

Eight-Year Growth and Survival of a Western White Pine Evaluation Plantation in the Southwestern Oregon Cascades

Andrew D. Bower
Richard A. Sniezko

Abstract—An evaluation plantation of western white pine (*Pinus monticola*) was established in southwestern Oregon in 1991 using 3-year-old seedlings. The planting was comprised of 98 full-sib families from Dorena seed orchards and 42 wind-pollinated families from parents in natural stands from a wide range in elevation, latitude, and longitude. All parent trees had previously been selected for above average resistance to white pine blister rust (caused by *Cronartium ribicola*) in seedling testing at Dorena. Growth, survival, and level of blister rust infection were assessed in 1993 at age 5 and in 1998 at age 10. Overall survival in 1993 and 1998 was 72.1 and 66.7 percent, respectively, and 7.5 percent of the trees were infected with blister rust by 1998. Significant differences were found between families within each seed type (both seed orchard and natural stand seed collections) for mean height increment and survival percentage, but not for rust infection. Within a subset of families from the Rogue River National Forest, significant differences were found between seed types for both height increment and survival percentage, and differences in infection percentage were nearly significant. Families from this forest originating from orchard seed were found have larger height increment (93.03 vs. 70.71 cm), higher survival (73.8 vs. 61.4 percent), and lower infection (6.0 vs. 9.6 percent) than trees from wild seed. In a stepwise regression, height increment of trees from orchard seed was only associated with seed weight, but trees from wild seed sources local to the planting site (when northerly and easterly sources were excluded) were only associated with latitude of the female parent. Large differences in height among families provide good potential for future selection in growth. Despite very slow initial growth, the plantation is progressing on a trajectory that suggests that we have successfully regenerated the site. Recent site visits indicate little additional mortality, low rust infection and increasing annual growth as well as some cone production on this site which was problematic for previous Douglas-fir (*Pseudotsuga menziesii*) reforestation efforts.

Key words: western white pine, *Pinus monticola*, white pine blister rust, *Cronartium ribicola*, height growth, survival, geographic location

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The authors are with the USDA Forest Service, Dorena Tree Improvement Center, 34963 Shoreview Road, Cottage Grove, Oregon, 97424, USA. Andrew Bower's current address is Forest Sciences Department, University of British Columbia, Vancouver, B.C. V6T 1Z4 CANADA, Phone: (604) 822-1951, Fax: (604) 822-9102, Email: adbower@interchange.ubc.ca.

Introduction

Western white pine (*Pinus monticola* Dougl.) was once a much larger component of forests in the Pacific Northwest than it is today. Historically and ecologically, western white pine has been considered important in the Pacific Northwest, yet information on its status is limited (Goheen 2000). In areas of Idaho and the Inland Empire, the white pine cover type spanned an area of five million acres (Fins and others 2001). However, due to logging, white pine blister rust (caused by *Cronartium ribicola* J.C. Fisch. in Rabenh.), mountain pine beetle (*Dendroctonus ponderosae* Hopk.) attack, and the exclusion of fire, it now is a minor component throughout its range with only 5 to 10 percent of the original five million acres of white pine cover type in the inland northwest still carrying a significant component of white pine (Fins and others 2001). A comparison of surveys done in 1957 and the mid-1990s in southwest Oregon showed a drop from 60 to 40 percent in the number of plots with 5-needle pines, and a drop in pine cover of five percent in 10 years from the 1980s into the 1990s (Goheen 2000).

Many areas where western white pine dominated historically are now populated by stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.), grand fir (*Abies grandis* (Dougl.) Lindl.), and western hemlock (*Tsuga heterophylla* (Rafn.) Sarg.). Western white pine is more suitable for wetter, root disease-prone sites (Harrington and Wingfield, 1998) because it is less susceptible to laminated root rot (*Phellinus weirii*), Annosus root rot (*Heterobasium annosum*) (Hadfield and others 1986), and insect attacks than Douglas-fir and grand fir (Fins and others 2001). Western white pine is also more tolerant to drought than western hemlock (Fins and others 2001) and is among the most tolerant conifers to frost (Burns and Honkala 1990). Despite these adaptive advantages, western white pine has been largely ignored by managers in Oregon and Washington as a species to plant in burned and harvested areas because of white pine blister rust. Despite the availability of resistant stock, western white pine has not achieved its reforestation potential or been used in restoration plantings, even on lands where historically it was present.

White pine blister rust has caused widespread mortality, but even in areas of heavy infection, a low percentage of trees remained disease free (Bingham and others 1953). The presence of naturally resistant stock formed the basis for an operational breeding program to produce genetically resistant western white pine that began in the USDA Forest Service Region 6 (Oregon and Washington) in the late 1950s, and has been based at the Dorena Genetic Resource Center

(Dorena) since 1966 (Sniezko 1996, Sniezko and others these proceedings).

Screening for rust resistance with artificial inoculation has revealed several different resistant mechanisms in western white pine (Struckmeyer and Riker 1951, Hoff 1984, 1986, Hoff and McDonald 1971, 1980, McDonald and Hoff 1970, 1971, McDonald 1979; Kinloch and others 1999). Field plantings have also shown differences in rust infection among families (Sniezko and others 2000, Sniezko and others, this proceedings), and breeding programs have resulted in offspring with increased resistance to white pine blister rust. The ultimate goal of these breeding programs is to produce stocks for reforestation that will be able to survive despite the presence of white pine blister rust.

The site described in this paper was planted with the purpose of assessing growth as well as rust resistance for families from a range of geographic origins in Oregon and Washington (fig. 1). Little information is available on family variation in growth and survival of western white pine in southwestern Oregon. Most of the seedlots included in this field planting represent the part of southwestern Oregon in which the planting occurs. The additional seedlots from throughout Oregon and Washington will provide basic information on adaptability of the species.

This report has two objectives: to present our results regarding the magnitude and potential sources of genetic variation in growth, survival, and blister rust infection in a field planting, and to use these results to illustrate that despite high rust hazard in many localities, there are areas in which western white pine is a suitable choice for reforestation, especially where other species may be unsuccessful.

Materials and Methods

Study Site Description

A 10-acre site in southwestern Oregon that had been logged in the early 1980s was chosen for the evaluation planting. The site is located on the Butte Falls Ranger District on the Rogue River National Forest at an elevation of approximately 1230 m (4035 ft) (fig. 1). The site is located in a white fir (*Abies concolor* (Gord. & Glend.) Lindl.)/Shasta red fir (*Abies magnifica* A. Murr.) mixed conifer plant association with an ENE aspect and gentle slope (10 percent). The soil is a sandy clay grading from relatively deep on the south and east to very rocky on the north half of the unit. The surrounding overstory is composed of Douglas-fir, white fir, englemann spruce (*Picea englemannii* Parry), Shasta red fir, and western white pine. Understory regeneration includes golden chinquapin (*Chrysolepsis chrysophylla* (Dougl.) A. DC.), pacific yew (*Taxus brevifolia* Nutt.), white fir, Shasta red fir, Douglas-fir, englemann spruce, western white pine, and some ponderosa pine (*Pinus ponderosa* Laws), with *Ribes* (the alternate host of *C. ribicola* in N. America) present in the shrub population. Although the site had been cleared for several years, there was little grass or brush growing before the site was planted with white pine in 1991. The location of the site and the surrounding canopies of mature trees make the site susceptible to frost. This is illustrated by the nearly complete mortality of the original Douglas-fir evaluation

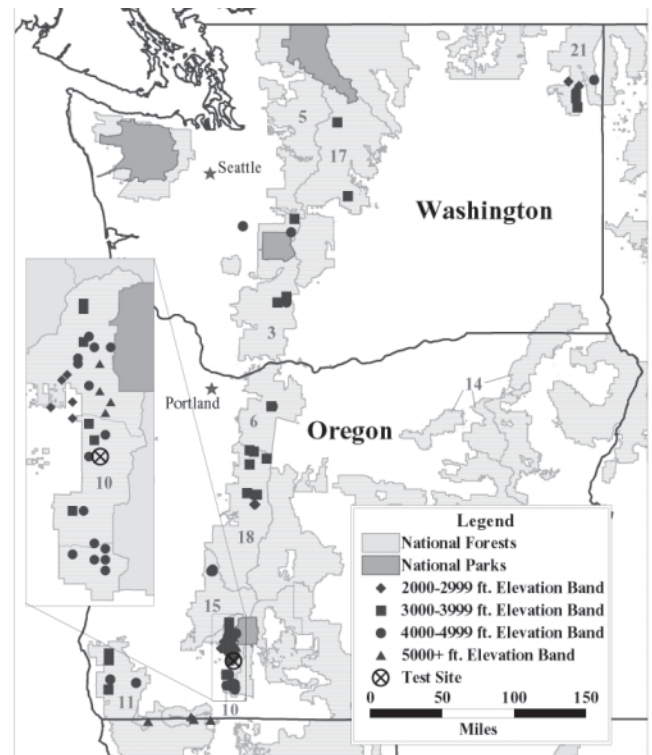


Figure 1—Map of parent test site and parent tree locations.

planting in the mid-1980s due to frost (Jim Hamlin pers. comm.). The local plant associations along with the environmental conditions made this site a good candidate for regeneration with western white pine.

Seed from 140 western white pine families were sown in containers at Dorena in spring of 1988. The population consisted of 42 wind-pollinated families from phenotypically rust-resistant trees selected in natural stands ("wild") from ten national forests (table 1), and 98 controlled cross families of clonal grafts growing in the Dorena orchards. All trees in the Dorena orchards had previously been screened for blister rust resistance at Dorena. Resistant individuals within families were then selected for inclusion in the orchards for future seed production of resistant stock. Selection was based entirely on the presence of one or more resistance mechanisms, without regard to growth. The 42 'wild' parents had also been selected as above average for rust resistance using artificial inoculation of progeny. Most seedlots (126) represented the southwestern portion of Oregon in which the planting site is located, but a small number (14) of seedlots representing a wider range of Oregon and Washington were also used. In all, 106 different female parents were used in at least one (but up to four) different crosses, and 66 male parents were used in usually one (but up to five) crosses. Forty-four trees were used as both male and female parents. Seedlings were transplanted from containers to 100 cm x 115 cm boxes with two families per box and 45-50 trees per family after the first growing season. They were grown outdoors for an additional two-and-one-

Table 1—Number of parent trees by source and elevation range (in meters).

Map # ^a	Source	Seed type	No. of females	Elevation mean	Elevation range
3	Gifford Pinchot NF	Orchard	1	1325	
5	Mt. Baker-Snoqualmie NF	Orchard	2	1250	1140-1355
6	Mt. Hood NF	Orchard	1	1200	
10	Rogue River NF	Orchard	23	1150	800-1463
		Wild	26	1450	900-1900
11	Siskiyou NF	Wild	6	1150	985-1290
14	Umatilla NF ^b	Wild	2		n/a
15	Umpqua NF	Orchard	34	1390	1310-1480
17	Wenatchee NF	Wild	2	990	930-1050
18	Willamette NF	Orchard	32	1075	645-1385
21	Colville NF	Wild	6	1060	800-1415
	Roseburg BLM	Orchard	3		n/a
	Eugene BLM	Orchard	2		n/a

^a Refers to national forest number as shown in figure 1.

^b Latitude and longitude data not available.

half years. In February of 1991 seedlings were lifted and stored near 0° C. until planting. Seedlings were planted in April and May of 1991 at 3 m x 3 m spacing in a randomized complete block design with seven replications (reps). Families were represented by four-tree or three-tree (when seedlings were limited) row plots. Weight per 100 seed (in grams) was available for 111 of 140 families.

The trees were assessed in 1993 for survival (S5), height growth (HT5) and percentage of trees with blister rust infection (RUST5) after two years in the field when trees were five years old from seed. A more comprehensive assessment was done in 1998 at age 10, with growth measurements including survival (S10), incidence of rust infection (RUST10) and tree height (HT10), and status/health measurements including the height, number, and type of blister rust cankers, canker activity (active or inactive), damage and severity of damage. To help remove differences in early height growth that may have been influenced by differences in seed weight, height increment from 1993 to 1998 was used to test for differences in growth. Only results on height increment from age 5 to age 10 (HTINCR), survival, and infection are presented here.

Statistical Analysis

The GLM, REG and CORR procedures of the SAS system were used for all statistical analyses (SAS Institute 1989). For height increment, individual tree data were used in an analysis of variance (ANOVA) to test for differences between reps and families for each seed type (orchard origin and wild stand origin) separately with the following model:

$$Y_{ijk} = \mu + R_i + F_j + RF_{ij} + e_{ijk}$$

Where μ is the overall mean, R_i is the effect of the i^{th} replication, F_j is the effect of the j^{th} family, RF_{ij} is the interaction of rep by family, and e_{ijk} is the error term. The rep and family effects were both tested using the rep-by-family interaction as the error term.

Plot means (using family rep means) were used in a separate ANOVA to test for differences in survival and rust infection using a similar model.

Due to the differences in distribution between orchard and wild families from different forests (see Figures 4 and 5, and Table 1), we could not test the significance of the differences in height growth, survival, and infection between seed types using data from all families. The Rogue River National Forest was the only seed origin location that included both orchard and wild seed types (table 1), so this subset of families was used to test for differences between the two seed types. For testing height increment, an additional ANOVA was performed using the following model:

$$Y_{ijk} = \mu + R_i + S_j + RS_{ij} + F(S)_{jk} + R(F(S))_{ijk} + e_{ijk}$$

Where μ is the overall mean, R_i is the effect of the i^{th} replication, S_j is the effect of the j^{th} seed type (orchard vs. wild stand origin), RS_{ij} is the interaction of rep by seed type, $F(S)_{jk}$ is the effect of the k^{th} family within the j^{th} seed type, $R(F(S))_{ijk}$ is the interaction of rep by family within seed type, and e_{ijk} is the error term, with appropriate error terms used as needed to test each effect. Seed type was tested with a composite error term as determined by SAS that was approximately $(RS_{ij} + F(S)_{jk} - R(F(S))_{ijk} - e_{ijk})$. For survival and infection percentage, the same model was used but without the rep x family within seed type interaction and the family within seed type term used as the error for testing the source main effect.

Pearson correlations were calculated using family means for five-year height increment (from 1993 to 1998) with seed weight, as well as between height increment, survival, infection percentages and seed weight with latitude, longitude, and elevation of both the female and male parent (when available). These correlations were used to examine the relationship of source location of the mother tree with seed weight, and the relationship of height growth with both mother tree location and seed weight for all orchard and wild seedlots. Infection and survival percentages were calculated on a family mean basis by rep, then averaged for each family. All trees killed by something other than blister rust were excluded when calculating infection percentage.

Families from the Colville and Wenatchee National Forests are from the eastern side of the Cascade Range, and the Colville families are also geographically disjunct from the

other families in this test which are on the western side of the Cascades (see fig. 1). Geographic and environmental differences of the source locations of these families may strongly influence the correlations of height growth with seed weight, latitude, longitude, and elevation. Therefore, these correlations were recalculated excluding these families.

To better understand the relationship between height and seed weight and parental location, regression was used twice; once for all families and once excluding the families from the Colville and Wenatchee National Forests. Variables with moderate correlations were included in stepwise simple regressions with an alpha = 0.05 level used for inclusion and retention in the model. PROC REG (SAS 1989) with height increment for both seed types as the independent variable and latitude, longitude, and elevation of the female parent, and seed weight as the independent variables was used in the regression analyses.

Results and Discussion

Overall Infection and Survival

Mean survival over all families in 1998 (S10) was 66.7 percent (a slight decrease from 72.1 percent in 1993) with a range in family means from 28.6 to 96.4 percent (fig. 2).

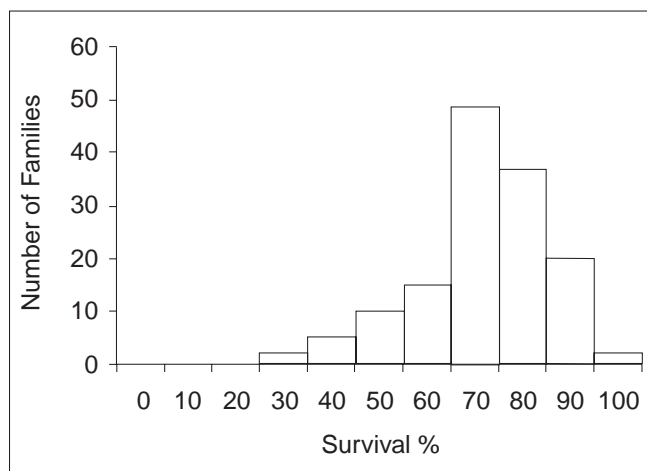


Figure 2—Distribution of survival percent in 1998 for 140 families.

Survival by seed type (orchard (S10o) and wild (S10w)) in 1998 was 69.5 and 60.2 percent, respectively, down from 1993 when it was 74.9 and 65.7 percent (table 2). Most of this early mortality appears to be due to gophers (Marc Ellis, pers. comm.) rather than blister rust. Survival at this site is within the range of western white pine survival reported elsewhere. (Parent 1998 and 1999, Bower 1987, Harrington and others 2003, Steinhoff 1981)

Significant differences ($p < 0.01$) were found between reps and families for orchard seed (S10o) and between families only for wild seed (S10w) for survival percentage. Rep mean survival percentage for orchard seed ranged from 61.7 to 73.5 percent with a general trend of the reps lower on the slope having lower survival than the higher reps. For wild seed, mean rep survival percentage ranged from 56.0 to 69.0 percent with a similar but weaker trend. The mean infection percentage for both orchard and wild seed was approximately 7.5 percent, with a range in family means from 0 to 31.25 percent. Significant differences in infection percentage were found only between reps for orchard seed. Neither reps nor families were significantly different for wild seed. Although reps were different for orchard seed, there was no clear pattern among reps that indicated that infection was higher or lower at a specific position on the slope. The lack of differentiation for infection is most likely due to the low level of infection present on this site.

Overall Height Growth

Mean height in 1993 (two years after planting and five years from seed) and in 1998 for both seed types is presented in table 2. When all families are included, overall mean height increment (HTINCR) was 87.2 cm, with a mean for the orchard families (HTINCRo) of 92.2 cm and a mean for the wild families (HTINCRw) of 75.7 cm. Height increment ranged from 72.6 cm in rep 1 to 106.9 cm in rep 7 for orchard seed and from 65.5 cm in rep 1 to 90.7 cm in rep 7 for wild seed. Height increment was significantly different ($p < 0.01$) for rep, family, and the rep x family interaction for both orchard and wild seed. Clear differences in height growth were visible between reps with height increment increasing from bottom to top of the slope. This would be expected due to the pooling of cold air lower on the slope. Tree heights at the time of planting are unavailable, so height increment

Table 2—Mean survival percent, height growth, and seed weight by seed type.

Variable	Orchard Seed		Wild Seed	
	n	mean	n	mean
Survival 1993	98	74.9% (1.12) ^b	42	65.7% (2.18) ^b
Survival 1998	98	69.5% (1.17)	42	60.2% (2.28)
Height 1993 (cm)	98	36.78 (0.53)	42	30.42 (0.86)
Height 1998 (cm)	98	128.93 (1.88)	42	106.65 (3.07)
Height Increment	98	92.2 (1.48)	42	75.73 (2.45)
Seed Weight ^a	70	2.376 (0.046)	41	2.13 (0.075)

^a Seed weight in grams, weights were not available for all seed lots.

^b Standard errors are in brackets

during the first two years in the field cannot be compared with height increment during the next five years. Although growth has been slow, site visits in summer of 2001 showed that growth had begun to accelerate, and many trees appeared to be at the age where rapid growth was commencing. Early height growth of western white pine is relatively slow compared with other white pine species until about age 10 to 15 when it begins to accelerate rapidly. This onset of rapid growth is usually later in natural stands than in plantations, but growth in both can continue at 30–90 cm per year for more than 100 years (Bingham and others 1972). The range among families in height increment was 50.27 to 138.25 cm which supports previously reported results showing considerable genetic variation in height growth of this species. Significant differences between family mean height have been reported in several studies for both controlled-cross and open-pollinated western white pines <15-years-old (Rehfeldt and Steinhoff 1970, Steinhoff 1979, Bower and Yeh 1988). These reports agree with earlier results that showed that although western white pine is highly variable, most of the variation is related to individual trees within a family or stand (Rehfeldt and Steinhoff 1970, Hanover and Barnes 1969). The range in height growth that was observed on this site indicates a good potential for selection opportunities in the future for growth, in addition to the rust resistance for which these families were originally selected.

Orchard vs. Wild Seed Source Type Comparison

Height Growth and Survival—Using only the subset of families from the Rogue River National Forest, significant differences were detected between orchard and wild seed for both height increment ($p = 0.0002$) and survival percentage ($p = 0.0017$). The orchard seedlots had greater height increment (93.0 vs. 71.6 cm) and higher survival (73.8 vs. 61.4 percent) than the wild seedlots. The differences between orchard and wild seedlots could be the result of a number of factors, including differences in the geographic ranges (even

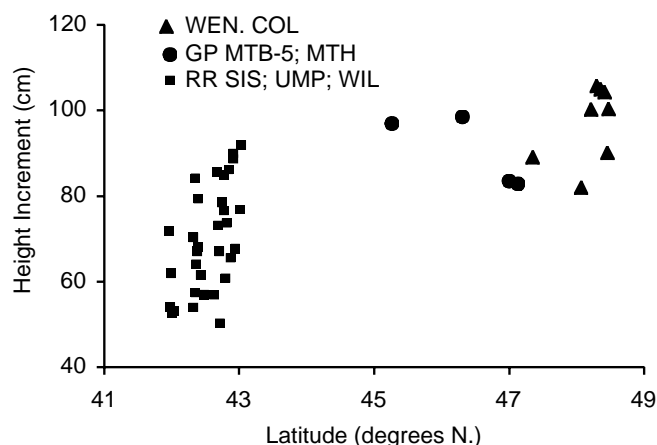


Figure 3—Scatterplot of latitude vs. family mean height increment by forest* for 44 families from wild seed.

*see table 1 for abbreviations

within the Rogue River N.F.) of the parents of these families (see Figures 4 and 5). Sites in southwestern Oregon are very diverse, covering a wide range of elevations, rainfall, and soil types, all of which most likely differ from the more stable environmental conditions experienced by the families from the orchard. In addition, orchard seed are generally harvested at the point of optimum ripeness before the cone scales begin to flare. Cones collected from wild stands may have been harvested at a point when they were accessible and available but may not have achieved the same ripeness. Potential differences in seed maturity may also contribute to the differences between orchard and wild seed (Jerry Berdeen, pers. comm.)

Infection—Using the same subset of families from the Rogue River National Forest, differences between seed types in infection percentage approached significance ($p = 0.0854$) with the wild seed having a higher level of infection than the orchard seed (15.9 vs. 9.3 percent). The seedlots from the orchard would be expected to show higher rust resistance since both the male and female contribution to the seed would be from resistant parents.

Seed Source Location Effects

Height growth—Previous reports of ecotypic variation in western white pine have been inconsistent. Squillace and Bingham (1958) reported that progeny from high elevation parents were shorter at four years than progeny from lower elevation parents within the same watershed when grown together at a low elevation site, but they were taller when grown on a high elevation site. Evidence of local differentiation at this small scale has not been substantiated by other research (Rehfeldt 1979); however, differentiation has been found on a larger scale. Steinhoff (1979) found that seedlings from higher elevation parents grew slower than seedlings from lower elevation parents at low- and mid-elevation sites, but he did not find them to be taller at high elevation sites. Townsend and others (1972) found no evidence of racial differentiation in monoterpenes, photosynthesis, or growth for 4-year-old seedlings, despite marked differences in elevation and geographic separation of certain sources.

In contrast, other studies have shown patterns of differentiation among western white pine populations. Results from these studies indicate that differences in height growth, isozymes, and cold hardiness have separated the western white pine range into a relatively small southern population (restricted to the Sierra Nevada mountains in California) and a broad northern population (covering the northern part of the species distribution, including the Washington Cascades), with a transition zone in the Southern Cascades and Warner Mountains in Oregon, but with no differentiation related to the elevation of the seed source (Steinhoff and others 1983, Rehfeldt and others 1984, and Meagher and Hunt 1998). The northern populations are characterized by relatively high growth potential and low cold hardiness, while the southern populations have lower growth potential and higher hardiness, with the transition zone population from southern Oregon (Cascades and Warner Mountains) arranged along a steep latitudinal gradient linking the two populations. In a western white pine provenance test in western Washington, the more southerly high elevation

Table 3—Correlation of height growth with seed weight for 111 families.

	Seed Weight			
	Overall	Orchard Seed (n = 70)	Wild Seed (n = 41)	Wild Seed* (n = 33)
Height 1993	-0.07	-0.13	-0.37 ^b	-0.14
Height 1998	-0.17 ^a	-0.26 ^b	-0.53 ^c	-0.34 ^a
Height Increment	-0.19 ^b	-0.28 ^b	-0.51 ^c	-0.33 ^a

* Correlation excluding Colville and Wenatchee families

^a significant at 10% level^b significant at 5% level^c significant at 1% level

sources were dramatically shorter than both northern and inland sources (Richard Sniezko, pers. comm.). Rehfeldt and others (1984) reported that an apparent relationship between seedling height and elevation for populations from this transition zone is derived from the strong correlation of latitude and elevation. Campbell and Sugano (1989) found similar trends across populations, as well as for families from within the transition zone, which they attributed to steep precipitation gradients. They also found, as others have, that most of the variation in western white pine is among individuals within a population, with only small

amounts occurring between populations. Similarly, when our data is separated by seed type and forest of origin, for the four groups with more than six female parents represented (table 1), we found that families were significantly different in all cases.

Our correlations of growth with latitude and elevation reflect a similar relationship across populations, especially for the wild seed (table 4), even when the more northerly and easterly populations are excluded (table 5), (so that the remaining families fall within the “transition zone” described above). A plot of seed source elevation vs. latitude

Table 4—Family mean correlations of survival, growth and seed weight with location, by parent and seed source type for 133 Families*.

	Orchard Seed (n=93*)			Wild Seed (n=40*)		
	Lat.	Long.	Elev.	Lat.	Long.	Elev.
Survival % – F**	-0.06	0.06	-0.06	0.29	0.40 ^b	0.07
Height Incr. – F	0.08	0.22 ^a	-0.11	0.71 ^b	0.76 ^b	-0.41
Height Incr. – M**	0.13	0.23 ^a	-0.06	N/a	n/a	n/a
1993 Height – F	0.23 ^a	0.40 ^b	-0.14	0.62 ^b	0.64 ^b	-0.48 ^b
1993 Height – M	0.27 ^b	0.36 ^b	-0.10	N/a	n/a	n/a
1998 Height – F	0.13	0.28 ^b	-0.12	0.75 ^b	0.79 ^b	-0.46 ^b
1998 Height – M	0.18	0.28 ^b	-0.07	N/a	n/a	n/a
Seed Weight – F	-0.18	-0.24	-0.12	-0.53 ^b	-0.49 ^b	0.26
Seed Weight – M	-0.11	-0.15	-0.14	N/a	n/a	n/a

* Latitude, longitude, elevation, and seed weight not available for all seedlots

** F = correlation with female location, M = correlation with male location

^a significant at 5% level^b significant at 1% level**Table 5**—Family mean correlations of survival, infection, growth and seed weight with maternal location for wild seed, excluding Wenatchee NF and Colville NF.

	Wild Seed		
	Lat.	Long.	Elev.
Survival %	0.25	0.55 ^b	0.28
Infection %	-0.08	0.13	0.07
Height Increment	0.25	0.40 ^a	-0.19
Seed Weight	-0.06	0.01	0.01

^a significant at 5% level^b significant at 1% level

(fig. 4) shows a significant negative relationship for wild seed ($r = -0.49$, $p < 0.01$) indicating that the northern sources in this study are generally from lower elevations than southern sources. With the Colville and Wenatchee National Forest sources excluded, the relationship is weaker and still nearly statistically significant ($r = -0.35$, $p = 0.051$). The plot also shows that when the more northerly sources are excluded, the remaining families come from a range of latitudes that is much more limited than the orchard seed, and these two groups should not be viewed as paired samples since they represent different parts of the ranges with only partial overlap.

An examination of a plot of the origin of the seedlots (fig. 5) shows that orchard and wild parents cover different ranges in geographic location. There are strong relationships between latitude and longitude for both orchard families ($r = 0.79$, $p < 0.01$) and wild families ($r = 0.92$, $p < 0.01$). When the northerly families are excluded, the correlation for

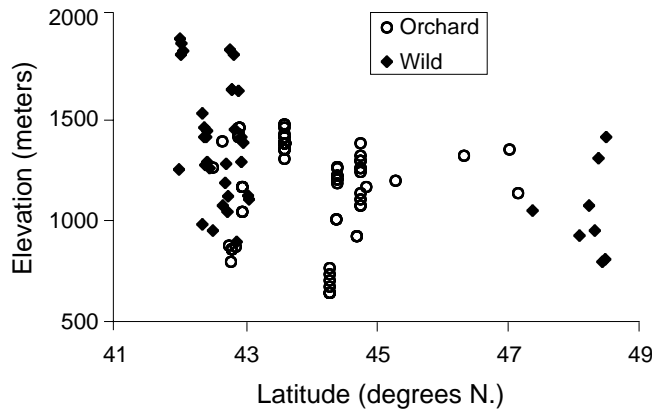


Figure 4—Latitude vs. elevation of female parents by seed type.

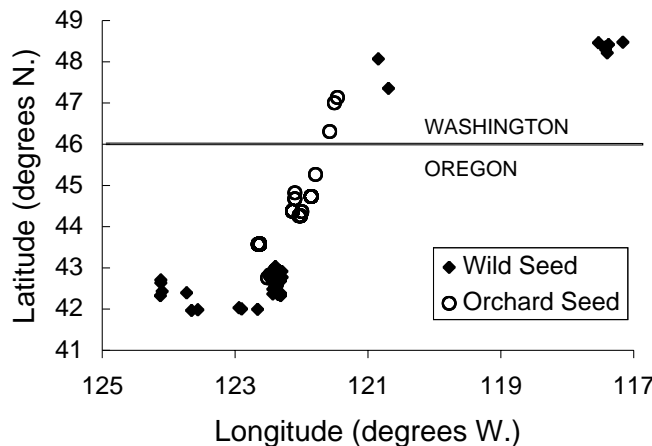


Figure 5—Latitude vs. longitude of female parents of orchard and wild seed families.

the wild families drops dramatically ($r = 0.39$), although it is still significant ($p = 0.02$). It is likely that the significant correlations between growth traits and longitude and elevation actually can be explained by differences associated with latitude, and our results suggest that height growth may be associated with latitude, at least within families from the Cascade Range in Oregon and Washington.

Seed Weight Effects—Previous studies have reported that total height for western white pine in the first several years of seedling growth is positively correlated with seed weight (Squillace and Bingham 1958, Squillace and others 1967). Squillace and Bingham (1958) found that seed weight had a variable effect on parent-progeny growth correlations. In our study, HT10o and HTINCRo both had significant but low negative correlations with seed weight ($r = -0.26$ and -0.28 ; $p = 0.033$ and 0.020 , respectively, Table 3). The correlation for HT5o was also negative, but weaker and non-significant ($r = -0.13$; $p = 0.273$). All three height growth variables for the wild seed had significant negative correlations with seed weight with moderate r-values (r-values ranged from -0.37 to -0.53).

However, using all families for each seed type, seed weight was also negatively correlated with latitude and longitude of the female parent, significantly so for the wild seed. In a stepwise regression of family mean height increment on seed weight, latitude, longitude, and elevation of the female parent for orchard seed, only seed weight was significant in the model ($p = 0.023$), while for the wild seed, only longitude was significant ($p < 0.01$) in the model. Latitude and longitude of the wild seed are highly correlated ($r = 0.922$), and the Colville families are more disjunct in longitude than latitude compared to the other wild families (see Forest 21 on fig. 1). When the regression was redone excluding the families from the Wenatchee and Colville National Forests, only latitude was significant in the model ($p < 0.01$). Although seed weight is correlated with height growth, the correlation is probably a function of maternal origin which is reflected by latitude of the mother tree. Heavier (larger) seed would be expected to produce larger seedlings, therefore the correlations of seed weight and height increment should be positive, as has been reported previously (Squillace and Bingham 1958, Squillace and others 1967). However, the correlation we observed was negative. This would indicate that wild seed from higher latitudes is smaller but the seedlings grow faster. Therefore, we feel that it is likely that the difference in height growth between orchard families and wild families is not due to differences in seed weight, but due to genetic effects associated with the source of origin of the parents.

Conclusions

Despite its desirable growth and adaptive advantages, white pine is underutilized for reforestation or restoration in Oregon and Washington due to potential losses from white pine blister rust and the limited availability of resistant seedlings. Our results from a young (10-year-old) western white pine plantation on a site with low rust-hazard (but high frost-hazard) show moderate to high survival among families, with significant differences between families, and low rust infection through age 10. Even though rust infection levels were low, orchard seedlots showed lower infection

than wind-pollinated wild seedlots from resistant parents, as expected. Although growth has initially been slow, observations in summer 2001 by the authors indicate that many trees appear to be entering the rapid phase of growth typical of western white pine. We found strong family differences in height growth that appear to be associated with seed weight and latitude of the parent trees, and also found differences between progeny from orchard and wild trees from similar geographic origins. Families from parents originating from the more northerly latitudes show higher average growth potential than families from more southerly latitudes, although the best families from southerly latitudes are comparable. These findings correspond with other results in the literature, which distinguish three zones for western white pine: (1) A broad zone north from northern Oregon; (2) A southern zone in California; (3) A distinct transition zone in the southern Oregon cascades. Current plans are to follow this planting over time to see if the growth differences that are apparent among sources from different latitudes will remain and/or increase as the trees age during the period of rapid growth, and to see if sources originating furthest from the planting site remain vigorous. In addition, the early results on this site show that with careful selection of appropriate sites and utilization of resistant planting stock, western white pine can be a viable choice for use in reforestation or restoration.

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