



Conifers' Responses to Stock Types After 11 and 12 Years in Northern Idaho

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Abstract

When planning the future composition of a forest stand, the target plant concept is a useful guideline for selecting an appropriate stock type. However, there is conflicting data as to whether using a larger stock type affects long-term growth. To test whether stock type affects the long-term growth of three conifer species native to the Pacific Northwest, seedlings of Douglas-fir (*Pseudotsuga*

menziesii var. *glauca*), western larch (*Larix occidentalis*), and western white pine (*Pinus monticola*) were grown in five of six container types (313B, 315B, 415B, 415C, 415D, 615A) and planted in 2007 and 2008 at two sites in northern Idaho. Authors measured morphological traits (heights and root-collar diameters) and calculated stem volumes and survival rates through 11 and 12 years. Some species and site combinations showed no difference among stock types while the largest container stock type (615A) had significantly greater growth for all three species. These results suggest that stock type selection may not affect long-term survival and growth in some species, while other species do respond positively to being grown in the 615A stock type. Based upon these results, when determining which stock types to use for a reforestation project in northern Idaho, the target plant concept should be followed and species and site conditions should be considered.

Introduction

The increased intensity and scale of forest disturbances in the Western United States have significantly amplified the demand for seedlings for reforestation, but the capacity is not meeting the demand. Reforestation on lands managed by the U.S. Department of Agriculture's Forest Service has fallen short of demand for over two decades (Dumroese et al. 2019). Increasing reforestation capacity and addressing the reforestation backlog are priorities of the Repairing Existing Public Land by Adding Necessary Trees (REPLANT) Act that became law in 2021. REPLANT and other efforts should help increase seedling production to address demand. For these efforts to be successful, seedlings need to survive and grow at desired rates following planting. This can be achieved by using the best stock type for given site conditions, but when programs call for planting millions of seedlings per year the general trend is using smaller stock types.

There are budget considerations for which stock type to use. Larger seedlings require more medium, fertilizer, and growing space than smaller containers, which increases production costs. If seedlings grown in smaller containers survive and grow comparable to larger ones in the long term, then nursery costs could be reduced without lowering field performance. Therefore, a properly selected stock type can significantly increase the cost-benefit ratio.

The best seedling stock type for a particular site depends on both site conditions and project considerations, such as drought, vegetative competition, and cost-effectiveness. To assist reforestation managers in selecting stock types for a project, the target plant concept was proposed to focus on morphological and physiological seedling characteristics linked to outplanting success (Landis 2009). Although many studies show that field performance is correlated to physiological qualities, physiological tests are often time-consuming and expensive. Therefore, nurseries tend to use morphological traits as indicators of seedling quality (e.g., height and root-collar diameter). Many studies suggest that seedlings with larger height and root-collar diameter outperform smaller seedlings after outplanting (Johansson et al. 2015, Regan et al. 2015, van den Driessche 1984). However, sufficient seedling height and root-collar diameter for a particular species to survive is often regionally specific.

Several studies have examined the impact of stock type selection on interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) growth, yet many of these studies are relatively short-term and results are often contradictory. Haase et al. (2006) reported that during the third and fourth growing seasons there were no differences in annual height or stem diameter growth. After 3 years, Douglas-fir seedlings grown in 20-in³ containers remained larger than seedlings grown in 8-in³ and 5.5-in³ containers.

Comparatively, van den Driessche (1992) examined the survival and growth of six different stock types of Douglas-fir over a 6-year period on a site in south-central Vancouver Island. The larger seedlings had a lower mean relative growth rate than smaller seedlings. Due to this growth rate difference, the average stem volume did not differ after six growing seasons despite large initial size differences. Wightman et al. (2018) found similar

results where the initial sizes (height, root-collar diameter, shoot and root volumes, and shoot/root ratio) differed significantly among stock types, but initial size differences disappeared after 8 years of growth. Pinto et al. (2018) also found the height, height increment, and root-collar diameter of Douglas-fir seedlings cultured in 4.9-in³ cavities were significantly smaller than the other three sizes (7.9, 12.2, and 15.3 in³). However, after 2 years, no differences in root-collar growth or mortality among stock types were observed.

These contrasting results make it difficult to determine general trends of stock type impacts on Douglas-fir seedling outplanting performance and suggest early differences among stock types may not continue as trees age. Thus, long-term trials are needed to capture stock type effects that may persist into later stages of a rotation.

A few studies (Pinto et al. 2011, South et al. 2005, Wightman et al. 2018) have examined the stock type effects linked to the seedling size and initial growth in the field, particularly the long-term effects. The general hypothesis is that larger stock types survive better under a broad range of field conditions. Smaller stock types may survive and grow equally well with improved vegetation management programs but may have fewer resources to overcome environmental stress.

The objective of this study is to examine the effect of a seedling's stock type on height, root-collar diameter, volume growth, and seedling survival over an 11- to 12-year period for three commonly planted conifer species: interior Douglas-fir, western larch (*Larix occidentalis*), and western white pine (*Pinus monticola*) at two moderately productive sites in northern Idaho.

Materials and Methods

Species and Seedling Production

The study used three common conifer species—interior Douglas-fir (DF), western larch (WL), and western white pine (WP)—that are ecologically important and economically valuable to western North America. The latitudinal range of DF is the greatest of any conifer of western North America; its native range extends from central British Columbia southward along the Pacific Coast Ranges for about 1,367 mi (2,200 km) and along the Rocky Mountains into the mountains of central Mexico over nearly 2,796 mi (4,500 km) (Herman and Lavender 1990). The deciduous conifer WL grows in a relatively moist, cool climatic zone with low temperatures limiting its upper elevational range and deficient moistures limiting its lower extremes in Montana, Idaho, Washington, Oregon, and southeastern British Columbia (Schmidt and Shearer 1990). WP grows along the west coast, from southern British Columbia southward through Washington and Oregon and in the Cascade Mountains. It is also found in northern California. In the interior, WP grows from British Columbia through eastern Washington and northern Idaho, and into western Montana. Its southernmost interior limit is in the Blue Mountains of northeastern Oregon (Graham 1990).

Seeds from single provenances of DF, WL, and WP were sown in March 2006 and 2007 at the University of Idaho Franklin H. Pitkin Forest Research Nursery and grown intermixed with

operationally produced seedlings. Seedlings were grown in five different sizes (313B for DF and WL, 315B for WP, and 415B, 415C, 415D, and 615A for all three species) of Styroblock (Beaver Plastics, Edmonton, AB, Canada) containers (table 1) using propagation protocols for container-grown seedlings of each species (Dumroese and Wenny 1995; Wenny and Dumroese 1992, 1994).

The seedlings were grown following the same protocol for each species, but being grown in different years resulted in differing greenhouse environments due to local weather conditions. At the end of the growing season, seedlings were lifted and stored in a freezer at 28.4 °F (-2 °C) until planting the following spring.

Outplanting Sites

Following freezer storage, seedlings were outplanted in April 2007 at site 1 and in June 2008 at site 2 in north-central Idaho (table 2). Both sites are western redcedar/bride's bonnet (*Thuja plicata/Clintonia uniflora*) habitat type and mixed, even-aged one-story plantations (figure 1). Both sites were treated with broadcast burn before planting. No thinning was conducted on the site after planting. The site index is 69 at site 1 and 94 at site 2 (Douglas-fir model). The study was a randomized complete block design: 4 blocks at site 1 and 3 blocks at site 2. The seedlings were planted in rows with 8 ft (2.4 m) of spacing between seedlings and 10 ft (3.0 m) between rows. At both sites, there were 20 seedlings per stock type of each species in each block. Prior to outplanting, WL seedlings grown in 615A containers were top pruned to remove tissue damaged due to dehydration during freezer storage. Additionally, at site 2, spring temperatures were too cool to outplant in April (NOAA), and seedlings were planted in June. By the end of June, temperatures quickly shifted from average spring (March to May) temperatures of 38.9 °F (3.8 °C) to summer (June to August) temperatures of 54.5–63.3 °F (12.5–17.4 °C).

Table 1—Styroblock types, configuration, and species associated with each type

Styroblock type	Species	Cavities per block (row x column)	Diameter (mm (in))	Depth (mm (in))	Volume (mL (in ³))
313B	DF, WL	160 (16 x 10)	30 (1.17)	126 (4.97)	65 (3.9)
315B	WP	160 (16 x 10)	30 (1.18)	151 (5.96)	90 (5.5)
415B	DF, WL, WP	112 (14 x 8)	36 (1.40)	148 (5.83)	108 (6.6)
415C	DF, WL, WP	91 (13 x 7)	39 (1.53)	151 (5.96)	130 (7.9)
415D	DF, WL, WP	77 (11 x 7)	42 (1.65)	151 (5.96)	164 (10.0)
615A	DF, WL, WP	45 (9 x 5)	59 (2.33)	151 (5.96)	336 (20.5)

DF = Douglas-fir; WL = western larch; WP = western white pine

Table 2—Outplanting sites and measurement dates

	Site 1	Site 2
Elevation	2,900 ft (900 m)	3,100 ft (945 m)
Aspect	Northwest	Southwest
Slope	17%	19%
Site preparation	Broadcast burn	Broadcast burn
Outplanting date	April 26, 2007	June 5, 2008
First measurement	Following outplanting	Following outplanting
Second measurement	November 2007	October 28, 2008
Third measurement	October 2014, 2010	September 17, 2010
Final measurement	June 19, 2019	June 24, 2019

Measurements and Statistical Analysis

Height, root-collar diameter, and survival were measured four times: following outplanting, at the end of the first growing season, in 2010, and in 2019 (table 2). Stem volume (V) was calculated by using the formula for an elliptical cone (Pinto et al. 2011).

$$V = (\pi d^2 h) / 6$$

where

d is the root-collar diameter (cm)

h is the height (cm)

The quasi-binominal logistic function estimated the odds of survival for each millimeter increase in diameter. One-way analysis of variance tested the stock types' effects on seedling survival rate, height, root-collar diameter, and stem volumes at each time point. Statistical significance was recognized at $\alpha = 0.05$ for all models. All analyses were done in R Programming (<https://www.r-project.org/>).



Figure 1—This study tested Douglas-fir, western larch, and western white pine seedling growth based on stock type at two similar sites in north-central Idaho. Photo by Andrew Nelson, 2019.

Results

Survival Rate and Odds of Survival

The survival rates of DF, WL, and WP decreased over time at both sites (figure 2). The survival rates between stock types were comparable and higher at site 1 than site 2. At site 2, the survival rates were lower than 80 percent, 65 percent, and 75 percent for DF, WL, and WP, respectively, in the 11th year. The survival rates of the species at both sites were not statistically different among stock types at each time of measurement (DF: $p=0.076$ to 0.736 ; WL: $p=0.082$ to 0.86 ; WP: $p=0.13$ to 0.934). The odds of survival did not change as root-collar diameter increased significantly in most years at site 1 (figure 3). However, the odds of survival increased as root-collar diameter increased in most years at site 2 (figure 4). The odds of survival in relation to initial root-collar diameter increased over time. For example, the odds of survival for WP at site 2 increased from 4.7 percent to 10.1 percent for each millimeter increase in root-collar diameter between years 1 and 11.

Height, Root-Collar Diameter, and Stem Volume

Height

Douglas-fir seedlings in the 615A stock type were the tallest for the entire study period at site 2, increasing from 13.9 in (35.3 cm) after outplanting to 200.9 in (510.3 cm) 11 years later. Differences between the other four stock types at site 2 were less consistent. For example, although 415D seedlings were shorter than other stock types after outplanting, their height did not differ in the following years through age 11. Similar trends were observed at site 1; 615A seedlings were the tallest in all years, while the other four stock types were less consistent following planting through age 12 (table 3a).

The seedling heights of WL in the 615A stock type were the tallest—13.5 in (34.2 cm)—after outplanting at site 1, but the difference among stock types shrank after the 1st and 3rd years and eventually disappeared in the 12th year. At 7.0 in (17.9 cm), WL 615A seedlings were also the tallest at the time of outplanting at site 2, but there was no difference between stock types immediately after the 1st growing season, which persisted through the 11th year (table 3b).

The seedling heights of WP in different stock types were significantly different in all years, and 615A was consistently the tallest: from 8.1 in (20.6 cm) after outplanting to 110.4 in (280.4 cm) 12 years later at site 2. However, significant differences in heights among stock types after outplanting and in the 12th year at site 1 were not observed (table 3c).

Root-Collar Diameter

DF 615A seedlings had the largest root-collar diameters across all years at site 1. Site 1 also had a greater differentiation of root-collar diameter than site 2; seedlings in larger stock types had larger increases in root-collar diameter through the third year after planting than those in smaller stock types. By the 12th year, root-collar diameter was greatest for the 415D and 615A containers:

3.2 in (81.2 mm) and 3.18 in (80.7 mm), respectively. At site 2, the DF 615A seedlings had the largest root-collar diameters, which persisted over time, while there were no differences among the other four stock types (table 4a).

The root-collar diameters of WL seedlings in the 615A stock type were also the largest in all years and the same as 415D, which was 3.07 in (78.0 mm) in the 12th year at site 1. The diameters of WL in 615A were the largest after outplanting at site 2. However, the root-collar diameter differences among stock types disappeared in the 11th year (table 4b).

Following outplanting and after the first year at site 1, WP 615A seedlings had the largest root-collar diameters (table 4c). However, the root-collar diameters of these seedlings were smaller than those in 415D containers in the 3rd year and smaller than both 415D and 415C containers in the 12th year. Root-collar diameters of WP in 615A were also the largest in all years at site 2. However, by the 11th year, there were no differences among stock types in root-collar diameter.

Stem Volume

DF 615A seedlings at site 1 had the largest stem volume for the entire study period, but seedlings in the 415D stock type had a comparable volume in the 12th year. The stem volumes of DF in 615A were also the largest for the study duration at site 2. The other four stock types did not have significant differences in volume during all years (table 5a).

The volumes of WL in 615A were also the largest after outplanting and in the first and third years at site 1. By the 12th year, volumes in 615A and 415D containers were similar: 1,495.5 in³ (24,506.4 cm³) for 615A and 1,501.8 in³ (24,609.9 cm³) for 415D (table 5b). At site 2, the stem volumes of WL in 615A were also the largest after outplanting and in the first year, and almost the same as 415D in the second year: 11.91 in³ (195.2 cm³) for 615A and 12.06 in³ (197.7 cm³) for 415D. However, by the 11th year, no significant differences among stock types were found.

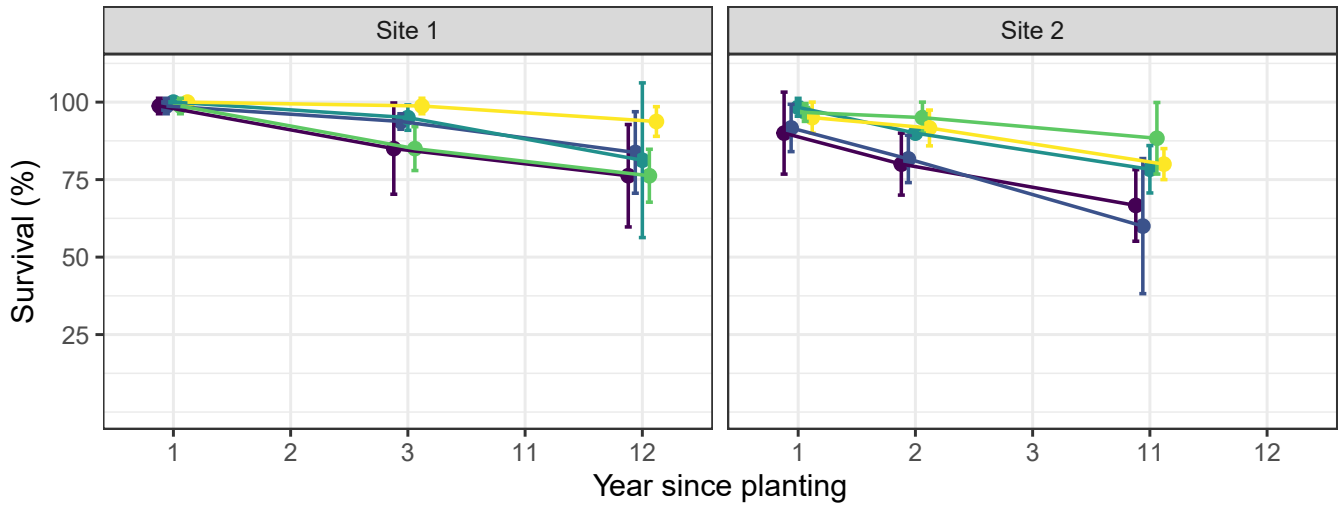
The stem volumes of WP 615A seedlings were also the largest after outplanting and in the 1st and 3rd years at site 1, but by the 12th year, there were no significant differences among stock types (table 5c). The volumes of WP 615A seedlings at site 2 were also the largest in all years and showed that there were significant differences among stock types in all years.

Discussion

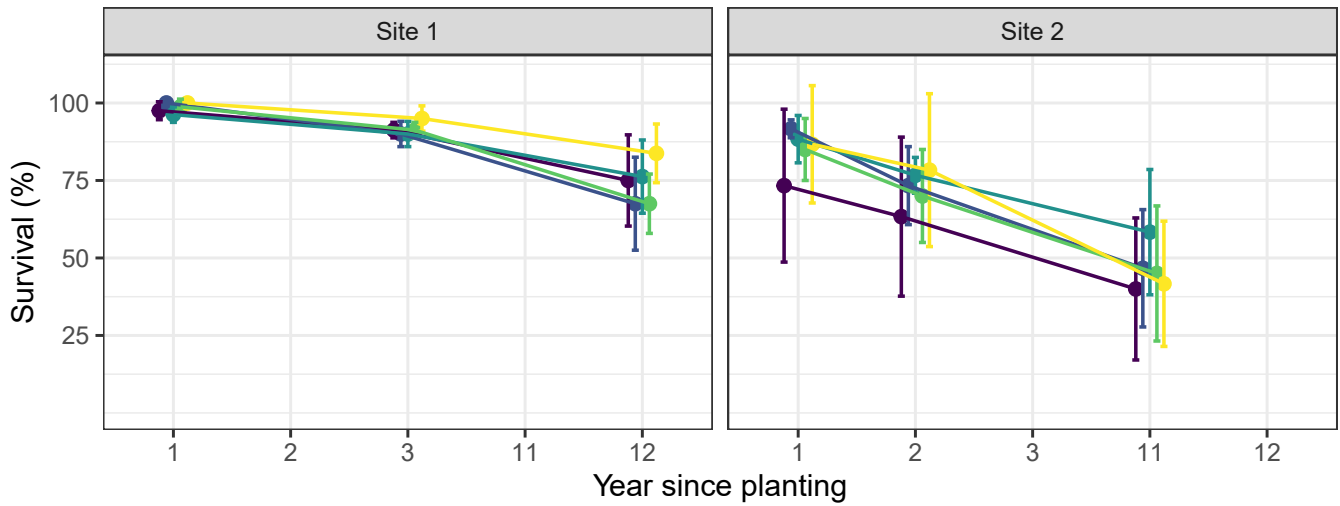
Large seedlings usually have higher survival rates than small seedlings after outplanting (van den Driessche 1984), although smaller seedlings may survive better on dry sites (Tuttle et al. 1987, van den Driessche 1991). Survival was slightly greater, although not statistically different, for larger stock types in this study (see figure 2). The inability to detect differences could be due to site quality since both sites are considered good quality for northern Idaho. However, survival rates varied more at each time point and were lower at site 2 than site 1. A possible cause is because the temperatures quickly changed from 38.9 °F (3.8 °C) to 54.5–63.3 °F (12.5–17.3 °C), and seedlings may have had less time with moist soil to grow new roots.

Stock type ● 313B ● 415B ● 415C ● 415D ● 615A

(a) Douglas-fir



(b) Western Larch



(c) Western White Pine

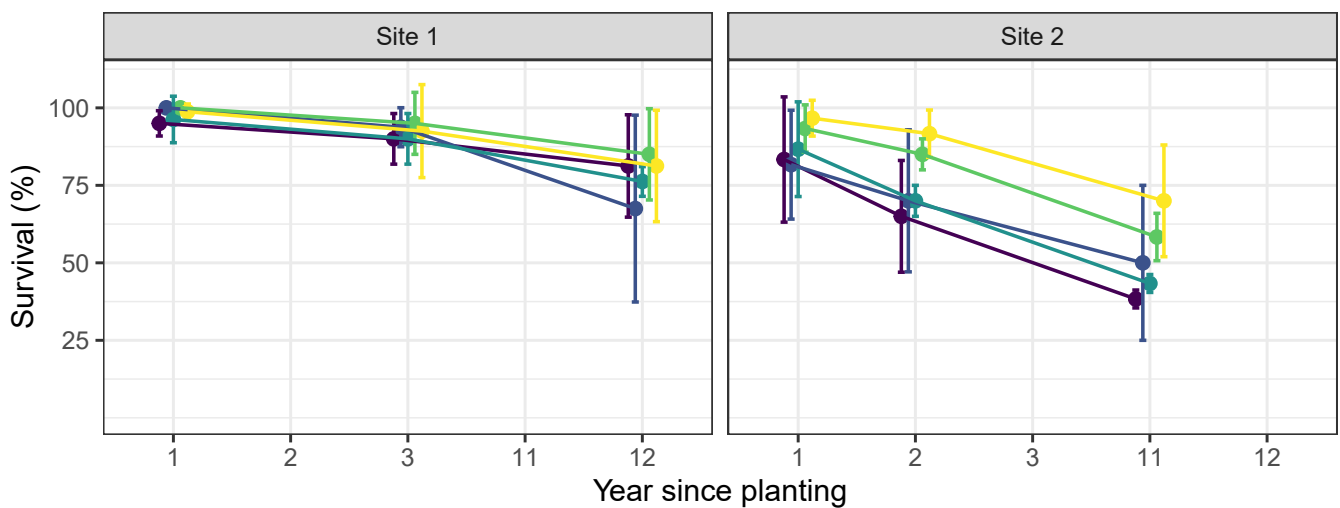


Figure 2—The survival rates of different stock types after different years since planting for (a) Douglas-fir, (b) western larch, and (c) western white pine at site 1 and site 2. There was no statistical difference among stock types at each time point.

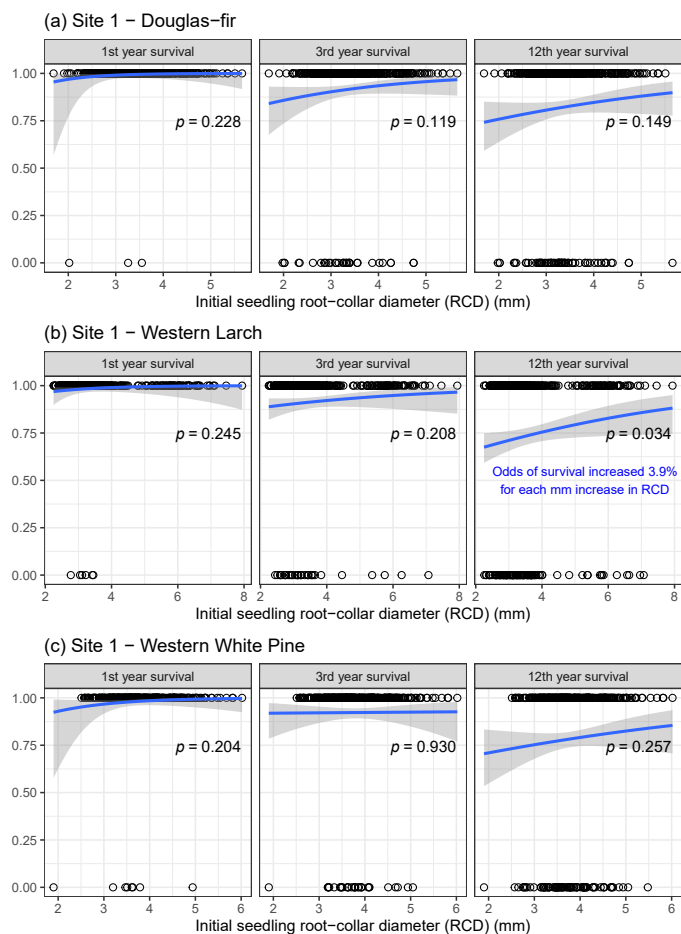


Figure 3—The odds of survival by initial root-collar diameter after different years since planting for (a) Douglas-fir, (b) western larch, and (c) western white pine at site 1.

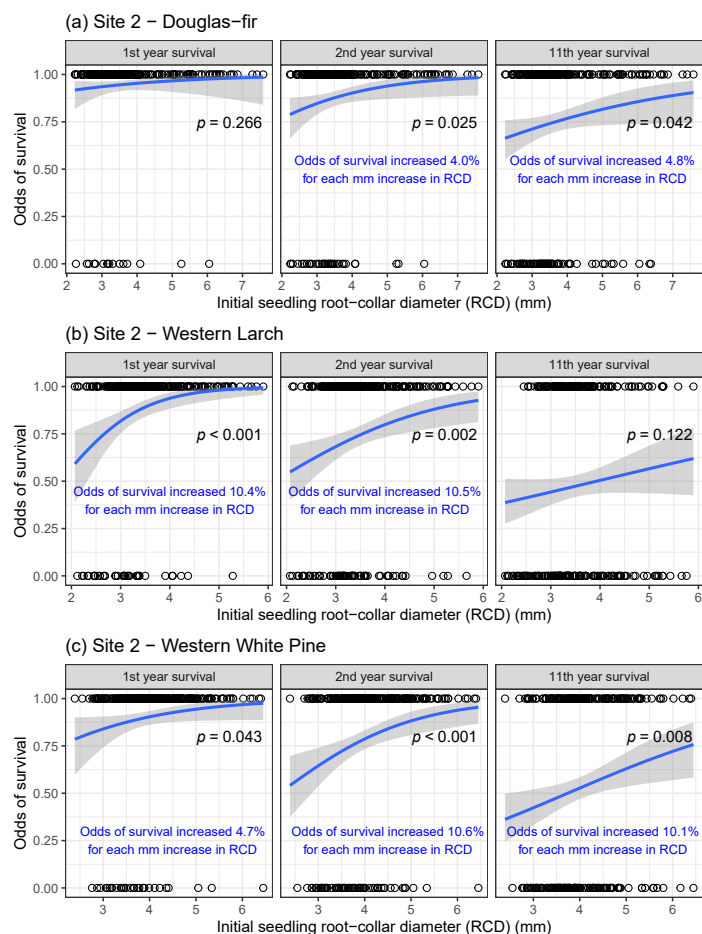


Figure 4—The odds of survival by initial root-collar diameter after different years since planting for (a) Douglas-fir, (b) western larch, and (c) western white pine at site 1.

Table 3a—Heights in centimeters (inches) by stock type for Douglas-fir at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
313B	16.7 ± 1.9 ^{cd} (6.6 ± 0.8)	23.6 ± 3.0 ^e (9.3 ± 1.2)	89.0 ± 25.5 ^e (35.0 ± 10.0)	471.1 ± 100.6 ^{ab} (185.5 ± 39.6)	18.7 ± 1.8 ^{bc} (7.4 ± 0.7)	26.8 ± 4.5 ^b (10.6 ± 1.8)	67.5 ± 16.9 ^b (26.6 ± 6.7)	442.2 ± 110.8 ^b (174.1 ± 43.6)
415B	16.1 ± 1.7 ^d (6.4 ± 0.7)	23.4 ± 2.8 ^e (9.2 ± 1.1)	90.6 ± 26.2 ^e (35.7 ± 10.3)	466.9 ± 122.6 ^b (183.8 ± 48.3)	20.2 ± 2.6 ^b (8.0 ± 1.0)	29.3 ± 4.4 ^b (11.5 ± 1.7)	69.5 ± 14.7 ^b (27.4 ± 5.8)	419.8 ± 116.6 ^b (165.3 ± 45.9)
415C	17.8 ± 2.1 ^b (7.0 ± 0.8)	26.2 ± 3.2 ^b (10.3 ± 1.3)	99.5 ± 26.2 ^{bc} (39.2 ± 10.3)	476.8 ± 110.5 ^{ab} (187.7 ± 43.5)	19.5 ± 1.9 ^b (7.7 ± 0.7)	27.6 ± 3.8 ^b (10.9 ± 1.5)	76.0 ± 16.8 ^b (29.9 ± 6.6)	446.4 ± 88.3 ^b (175.8 ± 34.8)
415D	17.2 ± 2.6 ^{bc} (6.8 ± 1.0)	26.2 ± 3.6 ^b (10.3 ± 1.4)	104.0 ± 23.6 ^b (41.0 ± 9.3)	516.3 ± 108.2 ^{ab} (203.3 ± 42.6)	17.8 ± 2.0 ^c (7.0 ± 0.8)	26.9 ± 5.8 ^b (10.6 ± 2.3)	71.9 ± 15.4 ^b (28.3 ± 6.1)	448.7 ± 103.8 ^b (176.7 ± 40.9)
615A	32.7 ± 3.3 ^a (12.9 ± 1.3)	42.0 ± 4.8 ^a (16.5 ± 1.9)	122.1 ± 24.7 ^a (48.1 ± 9.7)	520.6 ± 114.1 ^a (205.0 ± 44.9)	35.3 ± 5.8 ^a (13.9 ± 2.3)	48.1 ± 7.1 ^a (18.9 ± 2.8)	100.1 ± 24.0 ^a (39.4 ± 9.5)	510.3 ± 113.7 ^a (200.9 ± 44.8)
p-value	<0.001***	<0.001***	<0.001***	<0.01**	<0.001***	<0.001***	<0.001***	<0.001***

Table 3b—Heights in centimeters (inches) for western larch at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	2nd year	12th year	After planting	1st year	2nd year	11th year
313B	15.5 ± 2.1 ^b (6.1 ± 0.8)	29.6 ± 9.6 ^c (11.6 ± 3.8)	143.2 ± 45.6 ^b (56.4 ± 17.9)	521.4 ± 150.6 (205.3 ± 59.3)	15.6 ± 2.8 ^{bc} (6.1 ± 1.1)	33.9 ± 8.1 (13.4 ± 3.2)	89.9 ± 25.1 (35.4 ± 9.9)	439.6 ± 124.1 (173.1 ± 48.9)
415B	15.5 ± 2.2 ^b (6.1 ± 0.8)	32.2 ± 9.6 ^{bc} (12.7 ± 3.8)	153.3 ± 44.3 ^{ab} (60.4 ± 17.4)	535.4 ± 159.8 (210.8 ± 62.9)	14.8 ± 1.9 ^{bc} (5.8 ± 0.7)	35.3 ± 11.1 (13.9 ± 4.4)	106.1 ± 34.8 (41.8 ± 13.7)	464.7 ± 148.8 (183.0 ± 58.6)
415C	15.7 ± 2.8 ^b (6.2 ± 1.1)	34.5 ± 10.2 ^b (13.6 ± 4.0)	151.4 ± 37.4 ^{ab} (59.6 ± 14.7)	558.6 ± 159.6 (219.9 ± 62.8)	15.7 ± 2.8 ^b (6.2 ± 1.1)	34.4 ± 10.3 (13.5 ± 4.0)	94.0 ± 24.2 (37.0 ± 9.5)	467.7 ± 174.2 (184.1 ± 68.6)
415D	15.5 ± 2.3 ^b (6.1 ± 0.9)	36.2 ± 12.3 ^b (14.3 ± 4.9)	157.9 ± 47.4 ^{ab} (62.2 ± 18.7)	557.8 ± 183.1 (219.6 ± 72.1)	14.4 ± 2.0 ^c (5.7 ± 0.8)	39.3 ± 12.2 (15.5 ± 4.8)	106.8 ± 36.7 (42.0 ± 14.4)	457.5 ± 178.4 (180.1 ± 70.2)
615A	34.2 ± 2.8 ^a (13.5 ± 1.1)	48.5 ± 8.4 ^a (19.1 ± 3.3)	169.7 ± 45.6 ^a (66.8 ± 17.9)	598.1 ± 148.3 (235.5 ± 58.4)	17.9 ± 3.9 ^a (7.0 ± 1.5)	38.1 ± 13.2 (15.0 ± 5.2)	105.6 ± 38.6 (41.6 ± 15.2)	395.9 ± 170.0 (155.9 ± 66.9)
<i>p</i> -value	<0.001***	<0.001***	<0.01**	0.074	<0.001***	0.073	0.069	0.389

Table 3c—Heights in centimeters (inches) for western white pine at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	2nd year	12th year	After planting	1st year	2nd year	11th year
315B	12.0 ± 2.4 (4.7 ± 1.0)	17.0 ± 2.9 ^c (6.7 ± 1.1)	61.4 ± 18.0 ^b (24.2 ± 7.1)	345.9 ± 120.4 (136.2 ± 47.4)	14.7 ± 2.6 ^c (5.8 ± 1.0)	20.0 ± 3.2 ^c (7.9 ± 1.3)	52.3 ± 12.7 ^c (20.6 ± 5.0)	200.8 ± 74.0 ^b (79.1 ± 29.1)
415B	12.3 ± 2.4 (4.8 ± 1.0)	18.0 ± 2.8 ^{bc} (7.1 ± 1.1)	66.9 ± 20.6 ^b (26.3 ± 8.1)	362.4 ± 107.2 (142.7 ± 42.2)	17.5 ± 4.3 ^b (6.9 ± 1.7)	21.8 ± 4.6 ^{bc} (8.6 ± 1.8)	57.9 ± 16.0 ^{bc} (22.8 ± 6.3)	219.9 ± 74.8 ^b (86.6 ± 29.5)
415C	11.7 ± 2.2 (4.6 ± 0.9)	18.1 ± 3.3 ^{bc} (7.1 ± 1.3)	66.1 ± 18.4 ^b (26.0 ± 7.2)	369.3 ± 124.5 (145.4 ± 49.0)	15.1 ± 2.9 ^c (5.9 ± 1.1)	22.5 ± 4.8 ^b (8.8 ± 1.9)	61.1 ± 15.4 ^{bc} (24.0 ± 6.1)	231.4 ± 100.2 ^{ab} (91.1 ± 39.4)
415D	11.2 ± 2.6 (4.4 ± 1.0)	19.4 ± 4.3 ^b (7.7 ± 1.7)	75.9 ± 18.1 ^a (29.9 ± 7.1)	395.9 ± 98.5 (155.9 ± 38.8)	17.0 ± 2.6 ^b (6.7 ± 1.0)	25.0 ± 2.9 ^a (9.9 ± 1.1)	64.4 ± 11.4 ^b (25.4 ± 4.5)	256.0 ± 81.4 ^{ab} (100.8 ± 32.0)
615A	11.6 ± 2. (4.6 ± 1.0)	22.0 ± 4.3 ^a (8.7 ± 1.7)	81.4 ± 23.1 ^a (32.0 ± 9.1)	386.2 ± 107.9 (152.1 ± 42.5)	20.6 ± 3.6 ^a (8.1 ± 1.4)	27.0 ± 5.6 ^a (10.6 ± 2.2)	75.9 ± 21.6 ^a (29.9 ± 8.5)	280.4 ± 93.2 ^a (110.4 ± 36.7)
<i>p</i> -value	0.065	<0.001***	<0.001***	0.077	<0.001***	<0.001***	<0.001***	<0.01**

The superscript *a*, *b*, *c*, and *d* symbols are variables that indicate statistical similarities and differences ($\alpha=0.05$) between stock types (rows) for a specific measurement (columns); statistical differences were calculated by using Tukey's honest significance test (HSD). For example, in table 3a for site 1, the observed height of the 313B stock type in the first year is statistically similar to 415B, and 415C is similar to 415D (they share the same letter), while these two groups are statistically different. The observed height of the 615A stock type in the first year is not statistically similar to the other four stock types. By year 12, the observed heights for 313B, 415C, and 415D are statistically similar to 615A or 415B, but the observed height for 415B is not statistically similar to 615A

Table 4a—Root-collar diameters in centimeters (inches) by stock type for Douglas-fir at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
313B	2.8 ± 0.4 ^c (0.11 ± 0.02)	4.4 ± 1.1 ^c (0.17 ± 0.04)	24.2 ± 6.4 ^c (0.95 ± 0.25)	69.2 ± 18.3 ^b (2.72 ± 0.72)	2.9 ± 0.4 ^c (0.11 ± 0.02)	5.2 ± 1.0 ^c (0.20 ± 0.04)	14.6 ± 3.1 ^c (0.58 ± 0.12)	65.0 ± 18.6 ^b (2.56 ± 0.73)
415B	3.1 ± 0.4 ^d (0.12 ± 0.01)	4.9 ± 1.2 ^c (0.19 ± 0.05)	24.8 ± 7.2 ^c (0.98 ± 0.29)	67.7 ± 24.6 ^b (2.66 ± 0.97)	3.3 ± 0.4 ^b (0.13 ± 0.02)	5.9 ± 1.3 ^{bc} (0.23 ± 0.05)	16.2 ± 3.8 ^{bc} (0.64 ± 0.15)	63.1 ± 17.1 ^b (2.49 ± 0.68)
415C	3.4 ± 0.4 ^c (0.13 ± 0.01)	5.5 ± 1.3 ^b (0.22 ± 0.05)	26.3 ± 7.2 ^c (1.04 ± 0.28)	73.9 ± 21.6 ^{ab} (2.91 ± 0.85)	3.4 ± 0.3 ^b (0.14 ± 0.01)	6.3 ± 1.5 ^b (0.25 ± 0.06)	17.3 ± 3.8 ^b (0.68 ± 0.15)	65.2 ± 17.9 ^b (2.57 ± 0.70)
415D	3.6 ± 0.5 ^b (0.14 ± 0.02)	5.9 ± 1.1 ^b (0.23 ± 0.04)	29.5 ± 5.8 ^b (1.16 ± 0.23)	81.2 ± 20.2 ^a (3.20 ± 0.80)	3.5 ± 0.4 ^b (0.14 ± 0.02)	6.4 ± 1.4 ^b (0.25 ± 0.05)	17.3 ± 3.6 ^b (0.68 ± 0.14)	66.0 ± 18.9 ^b (2.60 ± 0.75)
615A	4.3 ± 0.6 ^a (0.17 ± 0.02)	7.7 ± 1.3 ^a (0.30 ± 0.05)	32.9 ± 6.0 ^a (1.30 ± 0.24)	80.7 ± 20.6 ^a (3.18 ± 0.81)	5.5 ± 0.9 ^a (0.22 ± 0.03)	8.7 ± 1.7 ^a (0.34 ± 0.07)	22.5 ± 4.2 ^a (0.88 ± 0.17)	81.7 ± 20.0 ^a (3.22 ± 0.79)
p-value	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

Table 4b—Root-collar diameters in centimeters (inches) by stock type for western larch at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
313B	2.8 ± 0.3 ^c (0.11 ± 0.01)	5.4 ± 1.6 ^d (0.21 ± 0.06)	23.0 ± 8.3 ^c (0.91 ± 0.33)	62.0 ± 25.6 ^b (2.44 ± 1.01)	2.8 ± 0.4 ^c (0.11 ± 0.01)	6.0 ± 1.3 ^b (0.23 ± 0.05)	13.7 ± 3.1 ^c (0.54 ± 0.12)	53.1 ± 18.8 (2.09 ± 0.74)
415B	3.1 ± 0.3 ^d (0.12 ± 0.01)	6.0 ± 1.8 ^{cd} (0.24 ± 0.07)	24.8 ± 9.0 ^{bc} (0.97 ± 0.33)	69.5 ± 26.5 ^{ab} (2.74 ± 1.04)	3.4 ± 0.4 ^b (0.13 ± 0.02)	6.4 ± 1.6 ^b (0.25 ± 0.06)	15.1 ± 3.9 ^{abc} (0.59 ± 0.15)	66.3 ± 21.9 (2.61 ± 0.86)
415C	3.3 ± 0.4 ^c (0.13 ± 0.02)	6.3 ± 1.5 ^{bc} (0.25 ± 0.06)	25.9 ± 8.3 ^{abc} (1.02 ± 0.33)	73.5 ± 26.0 ^{ab} (2.89 ± 1.02)	3.4 ± 0.4 ^b (0.13 ± 0.01)	6.5 ± 1.4 ^b (0.25 ± 0.06)	14.4 ± 3.7 ^{bc} (0.57 ± 0.15)	60.1 ± 24.9 (2.37 ± 0.98)
415D	3.6 ± 0.4 ^b (0.14 ± 0.02)	7.0 ± 1.9 ^b (0.28 ± 0.08)	28.0 ± 9.6 ^{ab} (1.10 ± 0.38)	78.0 ± 29.5 ^a (3.07 ± 1.16)	3.5 ± 0.4 ^b (0.14 ± 0.02)	7.5 ± 1.7 ^a (0.29 ± 0.07)	16.9 ± 4.9 ^{ab} (0.66 ± 0.19)	60.1 ± 29.1 (2.36 ± 1.15)
615A	5.9 ± 0.7 ^a (0.23 ± 0.03)	8.7 ± 1.4 ^a (0.34 ± 0.05)	29.1 ± 9.5 ^a (1.14 ± 0.37)	78.0 ± 27.8 ^a (3.07 ± 1.09)	4.6 ± 0.6 ^a (0.18 ± 0.02)	7.8 ± 1.8 ^a (0.31 ± 0.07)	17.3 ± 4.4 ^a (0.68 ± 0.17)	55.8 ± 29.7 (2.20 ± 1.17)
p-value	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

Table 4c—Root-collar diameters in centimeters (inches) by stock type for western white pine at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
315B	3.3 ± 0.4 ^d (0.13 ± 0.02)	4.7 ± 0.7 ^d (0.18 ± 0.03)	16.1 ± 4.7 ^b (0.63 ± 0.18)	48.8 ± 21.5 ^b (1.92 ± 0.85)	3.4 ± 0.4 ^d (0.13 ± 0.02)	5.2 ± 1.0 ^c (0.21 ± 0.04)	12.2 ± 2.5 ^c (0.48 ± 0.10)	31.4 ± 12.6 (1.24 ± 0.50)
415B	3.5 ± 0.4 ^{cd} (0.14 ± 0.01)	5.0 ± 0.7 ^{cd} (0.20 ± 0.03)	18.7 ± 7.2 ^{ab} (0.74 ± 0.28)	55.8 ± 18.1 ^{ab} (2.20 ± 0.71)	3.7 ± 0.6 ^c (0.15 ± 0.02)	5.6 ± 1.2 ^{bc} (0.22 ± 0.05)	13.4 ± 2.5 ^c (0.53 ± 0.10)	32.5 ± 10.6 (1.28 ± 0.42)
415C	3.6 ± 0.5 ^c (0.14 ± 0.02)	5.2 ± 0.7 ^c (0.21 ± 0.03)	18.4 ± 4.5 ^{ab} (0.72 ± 0.18)	58.4 ± 21.5 ^a (2.30 ± 0.84)	3.9 ± 0.5 ^{bc} (0.15 ± 0.02)	6.1 ± 1.1 ^b (0.24 ± 0.04)	13.8 ± 2.9 ^{bc} (0.54 ± 0.12)	38.0 ± 18.0 (1.50 ± 0.71)
415D	3.9 ± 0.5 ^b (0.15 ± 0.02)	5.8 ± 0.8 ^b (0.23 ± 0.03)	20.8 ± 5.1 ^a (0.82 ± 0.20)	63.3 ± 15.5 ^a (2.49 ± 0.61)	4.1 ± 0.5 ^b (0.16 ± 0.02)	6.8 ± 1.1 ^a (0.27 ± 0.04)	15.0 ± 2.7 ^{ab} (0.59 ± 0.11)	39.9 ± 12.3 (1.57 ± 0.48)
615A	4.6 ± 0.5 ^a (0.18 ± 0.02)	6.6 ± 1.1 ^a (0.26 ± 0.04)	20.5 ± 6.3 ^a (0.81 ± 0.25)	56.7 ± 17.9 ^{ab} (2.23 ± 0.70)	5.0 ± 0.7 ^a (0.20 ± 0.03)	7.1 ± 1.1 ^a (0.28 ± 0.04)	15.9 ± 3.2 ^a (0.62 ± 0.13)	41.5 ± 18.6 (1.63 ± 0.73)
p-value	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.051

Refer to the note under table 3 regarding the *a*, *b*, *c*, and *d* symbols.

Table 5a—Stem volume in milliliters (cubic inches) by stock type for Douglas-fir at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
313B	0.7 ± 0.2 ^c (0.04 ± 0.01)	2.6 ± 1.6 ^c (0.16 ± 0.10)	325.7 ± 246.5 ^c (19.88 ± 15.04)	13,792.1 ± 9,210.6 ^b (841.7 ± 562.1)	0.8 ± 0.3 ^b (0.05 ± 0.02)	4.0 ± 2.0 ^b (0.25 ± 0.12)	85.3 ± 53.3 ^b (5.21 ± 3.25)	11,738.8 ± 7,766.9 ^b (716.4 ± 474.0)
415B	0.8 ± 0.3 ^c (0.05 ± 0.02)	3.1 ± 1.9 ^c (0.19 ± 0.12)	348.3 ± 249.1 ^c (21.25 ± 15.20)	14,490.1 ± 11,641.3 ^b (884.2 ± 710.4)	1.2 ± 0.4 ^b (0.07 ± 0.03)	5.7 ± 2.9 ^b (0.35 ± 0.18)	107.3 ± 71.2 ^b (6.55 ± 4.34)	10,815.7 ± 6,745.8 ^b (660.0 ± 411.7)
415C	1.1 ± 0.3 ^b (0.07 ± 0.02)	4.5 ± 2.9 ^b (0.27 ± 0.18)	423.2 ± 320.3 ^{bc} (25.83 ± 19.55)	16,529.5 ± 11,163.9 ^{ab} (1,008.7 ± 681.3)	1.2 ± 0.3 ^b (0.07 ± 0.02)	6.3 ± 3.4 ^b (0.38 ± 0.21)	133.5 ± 77.2 ^b (8.15 ± 4.71)	11,604.5 ± 7,185.6 ^b (708.2 ± 438.5)
415D	1.2 ± 0.4 ^b (0.07 ± 0.03)	5.1 ± 2.1 ^b (0.31 ± 0.13)	517.5 ± 275.1 ^b (31.58 ± 16.79)	20,578.9 ± 11,794.8 ^a (1,255.8 ± 719.8)	1.2 ± 0.3 ^b (0.07 ± 0.02)	6.3 ± 3.7 ^b (0.38 ± 0.22)	124.1 ± 75.6 ^b (7.57 ± 4.61)	12,010.6 ± 7,657.4 ^b (732.9 ± 467.3)
615A	3.3 ± 1.0 ^a (0.20 ± 0.06)	13.6 ± 5.4 ^a (0.83 ± 0.33)	751.1 ± 394.3 ^a (45.83 ± 24.06)	20,769.4 ± 13,081.0 ^a (1,267.4 ± 798.3)	5.9 ± 2.4 ^a (0.36 ± 0.14)	20.3 ± 9.6 ^a (1.24 ± 0.59)	289.1 ± 171.6 ^a (17.64 ± 10.47)	20,805.2 ± 12,322.4 ^a (1,269.6 ± 752.0)
p-value	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

Table 5b—Stem volume in milliliters (cubic inches) by stock type for western larch at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
	0.6 ± 0.2 ^c (0.04 ± 0.01)	5.8 ± 9.0 ^c (0.35 ± 0.55)	542.6 ± 682.0 ^b (33.11 ± 41.62)	14,834.2 ± 16,528.2 ^b (905.2 ± 1,008.6)	0.6 ± 0.2 ^c (0.04 ± 0.01)	7.0 ± 4.0 ^c (0.42 ± 0.24)	101.8 ± 76.8 ^b (6.21 ± 4.69)	8,327.3 ± 6,697.4 (508.2 ± 408.7)
	0.8 ± 0.2 ^c (0.05 ± 0.01)	7.6 ± 7.7 ^c (0.46 ± 0.47)	640.5 ± 596.2 ^{ab} (39.09 ± 36.38)	18,439.5 ± 16,332.4 ^{ab} (1,125.3 ± 996.7)	0.9 ± 0.3 ^b (0.06 ± 0.02)	8.8 ± 7.4 ^{bc} (0.54 ± 0.45)	151.9 ± 107.4 ^{ab} (9.27 ± 6.55)	14,051.3 ± 11,516.2 (857.5 ± 702.8)
	0.9 ± 0.3 ^{bc} (0.06 ± 0.02)	8.5 ± 6.8 ^{bc} (0.52 ± 0.42)	644.6 ± 470.5 ^{ab} (39.34 ± 28.71)	20,637.9 ± 15,635.8 ^{ab} (1,259.4 ± 954.2)	1.0 ± 0.3 ^b (0.06 ± 0.02)	8.7 ± 7.0 ^c (0.53 ± 0.43)	119.8 ± 99.4 ^b (7.31 ± 6.06)	12,816.4 ± 13,120.3 (782.1 ± 800.7)
	1.1 ± 0.4 ^b (0.07 ± 0.02)	11.7 ± 12.3 ^b (0.71 ± 0.75)	846.1 ± 813.8 ^{ab} (51.63 ± 49.66)	24,609.9 ± 18,928.8 ^a (1,501.8 ± 1,155.1)	0.9 ± 0.2 ^b (0.06 ± 0.01)	12.7 ± 8.1 ^{ab} (0.78 ± 0.49)	197.7 ± 161.0 ^a (12.06 ± 9.82)	13,670.4 ± 14,383.9 (834.2 ± 877.8)
	6.3 ± 1.5 ^a (0.38 ± 0.09)	20.3 ± 9.9 ^a (1.24 ± 0.60)	943.7 ± 836.9 ^a (57.59 ± 51.07)	24,506.4 ± 21,858.3 ^a (1,495.5 ± 1,333.9)	2.1 ± 0.8 ^a (0.13 ± 0.05)	13.7 ± 9.1 ^a (0.83 ± 0.56)	195.2 ± 141.5 ^a (11.91 ± 8.63)	11,472.5 ± 12,339.5 (700.1 ± 753.0)

Table 5c—Stem volume in milliliters (cubic inches) by stock type for western white pine at sites 1 and 2

Stock type	Site 1				Site 2			
	After planting	1st year	3rd year	12th year	After planting	1st year	2nd year	11th year
315B	0.7 ± 0.3 ^c (0.04 ± 0.02)	2.0 ± 0.8 ^d (0.12 ± 0.05)	102.6 ± 95.6 ^c (6.26 ± 5.84)	6,423.4 ± 6,553.3 (392.0 ± 399.9)	0.9 ± 0.3 ^d (0.05 ± 0.02)	3.1 ± 1.5 ^c (0.19 ± 0.09)	44.8 ± 25.1 ^c (2.74 ± 1.53)	1,596.4 ± 2,034.3 ^b (97.42 ± 124.1)
415B	0.8 ± 0.3 ^{bc} (0.05 ± 0.02)	2.4 ± 0.9 ^{cd} (0.15 ± 0.05)	163.8 ± 274.4 ^{abc} (9.99 ± 16.75)	7,712.2 ± 6,629.7 (470.6 ± 404.6)	1.4 ± 0.7 ^{bc} (0.08 ± 0.04)	4.0 ± 2.6 ^{bc} (0.25 ± 0.16)	60.5 ± 32.9 ^{bc} (3.69 ± 2.00)	1,646.2 ± 1,438.3 ^b (100.5 ± 87.8)
415C	0.9 ± 0.3 ^{bc} (0.05 ± 0.02)	2.7 ± 1.1 ^c (0.17 ± 0.07)	135.9 ± 87.5 ^{bc} (8.30 ± 5.34)	9,122.0 ± 8,349.5 (556.7 ± 509.5)	1.2 ± 0.5 ^{cd} (0.07 ± 0.03)	4.7 ± 2.2 ^b (0.29 ± 0.14)	68.7 ± 40.6 ^{bc} (4.19 ± 2.48)	3,036.7 ± 3,537.4 ^{ab} (185.3 ± 215.9)
415D	1.0 ± 0.4 ^b (0.06 ± 0.03)	3.6 ± 1.4 ^b (0.22 ± 0.08)	198.6 ± 134.3 ^{ab} (12.12 ± 8.20)	9,797.5 ± 6,574.1 (597.9 ± 401.2)	1.6 ± 0.5 ^b (0.09 ± 0.03)	6.3 ± 2.4 ^a (0.39 ± 0.14)	81.8 ± 40.4 ^b (4.99 ± 2.46)	2,759.5 ± 2,179.2 ^{ab} (168.4 ± 133.0)
615A	1.3 ± 0.5 ^a (0.08 ± 0.03)	5.3 ± 2.4 ^a (0.32 ± 0.15)	220.5 ± 181.5 ^a (13.45 ± 11.08)	8,218.2 ± 6,712.1 (501.5 ± 409.6)	2.8 ± 1.1 ^a (0.17 ± 0.07)	7.6 ± 3.5 ^a (0.46 ± 0.21)	110.8 ± 65.9 ^a (6.76 ± 4.02)	3,771.8 ± 3,857.4 ^a (230.2 ± 235.4)
p-value	<0.001***	<0.001***	<0.001***	0.063	<0.001***	<0.001***	<0.001***	<0.05*

Refer to the note under table 3 regarding the *a*, *b*, *c*, and *d* symbols.

Although the stock types did not affect the survival rates, the odds of survival increased as the root-collar diameter increased in most species and years at site 2 (see figure 4) but not at site 1 (see figure 3). Despite the site indexes being comparable at both sites, the environment became harsher at site 2 than site 1 immediately after outplanting. This suggests that if the site quality or environment is unfavorable, the stock types and seedling sizes may be more important than at more favorable sites. Wightman et al. (2018) had a very different finding with coastal Douglas-fir (*P. menziessi* var. *menziessi*) where the largest stock type in their study had the lowest survival rate. They attributed this to the larger leaf area, and thus, increased evaporative demand that may increase water stress during stand establishment. However, it is also possible that the differences between these results are due to the differences in stock types tested, the sites where the seedlings were planted, and the species or variant of a species examined.

Similar to survival, each species' seedling height, root-collar diameter, and stem volume were minimally influenced by stock type over time. Sizes were statistically different for all species and metrics at the time of outplanting, except for the height of WP (see tables 3, 4, and 5). However, the effects of stock type disappeared after 11 or 12 years for some metrics of WL and WP. The most prominent trend in the results was that DF 615A seedlings remained larger than the smaller stock types 11 or 12 years after planting at both sites. This finding is similar to other studies of stock type effects on Douglas-fir (e.g., Haase et al. 2006, Haywood et al. 2012, Johansson et al. 2015, Regan et al. 2015). Comparatively, van den Driessche (1992) and Wightman et al. (2018) observed that initial differences in coastal DF at the time of planting disappeared 6 to 8 years after planting. These studies further suggest that results vary across sites, variants (e.g., coastal and interior), and stock types tested.

Regardless, findings from the current study suggest that if the objective is the largest interior DF trees in the shortest amount of time, larger stock types may be the best option. The less consistent results across sites and size metrics for WL and WP suggest that stock type selection may be less important for these species in this region; an interesting observation was the lack of differences between the 615A container and medium-sized containers (e.g., 415B, 415C, 415D), which suggests minimal gains in seedling size when using larger, more expensive stock types. It is also possible that this study did not document differences between stock types because the seedlings grown in the 615A stock type did not have enough time to reach that container's maximum capacity. These observations can help guide stock type selection, especially for large reforestation projects when maximizing nursery space occupancy and seedling quantity are considerations.

Haase et al. (2006) found that DF seedling growth rates did not differ among the stock types after three seasons of growth. However, van den Driessche (1992) showed that larger seedlings had lower mean relative growth rates than smaller seedlings, and the initial differences in performance disappeared after a 6-year period on a site in south-central Vancouver Island. Wightman et al. (2018) also reported that initial size (height, root-collar diameter, shoot and root volumes, and shoot/root ratio) differences at the time of planting disappeared after 8 years of growth, resulting in tree sizes being similar across stock types.

Although 615A seedlings had larger initial height, root-collar diameter, and stem volume, the differences lessened after 2 or 3 years and mostly disappeared after 11 or 12 years in DF, WL, and WP (see tables 3, 4, and 5). Tuttle et al. (1987) and Pinto et al. (2011) also found that site differences may play a role in the relationship between stock types and growth rates. Tuttle et al. (1987) found that the growth of loblolly pine (*Pinus taeda*) seedlings is negatively related to initial seedling height on drought-prone sites, while there was a positive relationship for favorable sites. Pinto et al. (2011) found that initial seedling traits (height, root-collar diameter, and stem volume) of ponderosa pine (*Pinus ponderosa*) lost predictive ability with time, especially on the higher quality site. That is, initial seedling traits were unable to predict long-term performance in their study. On the contrary, the absolute growth was reduced on a dryer site, but traits determined by the stock type persisted longer. In this study, because the planting years and climate conditions were different, site differences were not compared.

All these studies demonstrate that the results of growing DF in different stock types can be site specific (e.g., soil, weather, vegetation), that smaller seedlings may have better early performance on harsher sites (Wightman et al. 2018), and the initial differences may disappear over time.

WP was the slowest growing species among these three conifers. It had the lowest height and smallest root-collar diameter among the three species (see tables 3 and 4) and consequently, the smallest stem volumes (see table 5). The heights at site 1 after outplanting did not have any differences among stock types. This suggests that using a larger stock type (e.g., 615A) for WP increases the production cost without a statistical difference in survival. However, there is a potentially lower cost per established tree over the rotation of the stand due to better initial growth. This can also lead to fewer seedlings being planted per acre, better resistance to transplant stress, and a greater likelihood of achieving minimum stocking levels required by some laws in a timely manner. However, based on the results of this study, the value of using larger stock types for some species on good-quality sites with suitable environments is negligible.

The 615A stock type consistently showed larger height, root-collar diameter, and stem volume while the other four types did not show much difference across all the species. Therefore, from the cost-effectiveness point of view, if the stock types are smaller than 415D, it is best to choose the smallest one to decrease the cost and maintain the seedling performance. If larger seedlings that have better performances are preferred, the best choice is the 615A stock type. Still, the decision is subject to change depending on the species and sites and should follow the target plant concept.

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