Coast Redwood Regeneration Survival and Growth in Mendocino County, California

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ABSTRACT

Three stands of second-growth redwood forest were clearcut, and the logging slash in two of the units was broadcast burned following logging. Three types of redwood seedlings (plug, plug-one, and 2-year bareroot) were planted following logging and burning. Seedling survival rates were high, and there were no significant differences between survival and growth of stock types after 9 years. The native redwood sprouts were substantially larger than the planted seedlings, in both height and diameter, which could affect future growth of some seedlings. The status and dimensions of seedlings and native regeneration were periodically checked. The burned units were fully occupied by a dense, tall growth of brush within a few years, and the brush became re-established after a successful initial herbicide treatment.

Keywords: Seedling, sprout, broadcast burn, vegetation control, *Sequoia sempervirens*

Coast redwood (*Sequoia sempervirens*) is a species highly valued for wood quality, rot resistance, and fast growth. Redwood stumps sprout prolifically and redwood can readily reproduce by seed (Neal 1967, Boe 1975). Once cut at the base, a very high percentage of redwoods will sprout from the stump or base of the former tree (Barrette 1966, Lindquist 1989). Jackson Demonstration State Forest (JDSF) is located near the Pacific coast in central Mendocino County, California. In the Hare Creek watershed on JDSF, Lindquist (1989) determined that 93 percent of cut redwoods sprouted and that a total of 1,740 sprouts were established per acre.

In the redwood forest of western Mendocino County, redwood seedlings have been routinely planted in harvest areas since the early 1970s. During the 1960s, harvested areas were both planted and aerially seeded, but the majority of the second-growth timber harvesting conducted in this area was selective, so there was little need for planting. Large areas that had been harvested to remove residual old-growth trees were either planted or seeded during the 1960s. From 1930 to 1960, most harvest areas were left to regenerate naturally.

This study was initiated in part to test the hypothesis that larger seedlings would grow better than the plugs that were most commonly planted locally. Bareroot seedlings and plug-one seedlings may have been planted successfully at the time this study was initiated, but they were not produced locally on the Mendocino Coast or commonly planted on JDSF. We examined seedling survival and growth, natural redwood regeneration, and stocking by competing species of hardwood and brush.

Materials and Methods

The Caspar Creek watershed is located in JDSF. The watershed is forested by second- and third-growth redwood/Douglas-fir (*Pseudotsuga menziesii*) forest. The second-growth forest developed naturally following clearcutting of the old-growth forest in the late 1800s. The harvested units are located approximately 6 miles from the coast at an elevation between 400 and 1,000 ft (Figure 1).

Between May 1989 and May 1990, three stands of second-growth were clearcut (Units J, K, and L), using both cable skyline and tractor yarding. Unit J had a south- to southeast-facing aspect, whereas Units K and L had a primarily north- to northwest-facing aspect. Table 1 shows preharvest stand conditions for the three units.

The number of redwood trees in the three logging units was similar, but the available preharvest data included only stems larger than 12 in. dbh. It is quite common for stands of this type to contain many additional smaller stems with a variable spatial distribution. No information is available concerning the spatial distribution of stems in the stands, which ultimately affects the distribution of redwood sprouts.

Units J and L were yarded primarily by a skyline cable yarding system. Approximately 40 percent of Unit K was tractor yarded because of gentler upper slopes; the remainder was skyline yarded. Units J and L were broadcast burned in the fall of 1990. By the time broadcast burning occurred, most redwood stumps had already sprouted and grown for one season. Unit J had a burn that was relatively hot, which was attributed primarily to aspect. The burn in Unit L was most complete near the upper slopes of the unit, becoming less effective lower on the slope, where fall shade and fuel moisture levels remained high. Unit K was not burned.

Three types of redwood seedlings were planted along parallel transect lines approximately 200 ft in length, with the lines spaced 10 ft apart, in each of the three logging units. The transects were laid out in groups of three and oriented in the cardinal direction that placed lines as close as possible to directly up- and down-slope (either north-south or east-west). Each transect was planted with a

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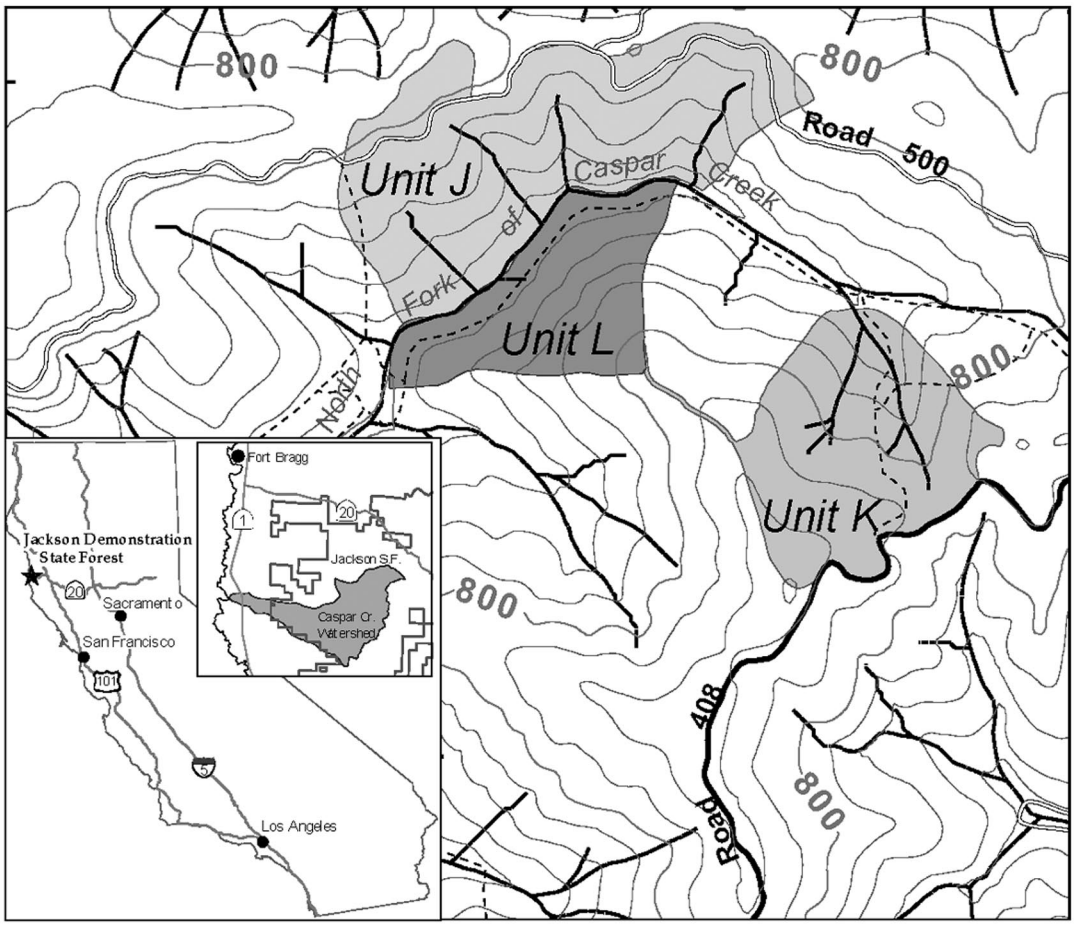

Figure 1. Location of experimental units.

Table 1. Preharvest stand conditions for conifer trees ≥12 in. dbh.[a]

	Unit J			Unit K			Unit L		
	No. of trees	Basal area	Volume	No. of trees	Basal area	Volume	No. of trees	Basal area	Volume
Redwood	86	250	56,329	83	203	61,927	78	177	37,807
Douglas-fir	34	90	31,815	43	161	63,960	32	152	51,247
Grand fir	2	8	5,452	6	22	9,625	31	85	29,365
All species	122	348	93,596	132	386	135,512	141	414	118,419

[a] All values are per acre. Basal area is square feet and volume is gross board feet, Scribner scale.

single type of seedling. The seedlings all originated from the same nursery, using seed collected from the appropriate local seed zone, and were planted in January and February 1991.

Seedlings were planted at 10-ft intervals along each transect. In each set of parallel transects, one line was planted with standard number 5 plug seedlings plug containing 5 in.^{3} of soil, one line was planted with 2-year-old bareroot seedlings (2 + 0), and the third line was planted with plug-one seedlings approximately 2 years of age (P + 1). Most lines contained 20 planted seedlings. A total of 537 seedlings were planted, with nearly equal numbers of each seedling type planted.

In Units J and L, hardwoods and brush were treated by a directed foliar spray of tryclopyr ester during March 1993, 2 years after planting. In addition, in Unit J, the tanoak was felled and treated by a direct stump application of tryclopyr amine. No treatments affecting the transects occurred in Unit K subsequent to planting. In January 1992, the individual seedlings were evaluated and measured. Each seedling was classified as either live or dead. For each live seedling, the total height and basal diameter (1 in. aboveground) were measured.

The seedlings were examined and measured subsequently in July and August of 1997 and spring of 1999.

Seedling mortality was analyzed using analysis of variance (ANOVA) as a measurement over time with plot sampling design (Gomez and Gomez 1984) (R Statistical Package 2005). Each measurement year was first calculated separately with unit, seedling type, and interaction to derive the mean squared errors of the experimental errors. A chi-square test for homogeneity of variance was next conducted and, if not rejected, the data were pooled.

In 1999, the study was expanded to include measuring natural regeneration of redwood, conifer seedlings, and hardwoods and brush growing in proximity to the planted redwood seedlings. Plots were established along the transects, centered on the location of the planted

Table 2. Redwood seedling percent survival by seedling type, year, and unit.[a]

	Unit J			Unit K			Unit L		
	1992	1997	1999	1992	1997	1999	1992	1997	1999
Plug	98	65	73	82	99	81	98	84	82
2 + 0[b]	97	65	77	96	94	87	100	87	93
P + 1	100	80	88	99	95	87	100	88	97

[a] A reduction in seedling mortality within Unit J from 1997 to 1999 is attributed to the fact that redwood seedlings in the early years after planting occasionally die back to the ground surface while remaining alive below ground. Dead tops were observed next to live sprouts extending from the same root crown in several instances (Ken Margiott, personal communication).
[b] P + 1, plug-one seedlings approximately 2 years of age; 2 + 0, 2-year-old bareroot seedlings.

Table 3. Redwood seedling percent mortality analysis of variance.

Factor	df	SS	MS	F	*P*
Unit	2	1885.8	942.9	9.229	0.000
Seedling type	2	601.3	300.7	2.943	0.059
Year	2	3459.2	1729.6	16.930	0.000
Unit × seedling type	4	313.1	78.3	0.766	0.551
Seedling type × year	4	270.9	67.7	0.663	0.620
Error	75	7662.1	102.2		

df, Degrees of freedom; SS, sum of squares; MS, mean square error; F, F valve; *P*, *P* value.

seedling. The plots were circular, with a radius of 10 ft (approximately 0.007 ac).

In each plot, the following information was collected:

- Number of conifer stems by species;
- Combined number of manzanita (*Arctostaphylos columbiana*), blueblossom (*Ceanothus thyrsiflorus*), and tanoak (*Lithocarpus densiflorous*) stems;
- Species, height, and dbh of the tallest conifer in the plot; and
- Notes pertaining to the condition and competition affecting the planted seedling.

The 1999 seedling height and the 1999 brush height and density were analyzed using ANOVA, with unit and an interaction term as factors.

Results

Planted Seedling Survival and Growth

Two years after planting, the seedling survival rate ranged from 82 percent to 98 percent for plugs, 96 percent to 100 percent for 2 + 0, and over 99 percent to 100 percent for P + 1 seedlings (Table 2). As of 1999, 9 years after planting, the survival of plug redwood seedlings ranged from 73 percent to 82 percent, whereas survival of 2 + 0 was 77 percent to 93 percent, and survival P + 1 was 88 percent to 97 percent. Seedling survival varied by unit (Table 3). Survival in Unit J was 73 percent to 88 percent, whereas that in Unit L was 82 percent to 97 percent. Total mortality appeared to decrease in some instances between measurements. This was attributed to the sprouting capability of redwood, where seedlings that appear to be dead have actually remained alive below ground and subsequently sprouted from the root crown between measurement years. Mortality did not vary significantly by seedling type (Table 3).

The average dbh for the planted saplings was approximately 0.5 in. in 1999, whereas the average total height ranged from 5.8 to 8.8 ft (Table 4). The plugs and (2 + 0) seedlings were approximately the same height and diameter. The P + 1 seedlings were approximately 1 ft taller on average, but not significantly different ($P = 0.407$; Table 5). At the time of original planting the P + 1 seedlings were approximately 0.9 ft taller than the two other seedling types. There were no significant differences in seedling growth between units as of 1999 ($P = 0.607$).

Table 4. Seedling height (ft) by seedling type, year, and unit, for live trees only.

	Unit J			Unit K			Unit L		
	1992	1997	1999	1992	1997	1999	1992	1997	1999
Plug	0.8	5.4	6.5	0.8	6.2	6.8	1.1	4.6	5.8
2 + 0[a]	1.3	5.1	5.8	4.3	4.3	6.1	1.1	5.4	7.1
P + 1	1.5	6.9	8.8	1.5	4.7	7.1	1.4	5.7	6.2

[a] 2 + 0, 2-year-old bareroot seedlings; P + 1, plug-one seedlings approximately 2 years of age.

Table 5. Redwood seedling height analysis of variance for 1999.

Factor	df	SS	MS	F	*P*
Unit	2	2.378	1.189	0.511	0.607
Seedling type	2	4.364	2.182	0.938	0.407
Unit × seedling type	4	16.093	4.023	1.730	0.181
Error	21	48.848	2.326		

Table 6. Density of natural conifer regeneration and other woody vegetation present in 1999.

	Trees or woody stems per acre			
	Redwood sprouts	Douglas-fir	Grand fir	Hardwood & brush
Unit J	788	23	15	1,816
Unit K	454	254	182	277
Unit L	986	360	170	2,307

Natural Regeneration

In the Caspar Creek harvest units, the total number of redwood sprouts present in the plots ranged from 454 to 986 sprouts/ac in 1999 (Table 6). Of these, 327–669 sprouts/ac were greater than 10 ft in total height 9 years after logging. The Caspar Creek plots were centered on seedlings planted along transects so were not intended to estimate numbers of redwood sprouts growing in the units.

In the plots surrounding and including the planted seedlings, the tallest conifer present was nearly always a redwood sprout and the range of average heights of the tallest tree in the plots was 15.5–22.3 ft in 1999 (Table 7). The tallest seedling after 9 years was a P + 1 at 22.7 ft, whereas the tallest measured redwood sprout on a plot was 38.9 ft. The largest redwood sprouts averaged in excess of 3 in. in diameter, compared with a little over 0.5 in. for the planted seedlings.

Although redwood sprouts were the dominant conifer vegetation, there were 213 Douglas-fir seedlings/ac and 127 grand fir seedlings/ac. A conifer other than redwood was the tallest tree in a plot in only 19 cases (3.5 percent), 12 of which were located in Unit K, the unit that was not burned.

Hardwoods and Brush

A dense growth of brush occurred in those areas that were broadcast burned following the logging (Units J and L). Despite a directed tryclopyr ester foliar spray applied to the hardwoods and brush present in 1993, a very dense growth of both blueblossom and manzanita was present in 1999. At the time of treatment, it was judged very effective in control of the brush. During the 1999 field measurement, hardwood stems were not differentiated from the

Table 7. Average dbh and height of planted saplings and natural regeneration in 1999.[a]

	Unit J		Unit K		Unit L	
	dbh	Height	dbh	Height	dbh	Height
Plug[b]						
Seedling	0.6	6.5	0.6	6.8	0.4	5.8
Rwd sprout[c]	3.2	17.2	3.6	20.5	2.5	16.5
Fir				8.5 [4][d]		3.0 [3]
Hwd/brush[e]		13.9		8.6		15.7
P + 1[f]						
Seedling	1.0	8.8	0.6	7.1	0.4	6.2
Rwd sprout	3.7	18.3	3.9	22.3	2.6	16.7
Fir				9.2 [8]		
Hwd/Brush		13.6		7.0		16.4
2 + 0[g]						
Seedling	0.4	5.8	0.5	6.1	0.5	7.1
Rwd sprout	3.1	15.8	3.9	20.4	2.4	15.5
Fir				8.7 [5]		1.7 [2]
Hwd/Brush		12.6		6.9		15.3
Combined[h]						
Rwd sprout	3.3	17.1	3.82	21.1	2.5	16.2
Fir				8.9 [17]		2.5 [5]
Hwd/Brush		13.4		7.5		15.8

[a] Redwood sprout and fir (Douglas-fir or grand fir) data are limited to the tallest of all natural conifer regeneration within a 1/100-ac plot.
[b] One-year-old plug seedling: Number of plots: Unit J, 60; Unit K, 58; Unit L, 60.
[c] Rwd, redwood; Hwd, hardwood; P + 1, plug-one seedlings approximately 2 years of age; 2 + 0, 2-year-old bareroot seedlings.
[d] [*n*] is the number of plots in which a fir was the tallest tree in the plot.
[e] Hwd/brush represents the maximum height of these species on a plot.
[f] Number of plots: Unit J, 60; Unit K, 58; Unit L, 60.
[g] Number of plots: Unit J, 60; Unit K, 60; Unit L, 60.
[h] Number of plots: Unit J, 180; Unit K, 176; Unit L, 180.

brush. The predominant hardwood present was tanoak, which sprouts readily following cutting or burning.

In 1999, 9 years after timber harvest, the combined density of hardwood and brush species was 1,816 and 2,307 stems/ac in Units J and L, respectively. In Unit K, which was not burned, the density of hardwood and brush stems was 277 stems/ac. In addition to the substantially greater density in the burned units ($P = 0.000$), the total average height of the hardwood and brush component was greater in the burned units: 13.4 ft in Unit J, 15.8 ft in Unit L, and 7.5 ft in unburned Unit K (Table 7).

Discussion

The results of this study suggest that 9 years after planting, there was not a significant size differential between the P + 1, plug, and 2 + 0 redwood seedlings. The native redwood sprouts are significantly taller than the planted redwood seedlings, which may have implications for future growth of the seedlings growing in close proximity to native redwood sprouts. To maintain growth of seedlings planted in close proximity to redwood and hardwood sprouts, an investment in periodic control of the competition may be necessary. Several additional costs were incurred in specific logging units of this study as part of the reforestation effort. These included broadcast burning, felling of hardwoods, herbicide treatment of cut hardwood stumps, and foliar herbicide treatment of the brush and hardwood sprouts.

Some bias was created in this study by planting seedlings along linear transects, which may have occasionally placed them in locations where they would not normally be planted (e.g., within redwood sprout clump). However, this effect was not quantified.

Given the stocking level of second-growth redwood present in these units prior to harvest, it appears evident that very few seedlings, if any, would be necessary to supplement redwood stump sprouts and fully stock the area. In the logging units associated with this study, the general area was planted at a spacing of 10 × 10 ft, and the planting contractor was directed not to plant trees within 10 ft of vigorous conifer regeneration. This resulted in the planting of approximately 252 trees/ac overall. Lindquist (1989) examined sprouting 1 year after cutting and burning in a nearby watershed, and found that 25 percent of redwood sprout clumps occurred on stumps 5 in. or less in diameter and that roughly 50 percent of the stumps in the stand were smaller than 10 in. in diameter. "This portion of the stand contributes to sprout regeneration capacity far beyond its volume" (Lindquist 1989). The ultimate distribution of subsequent sprouts is highly dependent on the distribution of the fresh redwood stumps. In Caspar Creek, the number of small redwood stems in the precut stand is unknown. The only locations sufficiently open to support good seedling growth would be locations between redwood clumps or trees, where fir and hardwood tend to become established.

If precommercial thinning is anticipated, the presence of a genetically or phenotypically superior seedling would offer additional options in the choice of trees to retain. However, considering that redwoods tend to sprout when cut or destroyed, a high-density planting of redwood, coupled with the naturally high density of native sprouts, may make precommercial thinning more of a necessity than an option to avoid overcrowding and to maintain a reasonable rate of diameter increment. Since the early 1970s, it has been standard practice to plant between 300 and 450 seedlings/ac in areas harvested with an even-aged management system, although this planting density has been reduced somewhat in recent years. At JDSF, a mix of redwood and Douglas-fir seedlings is most commonly planted. The California Forest Practice Rules (2003) specify stocking standards for harvested areas that call for an initial determination of stocking conditions within 2 years following harvest and a final determination within 5 years following harvest. For sites similar to Caspar Creek, the stocking standards specify a minimum stocking level of 300 trees/ac in a well-dispersed pattern across the harvested area. This regulatory standard has served as an encouragement to plant a large number of seedlings in a well-distributed pattern, primarily because the level of natural redwood sprouting and fir seeding is unknown and often has not yet been initiated at the time that the seedlings are planted. More recently, land managers have begun to reduce the number of trees planted, recognizing that a significant portion of the regeneration will ultimately consist of both redwood sprouts and natural fir seedlings.

This study compares the growth of three types of redwood planting stock and of planted redwood seedlings and native redwood sprouts. Care must be exercised when comparing results with those expected in other areas, under different stand or planting conditions, or with different seedling types. Many local factors may have contributed to seedling survival, such as aspect, topography, seedling condition and planting, planting quality, browsing by wildlife, fire severity, vegetative competition, soil depth, and soil moisture content. The Caspar Creek area is high site and has an ample stocking of redwood. Results may be comparable to those observed under similar conditions.

Broadcast burning has been widely used in the redwood region as a means of reducing slash concentrations to facilitate tree planting in areas that have recently been clearcut. Prior to the advent of reforestation efforts, broadcast burning of old-growth harvest areas was conducted while the logs were on-site as a means of reducing obstructions to the yarding process (Sawyer et al. 2000). Some foresters have argued that broadcast burning is a viable means to reduce

competition from existing hardwoods and brush. Although broadcast burning is likely to make tree planting easier and less expensive by reducing slash concentrations, it is generally followed by a dense growth of shrub species, such as blueblossom and manzanita. In addition, burning does little to reduce the sprouting capability of tanoak. This study suggests that burning has provided little or no benefit to date in terms of conifer establishment or growth in the study area, nor did it result in a greater survival rate for planted redwood seedlings.

A potential benefit of the burning and resultant dense growth of brush is that ceanothus is known to fix nitrogen in the soil, helping to replenish that lost in the biomass that is harvested from the site (Dahlgren 1998). There may also be an effect on future conifer species composition and tree size, which may affect the value of stands for timber production, but this study did not attempt to quantify this effect. A dense growth of brush as the result of burning may have a suppressing effect on conifer regeneration for a number of years. It is common for ceanothus to begin to die out and collapse at 20–25 years of age. The falling brush is expected to result in significant damage to both planted and natural seedlings in the years to come. Redwood sprouts may be more capable of withstanding the collapse of the shrubs, because of their girth and because the tops often extend above the brush. Conifer saplings other than redwood were the tallest trees in plots in only a few areas, and primarily in the unit that was not burned. This may be due to a number of factors, including the fact that the unit was not burned, combined with an aspect and proximity to a seed source more conducive to seedling establishment and survival. The tallest Douglas-fir encountered in any of the plots was 13 ft. It is expected that Douglas-fir will accelerate in height growth. Douglas-fir growth potential in this area, expressed as site index, is approximately 20–30 ft higher than the redwood at base-age 50 (Krumland and Wensel 1977).

We recommend that future studies follow the survival and development of planted redwood seedlings in managed stands to assess their contribution to future growth, stand composition, production, sprouting capability, and stand value.

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