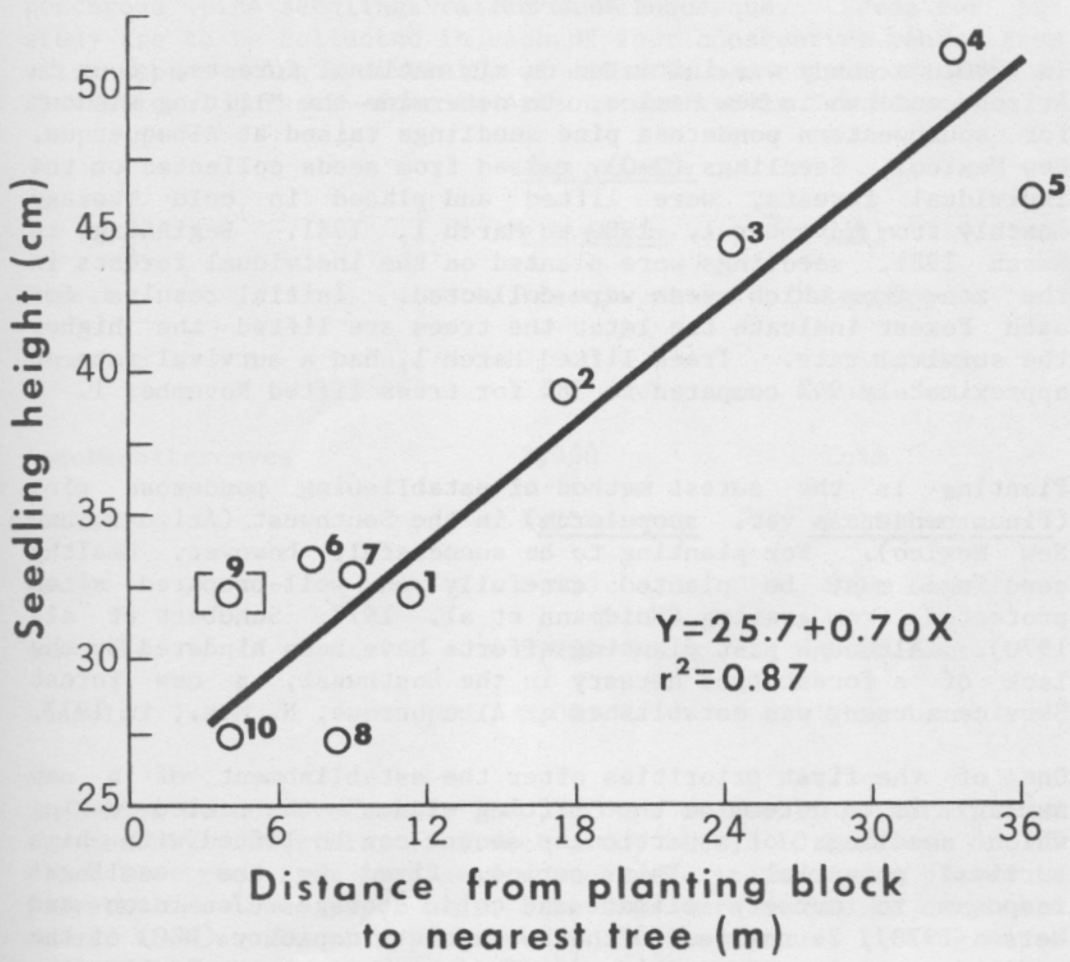

Figure 2. Root competition from nearby Douglas-firs and tanoaks reduced the growth of 1-0 Douglas-fir planted in the King Range. Seedlings were measured after two summers on the planting site.