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Survival and Growth of Douglas-fir Seed Sources in the Hospital Tract Rangewide Source Archive Plantation

by

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Forest Research Laboratory
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Summary

In 1954, Dr. Helge Irgens-Moller initiated a rangewide collection of seed and seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Nearly 700 trees or stands were sampled in 10 western states, Canada, and Mexico. From 1957 to 1971, 639 of these collections were planted in the Hospital Tract Rangewide Source Archive near Corvallis, Oregon. By 1989, the trees were from 20 to 34 years old; it became apparent that thinning the archive would be necessary in order to preserve the slower growing sources. This prompted growth and survival measurements and a complete inventory of the archive. Overall survival for all years of planting was greater than 80 percent for coastal sources (var. *menziesii*), but less than 60 percent for interior sources (var. *glauca*). The average diameter at breast height (DBH) of surviving trees was 29.05 cm; the range was from 1.2 to 61 cm. An analysis of the 1957 and 1961 plantings revealed that local and other low elevation coastal sources had the fastest growth and highest survival in the archive. High elevation sources from the Cascade Range had significantly smaller DBH, but higher survival. Southern interior sources from Arizona and New Mexico had the smallest DBH and lowest survival; northern interior sources from Montana and Idaho were intermediate in survival and DBH. Geographical variation among sources in the Hospital Tract was associated with environmental gradients, supporting the previously held conclusion that much of the genetic variation on a geographical scale in Douglas-fir is the result of adaptation.

Introduction

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) is one of the most widely distributed and economically important conifers of western North America. Its natural range is from Mexico to Canada and from the Pacific Ocean to the eastern slope of the Rocky Mountains. This vast range encompasses many different environmental and climatic conditions. Within it, 2 distinct varieties of Douglas-fir are recognized: *menziesii*, the coastal variety, and *glauca*, the interior variety (Hitchcock and Cronquist 1973, Ching and Hermann 1977).

The coastal variety is found along the Pacific coast from British Columbia to northern California, and inland to the Cascade Range. The area east of the Cascade crest and inland to the next range of mountains is considered a transition zone between the 2 Douglas-fir varieties (Sorensen 1979, Li and Adams 1989). In the Pacific Northwest, the coastal variety grows rapidly, producing some of the highest quality and most valued softwoods in the world. This variety has also been successfully grown as an exotic in many European countries and New Zealand. The interior variety occurs from the eastern slopes of the Cascade Range and Sierra Nevada to the Rocky Mountains; it plays an important ecologic and economic role throughout its range.

The old-growth Douglas-fir forests of the Pacific Northwest are presently the center of an ecological, economic, and ethical debate over the importance of Douglas-fir in forest ecosystems, as well as in timber-dependent economies (Franklin *et al*. 1981, Franklin and Spies 1984, Spies and Franklin 1988, Heilman 1990, Rubin *et al*. 1991). The ecological and economic importance of Douglas-fir has led to much research on patterns of genetic variation in this species (Munger and Morris 1936, Irgens-Moller 1958, 1962, 1967, Ching and Bever 1960, Wright *et al*. 1971, Rowe and Ching 1973, Griffin and Ching 1977, Ching and Hinz 1978, Rehfeldt 1978, Silen 1978, Sorensen 1979, Silen and Mandel 1983, White and Ching 1985, Campbell 1986, Merkle and Adams 1987, Strauss and Tsai 1988, Li and Adams 1989).

One of the primary methods for observing and describing geographic patterns of genetic variation in a species is provenance or common garden tests. In these tests, seed sources representing all or a portion of the geographic distribution of a species are planted in common environments.

Among the early investigators of genetic variation in Douglas-fir was Dr. Helge Irgens-Moller, Professor of Forestry at Oregon State University. From 1954 to 1965, Dr. Irgens-Moller collected Douglas-fir from throughout most of its natural range. He sampled nearly 700 individual parent trees or stands. His collections included open-pollinated seed and occasional live seedlings from 10 western states and parts of Canada and Mexico (Figure 1). The Pacific Northwest, the Southwest, and the Rocky Mountain regions were well sampled; however, no collections were made from the Sierra Nevada or from Nevada.

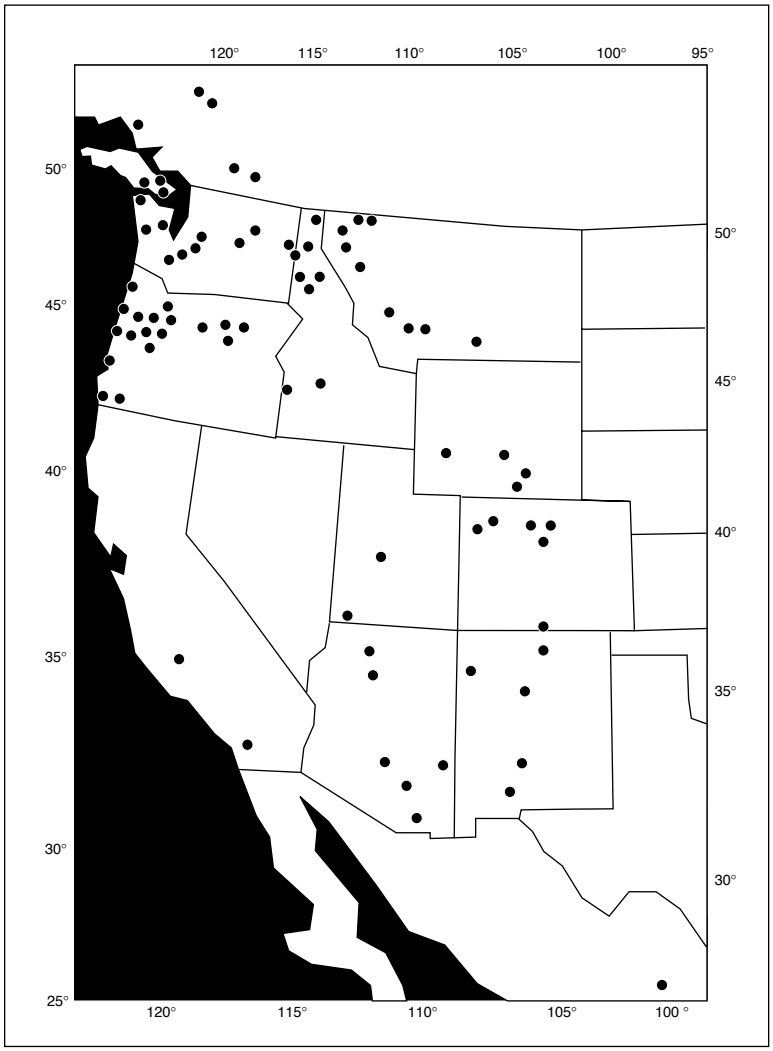

Figure 1. Location of Douglas-fir collections made by Dr. Helge Irgens-Moller and his associates from 1954 through 1965.

Today, the primary legacy of his effort is a Douglas-fir rangewide source archive plantation known as the "Hospital Tract." The Hospital Tract is located 10 miles north of Corvallis, Oregon, along State Highway 99, within the Oregon State University College of Forestry Research Forest. The Hospital Tract archive represents one of the most complete rangewide collections and earliest genetic plantings of Douglas-fir. Irgens-Moller's objective for the plantation was to establish a "Douglas-fir archive" as a source of easily accessible genetic material for genetics research and for making controlled crosses between different Douglas-fir sources (W.K. Ferrell, Professor Emeritus, Oregon State University, personal communication). The longevity of the archive and the diversity of seed sources represented make it valuable for both research and teaching.

After its establishment in 1957, few cultural activities occurred in the archive. By 1989, when the trees were from 20 to 34

years old, it became apparent that, in order to preserve the slower growing seed sources, the plantation would need to be thinned. This prompted measurements of all the trees and documentation of the surviving sources and revealed the need to fully investigate the history, present condition, and future value of the archive. This paper is the result of that investigation; its objectives are to describe the original field layout and content, past uses, and present condition of the archive, and to summarize the genetic patterns of variation in growth and survival of the seed sources 33 years after establishment.

Original Field Layout and Content

Between 1956 and 1969, the open-pollinated seeds collected from the individual parent trees or stands were sown at the Oregon State Nursery, which was then located only a short distance from the Hospital Tract. After 1-2 years in the nursery, bareroot seedlings from 639 parent trees or stands were planted in the archive at 12 x 12 ft spacing (Appendix, Table 1). Not all of the original collections were planted because of poor germination or mortality in the nursery. In addition to the original open-pollinated seed and seedling collections, seeds from 20 controlled, 2-parent crosses made during the spring of 1956 between parent trees located in and around the Willamette Valley and from 68 controlled crosses made in 1966 between trees growing in the archive were included in later plantings.[1]

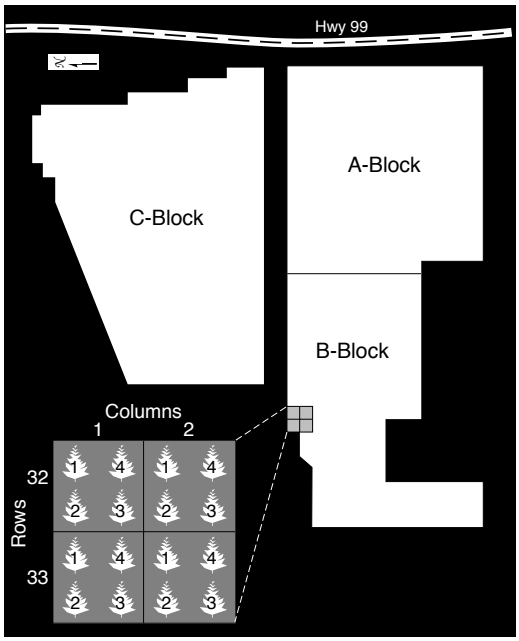

Figure 2. Grid layout and planting design of the Hospital Tract Douglas-fir rangewide source archive plantation.

The archive consisted of 3 blocks of 4-tree square plots arranged in a grid, with columns running north to south and rows east to west (Figure 2). Each 4-tree square plot originally consisted of seedlings from the same family; each family was replicated twice in plots randomly allocated in the same block.[2] Because of considerable mortality in the early years, some of the original planting positions were replanted with individuals from different families. Two of the 3 blocks (A and B) contain plantings from all years (1957-1971) and from both coastal and interior sources (Figure 2). The third block (C) contains only later plantings (1961-1971), primarily from interior sources and the 1966 controlled crosses. The blocks are not replicates, but only represent sets of families planted at different times. The result is essentially a complete spatial and temporal randomization of families, with no plot or block structure.

[1]Information on all trees planted, including parent tree source (geographic location, latitude, longitude, elevation), family number, location in the plantation, year of planting, DBH of surviving trees, and current status, can be accessed through the Forest Science Data Bank at the Department of Forest Science, Oregon State University, Corvallis, Oregon.

[2]A family refers to seedlings from seed collected from an individual parent tree.

Past Uses of the Archive

From 1954 to 1966, Irgens-Moller performed nursery experiments with seed from his collections to examine variation in growth of Douglas-fir seedlings from different geographical sources. In particular, he was interested in looking at the degree to which patterns of variation among sources reflected adaptations to the temperature and photo-period conditions of the sources' native environments (Irgens-Moller 1957, 1958, 1962). In 1965, weekly measurements of leader growth were made in the archive on 5 sources originating from an east-to-west transect across western Oregon, and on a number of interior sources from Montana, Colorado, Utah, Arizona, and New Mexico. These measurements of leader growth, along with the nursery experiments, were used to describe genetic variation in growth patterns among geographical sources of Douglas-fir (Irgens-Moller 1967, 1968).

In 1956 and 1966, Irgens-Moller made controlled crosses. The 1956 crosses included native trees from Corvallis, Lebanon, Sweet Home, Foster, and Newport, Oregon. The 1966 controlled crosses were made among trees in the archive from western Oregon, Washington, and Vancouver Island, B.C., as well as among progeny from the 1956 crosses, resulting in second-generation offspring. There are no clear indications of a breeding strategy, and Irgens-Moller's records are sketchy, making it unclear what his intentions were for the progeny of these crosses.

In 1964 and 1970, individual tree heights of many of the families were measured, but apparently were not utilized in research publications. Other measurements in the archive include survival, recorded in 1983 and 1989, and diameter at breast height (DBH, diameter at height of 1.37 m), recorded for all trees during the fall and winter after the 1989 growing season.

More recently, the plantation has been a source of materials for genetic studies of Douglas-fir with biochemical and molecular markers. Li and Adams (Department of Forest Science, Oregon State University) used collections from the archive for a preliminary analysis of allozyme variation. Results of this analysis led to a more complete collection and study of range-wide patterns of allozyme variation in Douglas-fir (Li and Adams 1989). Strauss and Tsai (1988) utilized 54 trees from the archive for their study of ribosomal gene number variability in Douglas-fir. Most recently, Ali, Neale, and Marshall (Institute of Forest Genetics, PSW Forest and Range Experiment Station, USDA Forest Service, Berkeley, CA) used needle collections from the archive to investigate chloroplast DNA restriction-fragment-length polymorphism in this species (Ali *et al*. 1991).

Present Condition of the Archive

Survival in the archive before thinning varied widely among geographic locations, from a low of 14 percent for families from Utah and Arizona, to around 90 percent for families from Oregon, Washington, and British Columbia (Figure 3). Trees from Mexico had higher survival than might be expected, but only 13 individuals from this source were originally planted. Survival also varied widely among families within geographic locations; in many cases, individual families experienced complete mortality in the archive (Appendix, Table 2). Of the 245 families with complete mortality due only to natural causes, 227 were interior variety families. The average DBH of remaining trees in 1989 was 29.05 cm, with a range from 1.2 cm (2 trees from Arizona and Colorado) to 61 cm (a western Oregon tree)(Appendix, Table 2).

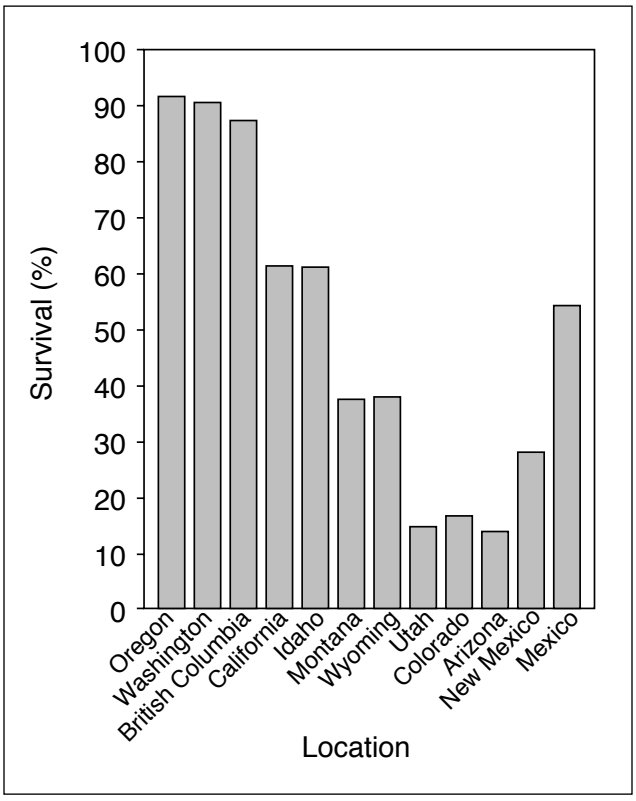

Figure 3. Average survival in 1990 by source state, country, or province for all trees in the Hospital Tract Archive.

The plantation was thinned in 1990 to reduce competition stress among trees. During the thinning operations a tree was accidentally felled into a powerline, starting a fire that killed 57 trees from 39 families. Unfortunately, all representatives from 6 families (all Oregon sources) were lost in this fire.

As of 1991, after all losses (from natural mortality, fire, and thinning), the archive contained 446 families from 10 western U.S. states, Mexico, and Canada, including 62 families from the controlled crosses made in 1956 and 1966 (Appendix, Table 1).

Recently, an interpretive trail was constructed through the plantation as part of a larger trail network. This trail affords visitors the opportunity to view a number of different sources of Douglas-fir from throughout its native range and to observe the effects of planting off-site seed sources.

Future management of the plantation should aim at maintaining as many of the different sources as possible. Annual surveys should be made to monitor for pests and to determine the need for thinnings. Thinnings should strive to maintain as many different sources (especially interior variety sources) as possible while creating spacing sufficient to minimize competition stress. Survival and DBH measurements should be made every 10 years to document changes in the plantation.

Patterns of Genetic Variation

The lack of replication and statistical design in the archive prevents detailed statistical analyses. Nevertheless, the presence of such a wide range of sources in one location and the longevity of the trees in the archive provide a rare opportunity to assess geographic patterns of genetic variation in an older plantation of Douglas-fir.

Materials and Methods

The data for the analysis were compiled from Irgens-Moller's original field notebooks and maps of the plantation, along with his observations in the archive. Geographic variables of source locations (latitude, longitude, distance from the Willamette River, elevation) were assembled from Irgens-Moller's collection records, and from maps when records were missing or incomplete. Survival and DBH at the end of the 1989 growing season were investigated for sources planted in 1957 and 1961. Only trees planted in 1957 and 1961 were used in the analyses, because only those 2 years provided a large enough sample of families to make analysis of geographic variation worthwhile.

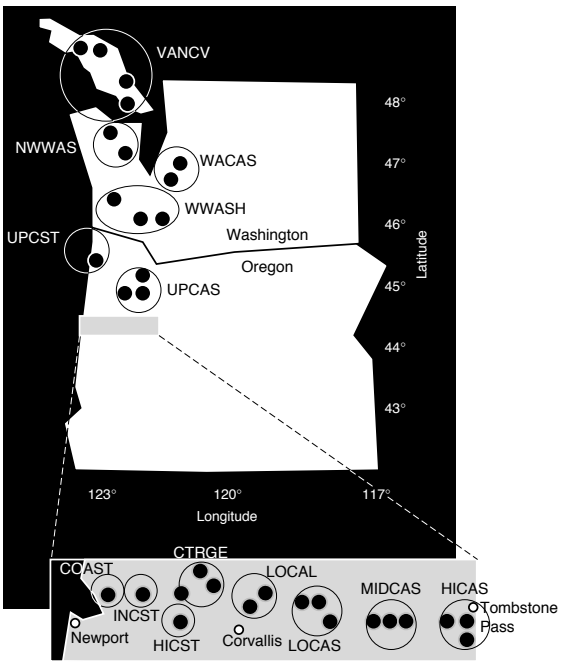

Figure 4. Locations of 14 seed sources planted in 1957 and analyzed in 1990, including 8 sources from a western Oregon transect (shown in enlarged box). Each source is circled and named in capital letters (see descriptions of sources in Appendix, Table 3). Dots represent locations of stands with one or more parent trees from which families were derived. Place names are in lower case.

The survival analyses utilized 526 trees from 90 families planted in 1957, and 400 trees from 126 families planted in 1961. Survival was analyzed by simply comparing the average family survival among sources. No analysis of variance was performed on survival because, in many cases, a family was represented by only one or a few trees.

Since trees that died were often replaced several years after the original planting, DBH analyses include only surviving trees from plots originally planted in the year of interest (i.e., 1957 or 1961). Analysis of trees planted in 1957 included 430 individuals of 77 coastal variety families from western Oregon, Washington, and Vancouver Island, B.C. (Figure 4, Appendix, Table 3). The 77 families were grouped into 14 sources based on the geographic proximity and similarity of elevation of their origin. Each source was represented by 3 or more families from 1 to 4 localities within 50 km of each other and differing by no more than 215 m in elevation (except for the UPCAS source, which had a 366-m elevational range between parent trees). The average elevation of the sources ranged from 30 to 1159 m.

For the 1961 planting, DBH analysis included 302 trees from 113 families of both Douglas-fir varieties (Figure 5, Appendix, Table 4). The 113 families were assigned to 8 sources. Each source was represented by 3 or more families from 1 to 10 localities within 500 km of each other and differing by no more than 870

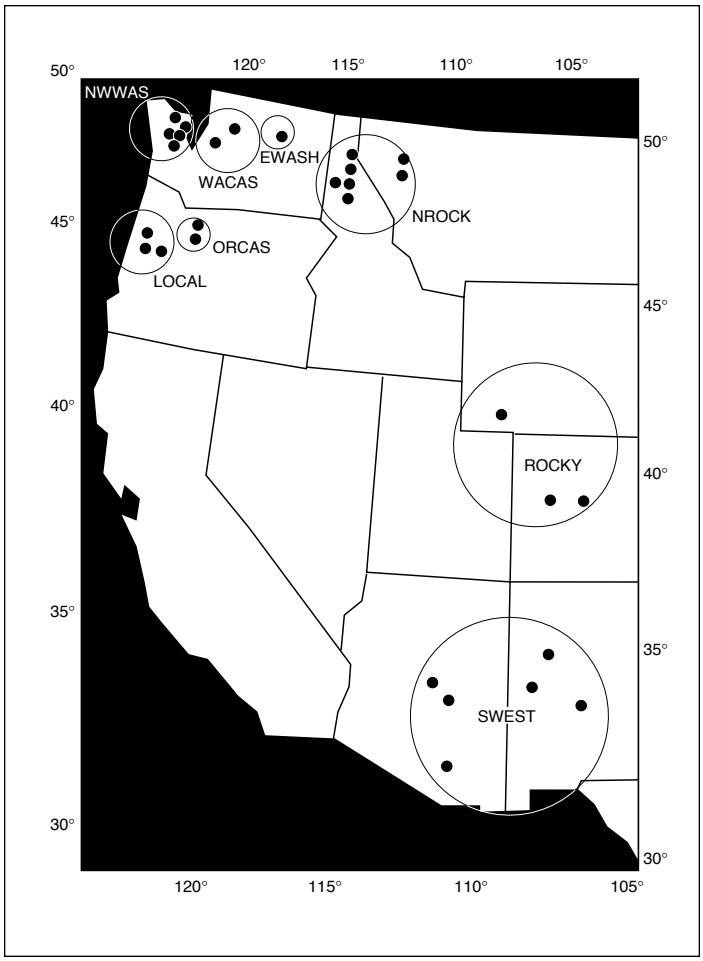

Figure 5. Locations of 8 seed sources planted in 1961 and analyzed in 1990. Each source is circled and named in capital letters (see descriptions of sources in Appendix, Table 4). Dots represent locations of stands, with one or more parent trees, from which families were derived.

m in elevation. The average elevation of sources ranged from 110 to 2688 m.

Measurements of DBH for trees in the 2 plantings were analyzed separately with a nested analysis of variance (ANOVA) procedure. The nested ANOVA was used to partition family variation into source and within-source components and to test their significance. In the 1957 planting, there were 2 levels of nesting (sources and families within sources); in 1961 there were 3 levels of nesting (varieties [coastal vs. interior], sources within varieties, and families within sources). Fisher's protected least significant difference multiple range test (Fisher 1966) was used to group sources according to mean DBH. For all analyses, differences at a probability level of 0.05 were considered significant.

Fifty-four families planted in 1957 came from a relatively narrow, coast-inland transect in western Oregon (Figure 4, bottom enlarged box). For these families, it was possible to investigate in more detail the relationship between DBH and geographic origin. Based on the comparison of scatter plots of mean family DBH to individual geographic variables, we tested the following independent terms in a model with a forward stepwise multiple regression procedure: elevation, elevation^2, distance from the ocean, (distance from ocean)^2, distance from the Willamette River, and the interaction term, distance from ocean*elevation. Significance level for retaining independent variables was 0.05.

For all analyses, the need for transformations and the assumptions of uniform error variance and normal distribution of residuals were assessed by examining residual plots and normal probability plots (Devore and Peck 1986, Stafford and Sabin 1990).

Results

Families Planted in 1957

Mean survival of individuals within families ranged from 80 to 100 percent among sources planted in 1957; the 2 sources from the highest elevations (UPCAS and HICAS) and a source from the coastal mountains (INCST) had 100 percent survival (Table 1). DBH differed significantly among sources and among families within sources (Appendix, Table 5). Average DBH of sources ranged from 29.0 to 36.1 cm (Table 1); 2 sources from near the Hospital Tract (LOCAL and LOCAS) and sources from northwest Washington (NWWAS) produced the largest trees. Fisher's multiple

Table 1. Summary statistics and multiple range test rankings for mean diameter at breast height (DBH) of sources planted in 1957.

Source	Number of trees	Survival (%)	Diameter at breast height (cm)	Fisher Range Test[1]
LOCAS	21	92.9	36.1	A
NWWAS	24	82.4	35.5	B A
LOCAL	73	96.5	35.1	B A C
WACAS	21	96.0	34.8	B D A C
UPCST	11	80.3	34.0	B D A C
VANCV	24	85.7	32.7	B D A C
CTRGE	40	96.4	32.8	B D A C
INCST	26	100.0	32.7	B D A C
MIDCA	14	92.9	32.4	B D E C
COAST	21	95.9	32.1	B D E C
HICST	46	95.5	31.8	D E C
WWASH	19	89.5	31.7	D E C
UPCAS	28	100.0	31.3	D E
HICAS	62	100.0	29.0	E
Total	430			

[1]The columns of letters represent groups of sources whose mean DBH differences are not statistically significant at the 0.05 probability level. See Figure 4 for locations of sources.

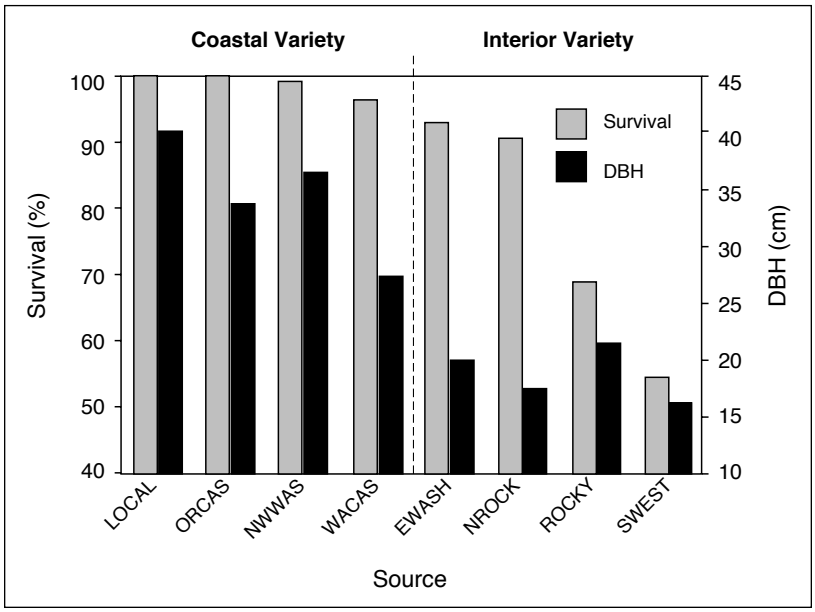

Figure 6. Average survival and diameter at breast height (DBH) as of 1990 for sources planted in 1961 in the Hospital Tract. See Figure 5 for location of sources.

comparison procedure revealed that the mean DBH of the UPCAS and HICAS sources were significantly smaller than those of the LOCAL, LOCAS, and NWWAS sources.

The forward stepwise regression analysis resulted in the two-variable model:

$$DBH = 37.037 - 0.003_{*}Elevation(m) - 0.07_{*}Distance\ from\ Willamette\ River\ (km)$$

$$r^2 = 0.36$$

The model and both independent variables are significant ($P < 0.01$), with elevation accounting for 27 percent of the variation, and distance from the Willamette River accounting for an additional 9 percent. The model predicts a 0.3-cm decrease in mean DBH for every 100-m gain in elevation, and a 0.07-cm decrease in mean DBH for each km of distance from the river.

Families Planted in 1961

With the exception of the SWEST and ROCKY source (54 and 67 percent), mean survival of families was generally high (>80 percent) for sources planted in 1961; both the LOCAL and ORCAS sources had 100 percent survival (Figure 6). Survival ranged from 10 to 100 percent for families from the 4 interior variety sources (EWASH, NROCK, ROCKY, SWEST) and from 60 to 100 percent among families from the 4 coastal sources (NWWAS, LOCAL, ORCAS, WACAS).

DBH of trees from the 8 sources differed significantly among varieties, among sources within varieties, and among families within sources (Appendix, Table 6). Coastal sources generally had greater DBH than interior sources, and the LOCAL source had the largest mean DBH (Figure 6). Mean DBH of the coastal variety sources was 34.4 cm (range among sources 27.5-40.1 cm) and of the interior sources, 18.1 cm (range 16.0-21.4 cm). DBH of the ROCKY source seems high relative to the other interior variety sources. This may be due to a small sample size, since the ROCKY source is represented by only 3 families and a total of 7 trees, or to misidentification of the trees in the plantation.

Discussion

It is not surprising that growth and survival in the archive were better for sources from the coastal, rather than interior, variety of Douglas-fir. As indicated by their high survival, coastal variety sources are presumably better adapted to the growing conditions in the archive (Appendix, Table 2, Figures 3 and 6). An example of poor adaptation of interior sources was their higher susceptibility to needle cast; interior sources were severely infected with rhabdocline (*Rhabdocline pseudotsugae*) and Swiss needle cast (*Phaeocryptopus gaumanni*) during establishment, whereas coastal sources were only nominally infected (W.K. Ferrell, Professor Emeritus, Oregon State University, personal communication). Presumably, the interior sources are more susceptible to needle cast infections when planted in coastal environments because their earlier flushing is associated with favorable environmental conditions for infection (Haddock *et al*. 1967). In 1965, for example, 80 percent of the interior sources planted in the archive had initiated growth by April 6, while only 5 percent of the coastal sources had shown signs of bud elongation (Irgens-Moller 1967). Thus, in addition to higher susceptibility to needle cast, the interior sources suffered higher mortality because their growth phenology was out of phase with the climate in western Oregon.

The differences in DBH among coastal and interior sources (Figure 6) also reflect adaptations to different regional environmental conditions. From his observations on height growth initiation and cessation in the archive during 1965 and 1966, Irgens-Moller (1967, 1968) noted that interior sources initiated growth earliest overall, had the shortest growth period, and were the slowest growing, while coastal sources grew the longest and fastest. He suggested that differences in growth rate and phenology among different geographic sources of Douglas-fir reflect adaptations to the different growing seasons, photoperiod and temperature regimes, and precipitation patterns encountered in their native habitats (Irgens-Moller 1957, 1958, 1962, 1967, 1968).

As expected, LOCAL had one of the largest mean DBHs of the sources planted in 1957 (Table 1), reflecting its adaptation to local environmental conditions. Fisher's test, however, revealed that the mean DBHs of sources from as far away as Vancouver Island, B.C. (VANCV) and northwest Washington (NWWAS) were not significantly different from LOCAL (Table 1). These results agree with those found in the Douglas-fir provenance study initiated by Dr. Kim Ching in 1954 (Ching and Bever 1960). This study revealed very little difference at age 25 in the relative performance of 14 different coastal variety sources from Vancouver Island, B.C., to northern California (White and Ching 1985). In particular, Ching's study found no differences among 8 low-elevation sources, and little indication of interaction between sources and planting location. This reflects the possibility of population buffering resulting from a broad genetic mix of families within a source. The small range in DBH among low-elevation sources planted in the archive in 1957 (Table 1) suggests relatively broad adaptability of low-elevation coastal Douglas-fir. It may also reflect the environment at the archive, which may not have been harsh enough to permit statistical differentiation among these sources.

While there appears to be broad adaptability, there is also evidence of significant geographic variability within the coastal variety. According to Fisher's test, much of the variation in DBH between sources planted in

1957 seems to be due to elevation (Table 1). Irgens-Moller (1957, 1962, 1967) reported that high-elevation sources from the Cascade Range burst bud later and had shorter total growing periods than did coastal and Willamette Valley sources. He suggested that high-elevation sources have adapted to flushing under longer photoperiods in the spring and initiating dormancy early to avoid the killing frosts typical at higher elevations during the early spring and fall (Irgens-Moller 1957, 1967). Therefore, the smaller DBH of the high-elevation sources (HICAS and UPCAS) reflects their adaptation to shorter growing seasons.

Although the relationship between family DBH and source location variables was weak within the Oregon Coast-inland transect, clinal changes in DBH with both elevation and distance from the Willamette River were indicated. The predicted decrease in DBH associated with increasing source elevation again reflects adaptation to the shorter growing seasons encountered at higher elevations. The predictions of decreasing DBH with distance from the river may reflect adaptations to environmental conditions associated with factors other than elevation. With increasing distance from the river to the east, the climate tends to be drier and colder; thus, sources are slower growing. With increasing distance to the west, sources may be faster growing under mild conditions, but are probably more susceptible to damage from cold or drought conditions in the archive, resulting in less overall growth than more local sources.

The patterns of genetic variation observed in the archive support the previously held conclusion that much of geographic variation in Douglas-fir is of adaptive significance (Irgens-Moller 1958, 1967, Hermann and Lavender 1968, Wright *et al*. 1971, Rehfeldt 1978, Silen and Mandel 1983, Campbell 1986). The striking differences in growth and survival between interior and coastal sources support the distinction of 2 varieties in this species. The relatively subtle differences in DBH among coastal variety sources, however, suggest generally broad adaptability of low-elevation sources of this variety when planted in mild environments.

Dedication

This paper is dedicated to Dr. Helge Irgens-Moller, who had the insight during the early years of genetic research on Douglas-fir to establish the Hospital Tract archive. Helge Irgens-Moller was born and raised in Denmark. He attended the Royal Danish College in Copenhagen, where he received an undergraduate degree in horticulture. In the early 1950s, he came to the United States on an exploration trip. While visiting the Arnold Arboretum at Harvard University, Dr. Irgens-Moller met Dr. Karl Sax, a professor of genetics; he later returned to begin a Master's program in genetics. Irgens-Moller left Harvard before completing his degree to come to Oregon State University and work with professor Bill Chilcote in the Department of Botany. He received a Ph.D. in Botany in 1959, and, in 1960, became an Assistant Professor of Forest Genetics in the College of Forestry at Oregon State University. He remained a professor at Oregon State University until the early 1970s, when he returned to Denmark to travel and lecture. For a brief period in the early 1980s, Dr. Irgens-Moller

ran a native plant nursery near Corvallis, Oregon, with his long-time friend Bill Ferrell, but again returned to Denmark in 1983. Dr. Irgens-Moller died of a heart attack in 1989 and is survived by his two daughters.

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Appendix

Table 1. Number of families and trees per family by state, country, or province of origin planted in the Hospital Tract archive from 1957 to 1971, and the total number remaining in 1991 after losses due to mortality and thinning. —

	Planted		Remaining	
Origin	Families	Trees/family (range)	Families	Trees/family (range)
Arizona	84	1-15	20	1-3
British Columbia	21	1-12	20	1-8
California[1]	5	1-7	4	3-6
Colorado	63	1-9	11	1-2
Idaho	50	1-10	37	1-5
Montana	81	1-12	41	1-6
Mexico[2]	3	1-11	2	1-5
New Mexico	65	1-14	24	1-3
Oregon	138	1-8	124	1-7
Utah	15	1-7	3	1-2
Washington	107	1-11	96	1-9
Wyoming	7	1-3	2	1-2
Crosses[3]	88	1-13	62	1-8
Total	727		446	

[1]Collections from California include seed from a single bigcone Douglas-fir (Pseudotsuga macrocarpa [Vasey] Mayr) tree in San Diego County, California.
[2]These collections from Coahuila, Mexico are recorded as Pseudotsuga flahaulti Flous in Irgens-Moller's collection books.
[3]"Crosses" includes families from 20 controlled crosses made during the spring of 1956 between parent trees located in western Oregon and 68 crosses made in the archive during 1966 between individuals of families from western Oregon, Washington, and Vancouver Island, B.C.

Table 2. Number of families by state, province, or country of origin that had complete mortality by 1990[1] and pre- and post-thinning average DBH for both early (1957-1964) and later (1965-1971) plantings.

State, province, or country	Families with complete mortality		DBH (cm)			
			1957-1964		1965-1971	
	Number	% of families planted[2]	Pre-thin	Post-thin	Pre-thin	Post-thin
Arizona	64	76	17.6	18.7	11.1	12.2
British Columbia	1	5	31.7	33.4	none planted	
California	1	5	37.7	42.4	21.6	22.0
Colorado	52	83	16.6	16.6	5.3	7.0
Idaho	13	26	17.5	18.8	15.9	20.0
Montana	40	49	14.5	14.6	11.0	11.3
Mexico	1	33	19.2	19.2	12.5	13.7
New Mexico	41	63	15.4	15.6	12.4	12.4
Oregon	10	7	33.6	34.4	24.8	25.7
Utah	12	80	all dead		9.8	10.6
Washington	5	5	31.1	32.1	20.0	20.0
Wyoming	5	71	all dead		5.5	all dead
Overall	245		28.5	29.2	20.3	22.5

[1]Includes mortality from natural causes only (not fire or thinning).

[2]Refer to Appendix, Table 1, for total number of families planted.

Table 3. Geographic information for sources and families within sources planted in 1957 and included in the 1989 DBH analysis.———

Source (designation)	Families		Location[2]		
	Number	Designations[1]	Latitude	Longitude (degrees)	Elevation (m)
Coastal Oregon (COAST)	3	55-57	44.63	124.02	30
Inner Oregon Coast Range (INCST)	4	48, 50-52	44.64	123.74	61
Oregon Coast Range (CTRGE)	7	38, 40, 41 42, 45, 46 47	44.58 44.60 44.58	123.52 123.63 123.83	214 214 244
High elevation Oregon Coast Range (HICST)	8	74, 76-82	44.47	122.54	811
Corvallis, Oregon and vicinity (LOCAL)	13 18	8-10, 12-17 34-37	44.65 44.56	123.28 123.27	180 92
Low elevation Oregon Cascades (LOCAS)	4	21 23, 24 25	44.53 44.51 44.40	122.88 122.86 122.74	114 122 168
Mid-elevation Oregon Cascades (MIDCA)	3	26 28 33	44.41 44.40 44.40	122.42 122.35 122.34	268 381 427
High elevation Oregon Cascades (HICAS)	12	29 31, 32 85-93	44.38 44.38 44.38	122.23 122.22 122.14	1098 1159 1220
Upper Oregon Cascades (UPCAS)	4	95 96, 108 97	44.58 44.56 44.75	121.92 122.57 122.08	884 518 732
Upper coastal Oregon (UPCST)	3	54 64 65	44.75 45.00 45.00	123.92 124.01 124.00	76 31 46
Western Washington (WWASH)	3	99 100, 101	46.42 46.33	123.00 122.66	107 217
Washington Cascades (WACAS)	4	98 103 104 105	46.33 46.80 46.70 46.80	121.80 122.98 121.18 122.25	358 458 473 336
Northwestern Washington (NWWAS)	4	66 67-69	47.38 47.17	123.17 123.00	3 61
Vancouver Island, BC (VANCV)	5	107, 119 110 113 651	49.12 49.25 49.33 50.17	123.92 124.67 124.42 126.83	58 210 79 151

[1]Family numbers originally assigned by Dr. Helge Irgens-Moller.

[2]Approximate location of individual parent trees or stands. See also Figure 4.

Table 4. Geographic location information for sources and families within sources planted in 1961 that were included in the 1989 DBH analysis.

Source (designation)	Families		Location[2]		
	Number	Designations[1]	Latitude	Longitude (degrees)	Elevation (m)
Eastern Washington (EWASH)	11	500-511	47.65	120.08	796
Western Oregon (LOCAL)	8	609	43.78	123.07	750
		613	43.67	123.32	381
		615	44.18	123.08	458
		624	43.92	122.83	229
		635-641	44.57	123.20	343
Northern Rocky Mountains (NROCK)	19	154, 156	46.58	115.58	854
		159	46.83	115.17	1068
		175, 176, 178	47.47	115.92	915
		182-185, 189	47.08	116.58	610
		190, 192	47.58	117.87	671
		195	47.58	117.92	671
		198-202	48.80	116.25	1296
		207	48.80	116.08	976
		209	48.08	115.33	1068
		728	47.83	115.63	747
Northwestern Washington (NWWAS)	40	430-432	47.58	123.22	232
		434-436, 438	47.37	123.00	61
		440-448	48.07	124.73	61
		455-462	47.95	124.37	107
		465-473	47.47	123.85	67
		474-483	47.55	121.85	131
Oregon Cascades (ORCAS)	4	550, 552, 554	44.38	122.17	1098
		627	44.42	121.92	229
Central Rocky Mountains (ROCKY)	5	383, 385	39.17	107.25	2440
		567	39.08	107.83	2532
Southwest United States (SWEST)	15	271	32.42	110.75	2440
		288, 292	33.42	105.75	3050
		328-337	35.33	107.75	2440
		345	36.25	105.67	3172
		575-584	32.67	109.92	2593
		588, 594	35.42	111.92	2379
		596	34.75	106.42	2745
Washington Cascades (WACAS)	13	484-493	47.27	121.20	692
		494-499	47.33	120.67	1242

[1]Family numbers as originally assigned by Dr. Helge Irgens-Moller.

[2]Approximate location of individual parent trees or stands. See also Figure 5.

Table 5. Nested analysis of variance of DBH for sources planted in 1957.

Source	df	Mean square	F-value	Prob >F
Source	13	148.24	2.37	0.0118
Family (Source)	63	62.53	1.56	0.0067
Error	349	39.98		

Table 6. Nested analysis of variance of DBH for sources planted in 1961.

Source	df	Mean square	F-value	Prob >F
Variety	1	9086.60	18.08	0.0054
Source (Variety)	6	502.70	5.73	0.0001
Family (Source)	105	87.66	1.91	0.0001
Error	189	45.95		

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