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Effect of Sites and Provenances on 6th-year Performance of Noble Fir in Coastal British Columbia

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BC Forests

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SUMMARY

A range-wide sample of 23 noble fir provenances was tested over 12 locations in the coastal region of British Columbia. Site means of 6th-year height varied from 37 to 119 cm, 3rd-year leader elongation from 3 to 25 cm, 1st-year survival from 26 to 97%, and 6th-year survival from 81 to 91% (trees which died during the first winter were replanted the second year). Generally, the more maritime the site, the more vigorously the noble fir grew. Provenance variation was large, but showed no discernible pattern of geographic variation.

Noble fir is ecologically and genetically adapted to a maritime climate; it is susceptible to frost at sites with continental influence. The species grows well at sites in the warmer variants of the Dry and Moist Maritime Coastal Western Hemlock subzones, and the wetter variant of the moist Mountain Hemlock subzone. Sites on warm aspects particularly encourage its growth. Planting of noble fir at present should be limited to sites within these biogeoclimatic units.

Provenances from French Butte, McKinley Lake and Stevens Pass of Washington, and Laurel Mountain of Oregon, were fast growing, particularly at high-vigor sites. These should be considered as the primary areas of seed sources for introduction.

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INTRODUCTION

This paper reports the performance of a range-wide sample of 23 noble fir (*Abies procera*) seed sources after six growing seasons in a provenance trial of 12 sites in the south-coastal region of British Columbia. The silvicultural and genetic implications of introducing this species are also discussed.

Noble fir does not grow naturally in British Columbia, but the northern limit of its present natural range (Stevens Pass) is approximately 1° of latitude south of the Canada–United States border (Figure 1) (Franklin 1982). Sites similar to its natural habitats are common north of the species' northern limit. However, its slow migration rate — a result of the species' poor capacity for long-distance seed dispersal (because of heavy seed) and low competitive ability (because of shade intolerance) rather than of ecological and genetic adaptability — may have effectively limited northward expansion of its natural range (Franklin 1964).

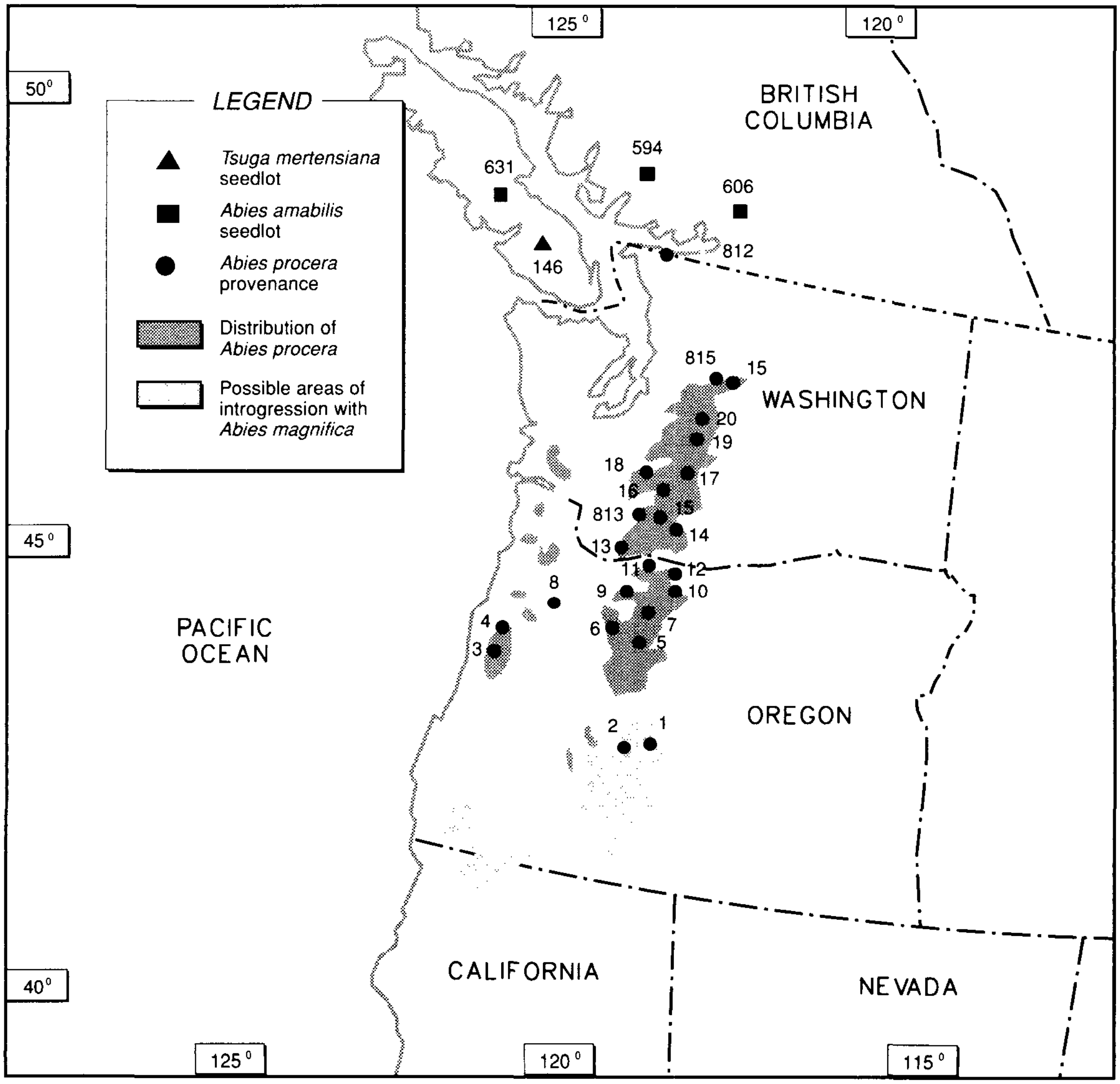

FIGURE 1. Location of provenance samples of noble fir, Pacific silver fir and mountain hemlock.

Within its natural range (44–48°N), noble fir occurs most often in areas of mild climate and abundant annual precipitation, along the western slope of the Cascade Range, from 900 to 1700 m altitude (Franklin 1982). Noble fir is able to sustain good growth for over 1 or 2 centuries, and it produces a higher volume of wood than most other conifers at the same height because of its columnar stem form and thin bark. It also has strong wood and is relatively free of insects and diseases (Franklin 1982).

Because of these attractive silvicultural characteristics, foresters in British Columbia have long been interested in noble fir's introduction. It was first planted at Agassiz Agricultural Experimental Station in the Fraser Valley in 1893, and is still being operationally planted along the lower coast of British Columbia, although in small scale (Pendl and D'Anjou 1983). In species and stocktype trials at mid- to high elevation sites in Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) zones, noble fir has shown promising performance at certain sites compared with native species (Bower 1983; Arnott *et al.* 1989; Scagel *et al.* 1989).

Species selection guidelines for the Vancouver Forest Region (R.N. Green, pers. comm., 1992) recommend noble fir as a potential reforestation species on fresh and nutrient-medium to -rich sites in both leeward and windward variants of moist MH subzones (MHmm1 and MHmm2), montane variants of moist and very moist CWH subzones (CWHmm1 and CWHvm2), and warm variants of dry and moist submaritime CWH subzones (CWHds1 and CWHms1), south of latitude 50°N. These recommendations are based on ecological considerations of native habitats of noble fir, not on testing results of genetic adaptability.

Genetic research with noble fir has focused on the species' evolution and the taxonomy of its hybridization with other true firs (Parker 1963; Silen *et al.* 1965; Zavarin *et al.* 1978). Studies of its geographic variation are recent (Sorensen *et al.* 1990). Long-term field testing of provenance variation to assess genetic adaptation is still rare. This study is probably the first systematic field trial of a range-wide sample of noble fir provenances in the Pacific Northwest.

The objectives of this study were:

1. to establish long-term provenance tests within the biogeoclimatic units where noble fir is a potential reforestation species, and to delineate common environments for planting this species, based on vigor, survival and damage;
2. to relate these common environments to British Columbia's biogeoclimatic classification units;
3. to identify noble fir seed sources suitable for use in these units; and
4. to evaluate seed source x test site (and seed source x biogeoclimatic unit) interactions.

MATERIALS AND METHODS

Provenance

Location of the noble fir provenance samples is shown in Figure 1 and their geographic origins are given in Appendix 1. Seed of 25 provenances was acquired, 22 through the cooperation of the International Union of Forestry Research Organizations, and three through the Vancouver Forest Region of the B.C. Ministry of Forests. Two provenances (Nos. 1 and 2), possibly hybrids between noble and red fir (*A. magnifica*) (Figure 1), failed to produce enough seedlings because of poor germination and were excluded. Three Pacific silver fir (*A. amabilis*) and one mountain hemlock (*Tsuga mertensiana*) seedlots (Figure 1; Appendix 1) were included for comparison.

Test stock was raised at Campbell River Forest Nursery (Lat. 50°, Long. 125°15′) on central Vancouver Island. Seed was either directly sown in styro 8 (PSB 415) containers or pre-germinated and transplanted into containers in April 1980. Seedlings were removed from containers and transplanted to nursery beds in April 1981 for one more season before being lifted for outplanting. Containers were randomly arranged in three replications in the shelterhouse, and seedlings in two replications in the nursery beds.

Test Site

Twelve tests (Figure 2) were established, all in the fall of 1981, except Uztlius Creek which was planted in the spring of 1982. Ecological diagnosis of the test sites was done in 1988, and the information is summarized in Appendix 2. The 12 sites are distributed over six biogeoclimatic variants in three zones (Appendix 2). The biogeoclimatic ecosystem classification (BEC) in British Columbia organizes ecosystems into a hierarchical classification of zones, subzones and variants based on an interpretive synthesis of climate, vegetation and soil information (Pojar *et al.* 1987). The subzone is the basic biogeoclimatic unit reflecting the dominant influence of regional climate and landscape pattern on vegetation formation. Subzones with similar regional climates are combined into zones, and variants further differentiate within-subzone areas with different precipitation, temperature and snowfall. Climax rather than seral ecosystems are used to develop the classification. In British Columbia, BEC provides the framework by which silvicultural operations are planned.

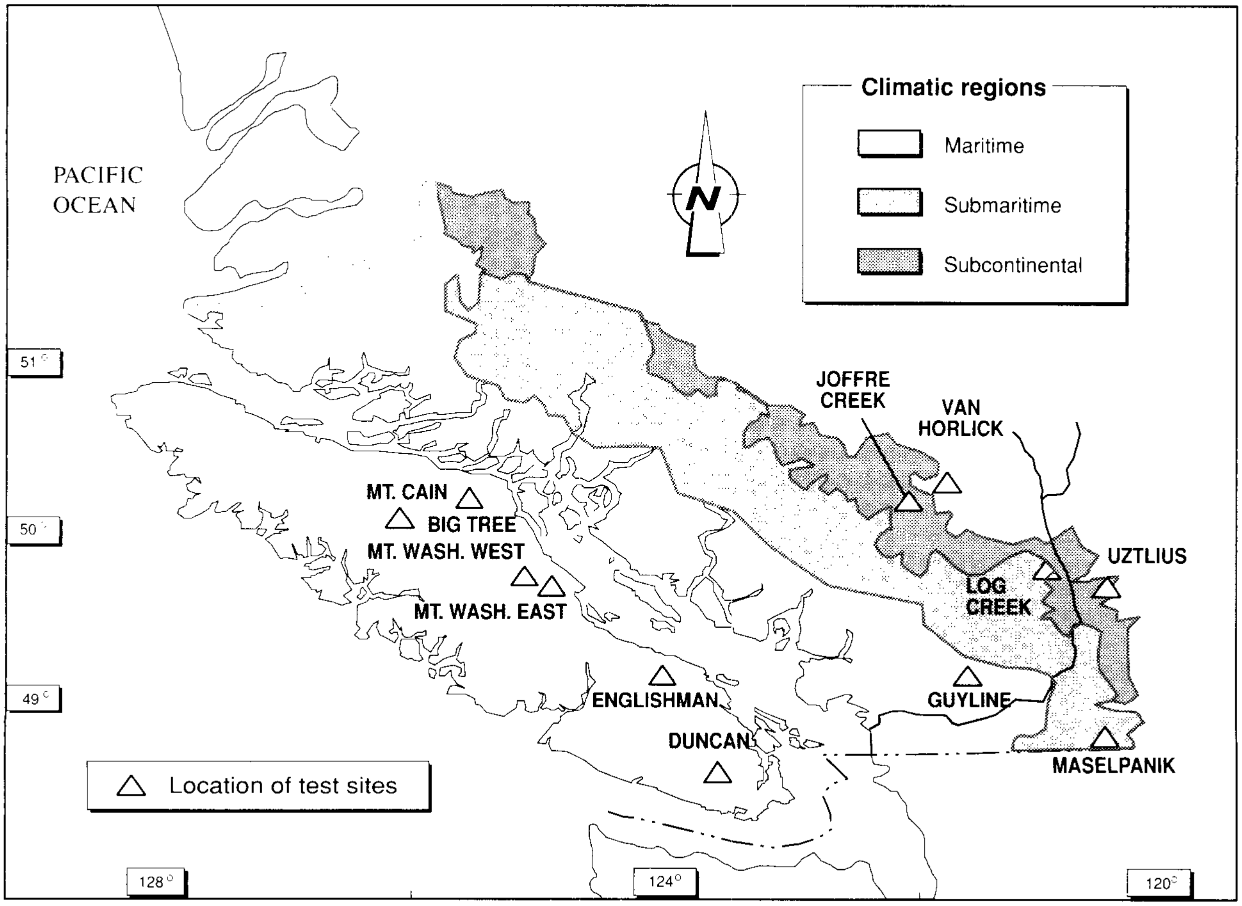

FIGURE 2. Location of the 12 test sites.

Selection of test sites was based on the premise that the introduction of noble fir would most likely succeed at sites ecologically similar to the species' native habitats, that is, the Moist Maritime MH subzone and Montane Variants of the Moist Maritime CWH subzones (Klinka *et al.* 1984). Therefore, the majority of the tests are located in these biogeoclimatic units. Within these broad BEC units, noble fir is expected to grow well at mid- to high elevation (700–1500 m) sites on warm aspect and leeward slopes. At steep slope sites, noble fir is expected to withstand snow press better than some native species, such as western hemlock (*Tsuga heterophylla*), because of its thick calibre. To assess noble fir performance outside the maritime climate region, three tests (Log Cr., Joffre Cr. and Maselpanik)) were established in the submaritime climate region and two tests (Van Horlick and Uztlius) in the subcontinental climate region (Figure 2; Appendix 2).

Soil moisture (SMR) and nutrient (SNR) of the test sites were surveyed in 1988 according to the edatopic grid system (Pojar *et al.* 1987). The SMR varies from site to site and within sites, from moderately dry to wet. Uztlius is the most dry site because it is located at the crest of the coast-interior pass, fully exposed to winds and weather systems. Joffre Cr. is the site most variable in SMR (from slightly dry to wet). On average, the majority of the sites can be described as fresh to moist. In terms of SNR, Mt. Cain, Van Horlick, Uztlius and Joffre Cr. are poor; the rest of the sites are of medium soil nutrient (Appendix 2). Soils of the test sites are dominantly sandy or sandy loams (Appendix 2).

Each test contains 20 noble fir provenances (19 at Uztlius), 18 of them common to all. Two of the four seedlots of native species (Figure 1; Appendix 1) were included in each test for comparison, except Uztlius. Provenances were planted in completely randomized blocks of 5-tree line plots replicated 12 times (6 replications only at Mt. Washington E.), at 2.5 m spacing. Seedlings that died during the first winter were replanted. Because of a shortage of stock for a few provenances, 7, 9 and 22% of the trees at Log Cr., Joffre and Van Horlick, respectively, were not replanted. All tests have been carefully maintained.

Data Collection and Analysis

Survival and frost injury were recorded after one, three and six growing seasons, total height after three and six seasons, and leader elongation during the third season.

Data were first subjected to analysis of variance (ANOVA) by individual sites to assess provenance effect. Combined ANOVA of all sites followed the model described in Appendix 3, in which variances associated with sites were subdivided into two components: BEC subzones and sites within subzones. This allowed us to assess the relative magnitude of site x provenance interaction associated with the two components, and thus the adequacy of subzones for guiding the selection of planting sites of noble fir. Since test sites were located in only one variant in four of the five subzones (Appendix 2), statistical inference of the effect of subzones reflects mainly that of variants. Analyses were based on plot means.

Clustering procedures were used to group test sites and provenances. The purpose was to delineate common environments in terms of growth of noble fir provenances. Site clustering was based on provenance means of total (6th-year) height and 3rd-year leader elongation. A minimum-variance clustering procedure (Ward's method) was adopted, in which the increase of within-cluster variance was the smallest in each step of fusion of clusters (Pielou 1984). Acceptance of the number of clusters was according to the pattern of clustering as illustrated by the dendrograms, and practicability of the resulting site groups was judged against the ecological site diagnosis in Appendix 2.

ANOVAs were done for each site group derived from the above cluster analysis and were based on a random model (Appendix 4). Results from this ANOVA provided a form of statistical validation of the site grouping (Everitt 1979). Site grouping can be accepted as reasonable if the variance component of site-by-provenance interaction is statistically insignificant or much smaller than the provenance component. Simple correlation of provenance means among sites provided another indirect indication of the effectiveness of site grouping.

Cluster analysis was again used to group provenances within each site group, in an attempt to identify seed sources suitable for reforestation at each site group. Clustering followed the same procedure used to group sites, with provenance means of total height and 3rd-year leader elongation at individual sites as the input data matrix. Each provenance would then be a sample point in a six-dimensional space if there were three sites in the site group.

Only noble fir provenances were used in ANOVA and clustering.

Since the main objective of this study was to delineate and differentiate sites for their potential for planting of noble fir, and to locate seed sources which are expected to grow well at these sites, data analyses emphasizing grouping of sites and provenances appear to be practical and logical.

RESULTS

Site and Provenance Effect

ANOVA of individual sites are summarized in Table 1. Provenance means of 6th-year height and 1st- and 6th-year survival at individual sites are given in Tables 2, 3 and 4, respectively.

Site differences were large in growth, survival and winter injury. After 6 years, the average height of noble fir at the best site was 3 times taller than at the poorest site, 64% of the trees suffered severe winter injury (killed leader) at Uztlius (Table 1), and survival varied from 81 to 97% (Tables 1 and 4). Leader elongation of noble fir at Bigtree Cr. was 8 times more than at Uztlius (Table 1). High mortality occurred the first winter at Van Horlick (74%), Joffre (47%) and Log Cr. (42%) (Tables 1 and 3). After replanting, survival at these sites was improved and changed very little from years 3 to 6. Severe local weather during the first winter at these sites may have caused the high mortality. Generally, the stronger the influence of maritime climate on the site, the higher the survival and the more vigorously the noble fir grew.

Provenance effects on growth were statistically significant at the 10% probability level at most sites (Table 1). Provenance differences generally were larger at productive sites, such as Bigtree Cr. and Duncan (Table 2). Differences among noble fir provenances in 1st-year survival were large and statistically significant at Van Horlick, Joffre and Log Cr., but small at the remaining sites although statistical significance was detected at Maselpanik and Guyline (Tables 1 and 3). Sixth-year survival was high among all provenances at all sites (except for one source at Van Horlick), but statistical significance of provenance differences was detected at five sites (Tables 1 and 4). However, it should be noted that a non-normality of the percentage data based on a five-tree plot tends to produce more significant results in F-tests (Snedecor and Cochran 1967). In these analyses, transformation did not make any difference.

Combined ANOVA indicated that BEC subzones (variant) and sites within subzones accounted for about 70–80% of the total variation (Table 5). Lack of statistically significant differences among subzones was largely due to the high site variation within subzones (Table 5). Provenance differences over all the sites were statistically significant, but not consistent across all the sites in view of the significant interaction of provenances with subzones and sites within subzones (Table 5). Transformation (standardization) did not remove the interaction, suggesting it was not a scale effect. Survival showed a similar pattern.

TABLE 1. Test site means of noble fir provenances in 1st- and 6th-year survival (%) (6th-year survival including the trees replanted after the first winter), 3rd-year leader elongation (cm), 6th-year total height (cm) and probability level of significance in F-tests of provenance effect (P), and 6th-year winter injury (%)

Site[a]	Survival (%)				Leader (cm)		Height (cm)		Winter injury (%)
	1st-year	P	6th-year	P	3rd-year	P	6th-year	P	6th-year
Vancouver Island									
MC	95	.48	97	.45	19	.00	111	.08	2
BT	97	.41	93	.13	25	.00	116	.00	0
WW	86	.61	90	.07	9	.09	73	.06	7
WE	85	.05	89	.00	5	.17	68	.12	10
EM	85	.13	90	.02	8	.01	62	.00	6
DU	88	.23	92	.01	22	.01	119	.00	0
Mainland									
MP	86	.01	89	.35	5	.31	54	.03	3
GL	89	.01	94	.16	11	.11	82	.18	3
LG	58	.00	87	.36	7	.00	67	.00	4
UZ	83	.92	85	.79	3	.05	37	.36	64
JF	53	.00	81	.62	8	.01	78	.21	5
VH	26	.00	90	.00	5	.01	67	.00	11

[a] See Appendix 2 for site acronyms.

TABLE 2. Provenance means of total height after 6 years at each site

Species prov.	**Site group[a]**											
	I			**II**			**III**					
	BT	**DU**	**MC**	**WW**	**GL**	**JF**	**EM**	**WE**	**MP**	**LG**	**VH**	**UZ[b]**
A. procera												
3	107	115	108	68	76	73	61	60	56	62	69	38
4	104	93	106	58	79	70	53	61	49	64	65	32
5	108	120	107	66	79	81	62	63	53	71	71	34
6	105	114	103	76	80	82	60	65	52	67	58	34
7	104	113	110	70	82	77	64	62	56	66	71	36
8	128	140	115	79	89	83	61	72	56	67	72	42
9	130	136	126	73	77	72	63	66	54	73	75	38
10	121	132	114	74	86	80	70	71	56	66	61	42
11	123	116	105	76	80	81	61	67	53	63	67	37
12	107	122	107	77	84	79	65	68	57	68	74	38
13	113	118	110	75	86	76	56	69	53	66	64	37
14	125	96	115	70	77	76	63	67	50	69	60	39
15	115	120	108	77	83	75	66	72	48	69	49	39
16	135	137	114	77	88	86	69	84	59	78	71	40
18	130	121	117	76	88	86	64	77	58	75	71	39
20	120	123	105	68	80	76	62	67	52	64	67	39
21	124	134	123	85	84	83	67	68	54	69	61	38
22	104	99	99	69	79	72	56	68	54	59	65	35
17	-	-	116	78	82	78	-	-	57	67	63	-
19	-	-	-	-	-	-	-	72	59	-	-	35
812	103	105	-	-	-	68	53	-	-	56	-	-
813	114	125	-	70	85	-	66	-	-	-	-	-
815	-	-	110	-	-	-	-	65	-	-	76	-
Mean	116	119	111	73	82	78	62	68	54	67	67	37
A. amabilis												
594	-	-	-	-	70	69	-	-	45	57	65	-
606	-	-	-	-	65	64	-	-	45	68	58	-
631	91	105	92	55	-	-	54	-	-	-	-	-
T. mertensiana												
146	103	114	102	89	-	-	65	78	-	-	-	-
Site mean	114	118	110	73	81	77	62	68	53	67	66	37

[a] See Figure 3 for site clustering.

[b] Planted in June 1982; the other sites planted in October 1981.

TABLE 3. Provenance means of survival (%) after the first winter at each site

Species prov.	Site group[a]											
	I			II			III					
	BT	**DU**	**MC**	**WW**	**GL**	**JF**	**EM**	**WE**	**MP**	**LG**	**VH**	**UZ[b]**
A. procera												
3	100	88	98	80	90	43	98	97	86	44	12	85
4	97	88	92	87	90	57	85	73	83	57	15	92
5	100	92	95	77	78	38	85	77	81	47	27	78
6	95	85	95	87	92	62	85	80	82	67	32	85
7	97	95	97	85	93	62	87	73	88	62	30	87
8	97	85	95	92	82	40	75	87	75	52	18	88
9	95	98	93	90	90	72	76	93	85	77	12	88
10	98	92	100	92	93	43	92	90	78	70	57	87
11	98	88	92	90	78	47	85	90	69	35	8	93
12	100	98	95	85	93	73	82	83	88	70	37	83
13	100	92	97	90	95	75	92	87	93	69	37	85
14	95	78	97	88	85	13	85	90	87	48	7	83
15	97	92	98	83	97	67	85	77	92	75	28	-
16	95	86	95	90	93	72	80	100	93	77	55	93
18	93	77	95	88	97	60	77	80	85	68	15	90
20	95	82	95	87	90	47	90	97	80	47	15	83
21	98	88	100	88	97	67	77	87	97	65	52	90
22	100	88	95	83	88	33	95	83	95	35	20	87
17	-	-	97	79	90	58	-	-	85	60	25	-
19	-	-	-	-	-	-	-	83	87	-	-	92
812	92	87	-	-	-	35	87	-	-	43	-	-
813	95	88	-	87	78	-	80	-	-	-	-	-
815	-	-	88	-	-	-	-	78	-	-	13	-
Mean	97	88	95	86	89	53	85	85	86	58	26	87
A. amabilis												
594	-	-	-	-	100	80	-	-	98	88	80	-
606	-	-	-	-	100	65	-	-	97	80	77	-
631	93	97	88	88	-	-	77	93	-	-	-	-
T. mertensiana												
146	98	87	95	97	-	-	63	100	-	-	-	-
Site mean	97	89	95	87	90	55	83	86	87	61	30	87

[a] See Figure 3 for site clustering.

[b] Planted in June 1982; the other sites planted in October 1981.

TABLE 4. Provenance means of survival (%) after 6 years (including trees replanted after the first winter) at each site

Species prov.	Site group[a]											
	I			II			III					
	BT	DU	MC	WW	GL	JF	EM	WE	MP	LG	VH	UZ[b]
A. procera												
3	88	90	95	92	97	75	93	90	87	90	87	82
4	93	88	95	93	93	75	88	80	92	88	100	77
5	92	88	97	75	88	80	87	83	88	88	93	78
6	95	90	98	97	98	83	83	90	92	85	94	83
7	90	95	98	88	92	92	88	80	97	82	85	85
8	93	92	95	88	88	85	93	93	83	83	93	80
9	87	97	100	87	93	78	92	90	90	95	92	85
10	83	92	100	90	90	78	88	93	85	83	82	87
11	97	95	98	92	95	75	98	100	77	75	91	93
12	90	93	100	92	92	90	82	97	97	88	90	87
13	98	93	95	90	97	83	95	93	88	88	88	82
14	95	95	97	93	83	78	92	93	90	93	80	92
15	97	85	98	92	93	83	90	70	95	87	76	-
16	93	88	98	90	98	87	98	93	82	92	90	90
18	100	97	97	83	97	82	90	100	92	90	97	87
20	93	83	92	92	93	77	90	87	90	82	92	83
21	98	93	98	98	98	82	90	100	88	92	98	87
22	98	97	97	92	95	85	87	90	93	90	58	82
17	-	-	100	85	98	89	-	-	88	92	100	-
19	-	-	-	-	-	-	-	79	88	-	-	87
812	85	83	-	-	-	73	97	-	-	89	-	-
813	95	93	-	87	95	-	75	-	-	-	-	-
815	-	-	93	-	-	-	-	80	-	-	85	-
Mean	93	92	97	90	94	81	90	89	89	87	90	85
A. amabilis												
594	-	-	-	-	93	83	-	-	92	87	95	-
606	-	-	-	-	100	90	-	-	83	92	93	-
631	93	95	93	78	-	-	73	97	-	-	-	-
T. mertensiana												
146	93	92	95	97	-	-	82	100	-	-	-	-
Site mean	93	92	97	90	94	82	89	90	89	87	90	85

[a] See Figure 3 for site clustering.

[b] Planted in June 1982; the other sites planted in October 1981.

TABLE 5. Mean squares, variance components (percent of all components), and probability level of significance in F-tests for 3rd-year leader elongation and 6th-year height (cm) derived from combined ANOVA based on the 18 common noble fir provenances (see Appendix 3 for ANOVA model)

Source	Leader			Height		
	MS	VC (%)	P	MS	VC (%)	P
Subzone	198987	22.2	.20	19848	43.9	.09
Site (subzone)	100727	48.1	.00	5745	36.0	.00
Block (site, subzone)	1481	6.8	.00	38	1.7	.00
Provenance	2580	1.9	.00	109	0.9	.00
Prov. x subzone	544	1.1	.00	30	0.6	.02
Prov. x sites (subzone)	242	0.4	.04	18	0.6	.00
Error	201	19.5		13	16.1	

No meaningful relationship was found between winter injury at Uztlius and mortality or height growth at other sites (Table 6). The low variation among provenances in percentage of winter-injured trees at Uztlius (45–75%) may contribute to the low correlation. However, between-site correlations in 1st-year survival were high and statistically significant among the three sites with the highest mortality and the highest provenance variation (Log Cr., Joffre Cr. and Van Horlick). So was the correlation in height among the three most productive sites (Duncan, Bigtree Cr. and Mt. Cain) (Table 6). Between-site correlations of survival with height were all positive, although not statistically significant (Table 6). High correlations in provenance survival among low-vigor sites and provenance height among high-vigor sites suggest provenance differences in cold hardiness and growth potential.

TABLE 6. Correlation coefficients to compare winter injury, survival and height of noble fir provenances between different sites: % trees suffering winter injury at Uztlius (UZWI6), 1st-year survival (%) at Log Cr. (LGSURV1), Joffre Cr. (JFSURV1) and Van Horlick (VHSURV1), and total height at Bigtree Cr. (BTHT6), Duncan (DUHT6) and Mt. Cain (MCHT6)[a]

	LGSURV1	JFSURV1	VHSURVI	BTHT6	DUHT6	MCHT6
UZWI6	.03	.25	-.29	.04	.19	-.02
LGSURV1		.91**	.65**	.26	.30	.37
JFSURV1			.61**	.12	.31	.20
VHSURV1				.17	.44*	.17
BTHT6					.63**	.71**
DUHT6						.59**

[a] * Significant at 0.05 probability level; ** Significant at 0.01 level.

Despite the high provenance variation in survival and height, correlation and regression analyses showed no discernible pattern of provenance variation related to their geographic origin. For example, correlation coefficients of provenance means of 1st-year survival with latitude, longitude and elevation at Joffre were respectively .22, -.13 and -.05.

Site Grouping

Duncan, Bigtree and Mt. Cain appear to form one group naturally (Figure 3); Uztlius appears to stand by itself (Figure 3). The climate at this site may be too continental for noble fir, as shown by extremely poor growth and high winter injury (Table 1). The remaining eight sites were classified into two groups (Figure 3).

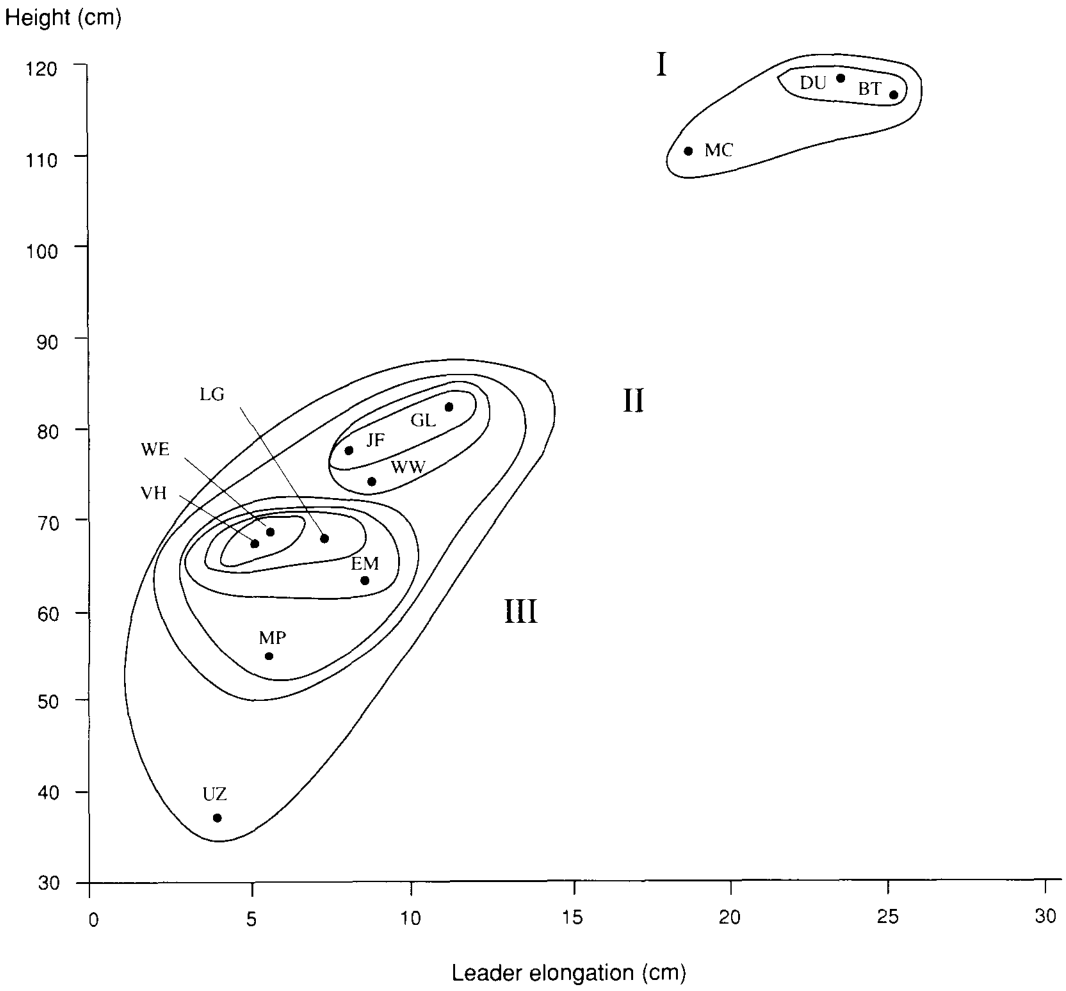

FIGURE 3. Illustration of successive fusion in each step of clustering of the 12 test sites.

Results of ANOVA for each site group (Appendix 5a,b,c) suggest that site grouping in terms of growth potential was satisfactory. Provenance-and-site interaction was either not statistically significant or the provenance component accounted for a much higher proportion of the variance than did the interaction term. The only exception was leader growth at site group III.

The effect of site grouping on survival was not as clear (Appendix 5a,b,c). Significant provenance-by-site interaction in 6th-year survival was most likely a statistical artifact as suggested before, and of no practical significance since all provenances had very high survival (Table 4). Low 1st-year survival at Joffre contributed to the significant interaction in site group II, and Van Horlick and Log Cr. to that in site group III (Table 3).

It may take much longer than 6 years for the provenance site interaction in survival to become manifested in long-term field tests.

As shown by the between-site correlation coefficients, provenance growth was most consistent at the three most productive sites in site group I and least consistent at site group III (Table 7). In the former, between-site correlations were consistently higher within than between site groups, but no such consistency occurred in the latter. The high correlation of provenance performance at high-vigor sites (site group I) suggests that clustering is effective in delineating sites suitable for the planting of noble fir, and also in identifying suitable seed sources for these sites.

TABLE 7. Average correlation coefficients between and within site groups in 6th-year height based on 18 provenances common to all sites

Site group	I	II	III
I	.64	.49	.43
II		.62	.45
III			.38

Provenance Grouping

The dendrograms generated from cluster analyses for site group I are shown in Figure 4a, for site group II in Figure 4b, and for site group III in Figure 4c. Given the distance (within-cluster variance) in each step of clustering, provenances can be divided into three groups in all three site groups (Figures 4a,b,c) (Pielou 1984). Pair-wise comparison by t-test of mean height and leader elongation among provenance groups indicates that clustering was an effective way to identify productive provenances. All comparisons were significant at 5% probability, except leader elongation between provenance group A and B in site group II, and total height between provenance groups B and C in site group III (Tables 8a,b,c). Differences in growth among provenance groups were much larger at productive sites (group I) than at less productive sites (group III). At the former, total height of the productive provenance group (A) was 20% taller than in the poorest group (C) (Table 8a), compared to that of only 12% at the latter (Table 8c).

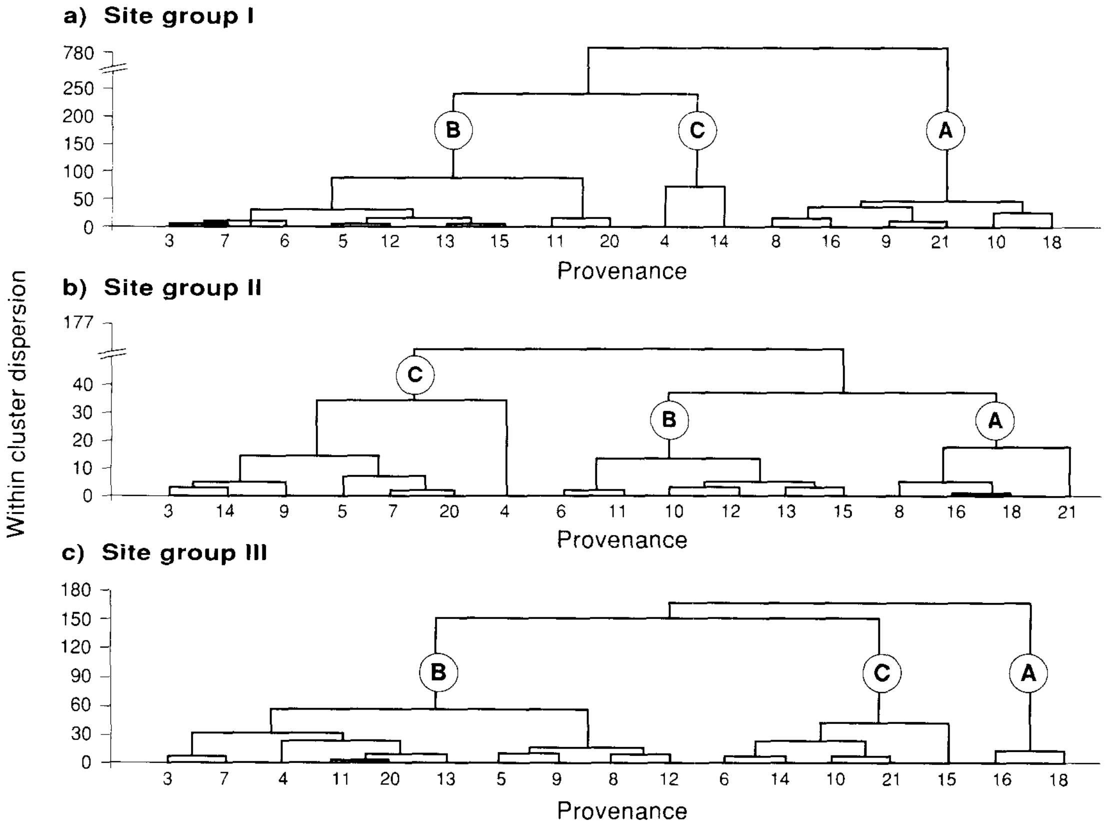

FIGURE 4. The dendrogram illustrating the clustering process of the 17 common provenances of known origin: (a) at site group I; (b) at site group II; and (c) at site group III (Figure 3).

There were few differences among provenance groups in 6th-year survival at all three site groups, although some differences were statistically significant (Tables 8a,b,c). Differences were substantial, however, in 1st-year survival at site groups II and III (Tables 8b,c), although the fast-growing provenance group (A) had higher survival (Tables 8b,c).

Performance of some provenances was consistent across sites. For example, provenances 16 and 18 were always in the A group, whereas provenances 4 and 14 were always in the C group (Figure 4). Provenance performance was not strongly related to geographic origins, however, as correlation coefficients of provenance mean height, leader elongation and survival were low and not statistically significant (e.g., correlation coefficient of height with latitude, longitude and elevation for site group I were respectively 0.39, -0.22 and -0.05).

Since there was no strong correlation between performance and geographic origin of provenances, it is difficult to delineate geographic areas for seed collection. Introduction of productive and adaptable noble fir has to be provenance-specific.

TABLE 8a. Comparison among provenance groups of noble fir and the native Pacific silver fir and mountain hemlock in leader elongation (cm), total height (cm), and 1st- and 6th-year survival (%), and their range of provenance means for site group I (Figure 4a)

Species/ provenances/ t-test	**3rd-year**		**6th-year**		**1st-year**		**6th-year**	
	Leader	**Range**	**Height**	**Range**	**Survival**	**Range**	**Survival**	**Range**
Noble fir								
A. (18,10,21,9,16,8)	24	23–25	127	123–131	93	92–98	95	89–98
B. (20,11,15,13,12,5,6,7,3)	22	21–23	112	107–116	95	91–98	93	89–97
C. (4,14)	20	19–21	106	101–112	91	90–92	94	92–96
Mean	22		115		93		94	
t-value (A vs. B)	5.97	(p < .01)	8.67	(p < .01)	1.77	(p = .08)	2.08	(p = .03)
t-value (B vs. C)	1.72	(p = .04)	2.31	(p = .02)	2.38	(p = .02)	1.42	(p = .25)
Pacific silver fir	17		96		93		93	
Mountain hemlock	18		106		93		93	

TABLE 8b. Comparison among provenance groups of noble fir and the native Pacific silver fir and mountain hemlock in leader elongation (cm), total height (cm), and 1st- and 6th-year survival (%), and their range of provenance means for site group II (Figure 4b)

Species/ provenances/ t-test	**3rd-year**		**6th-year**		**1st-year**		**6th-year**	
	Leader	**Range**	**Height**	**Range**	**Survival**	**Range**	**Survival**	**Range**
Noble fir								
A. (21,18,16,8)	11	10–11	84	83–84	80	71–85	90	87–93
B. (15,13,12,10,11,6)	10	10–11	79	78–80	80	72–86	89	86–91
C. (4,20,7,5,9,14,3)	9	8–9	74	69–76	73	62–84	86	81–91
Mean	10		78		76		89	
t-value (A vs. B)	1.25	(p = .20)	2.93	(p < .01)	0.00	(p = .90)	0.58	(p = 0.60)
t-value (B vs. C)	5.11	(p < .01)	4.01	(p < .01)	3.96	(p < .01)	2.03	(p = 0.04)
Pacific silver fir	9		71		87		84	
Mountain hemlock	9		89		97		97	

TABLE 8c. Comparison among provenance groups of noble fir and the native Pacific silver fir and mountain hemlock in leader elongation (cm), total height (cm), and 1st- and 6th-year survival (%), and their range of provenance means for site group III (Figure 4c)

Species/ provenances/ t-test	**3rd-year**		**6th-year**		**1st-year**		**6th-year**	
	Leader	**Range**	**Height**	**Range**	**Survival**	**Range**	**Survival**	**Range**
Noble fir								
A. (16,18)	7	6–8	70	68–71	73	65–81	92	91–94
B. (12,8,9,5,13,20,11,4,7,3)	6	5–7	63	58–66	66	61–76	89	86–92
C. (15,21,10,14,6)	7	5–8	62	60–64	71	63–77	88	84–94
Mean	6		63		68		89	
t-value (A vs. B)	3.99	(p < .01)	5.48	(p < .01)	3.22	(p < .01)	1.73	(p = .08)
t-value (B vs. C)	2.96	(p < .01)	1.33	(p = .20)	3.50	(p < .01)	0.87	(p = .45)
Pacific silver fir	7		51		86		84	
Mountain hemlock	10		71		81		91	

Generally, at productive sites, most noble fir provenances were taller than either the native Pacific silver fir or mountain hemlock, and survived as well as the native species (Table 8a). At poor sites, the native species had much higher 1st-year survival than noble fir, particularly at Van Horlick, Joffre and Log Cr. (Tables 8b,c). However, since only two seedlots of native species were included in each test, and not always the same seedlot was used in all the tests, comparison of native species with noble fir is not realistic.

DISCUSSION

Site Effect

Noble fir grew poorly (exhibiting low vigor, high first-winter mortality or severe winter injury) at sites in the subcontinental ESSF (e.g., Uztlius) or in the submaritime subzone of CWH (CWHms) (e.g., Joffre) (Figure 2; Appendix 2; Table 1). At these sites, which are subjected to considerable continental influence, the native Pacific silver fir and mountain hemlock grew as tall as noble fir (Table 2) and had lower first-winter mortality than the latter (Table 3). On the other hand, sites that showed most vigorous growth of noble fir are located in the warmer variants of the moist and dry maritime CWH subzones (e.g., Duncan and Bigtree) and the wetter variant of the moist maritime MH subzone (e.g., Mt. Cain) (Figure 2; Appendix 2). These large differences in growth and survival between sites in maritime vs. submaritime/subcontinental climate suggest that noble fir is ecologically adapted to a maritime climate.

Indirect evidence also supports the above conclusion. Over 60% of the noble fir trees suffered severe winter damage (leader killed) every year at Uztlius, the most continental of the 12 sites. However, Engelmann spruce and lodgepole pine planted at the same site grew vigorously and showed no sign of any winter injury, strongly suggesting that this site is beyond the ecological range of noble fir. The higher 1st-year survival of native Pacific silver fir than noble fir at sites with continental influence (e.g., 78 vs. 26% at Van Horlick, 73 vs. 53% at Joffre, and 84 vs. 58% at Log Cr.) (Table 3) also suggests less tolerance of noble fir to continental climate.

In a separate trial, extra stock from this study was planted in the fall of 1982 at two small plantations on northern Vancouver Island, one at Holberg (Lat. 50°36′, Long.127°59′, elev. 450 m) and the other at Jeune Landing (Lat. 50°28′, Long.127°45′, elev. 800 m). Both sites are located in the southern hypermaritime subzone of the CWH, which can be climatically characterized as having a mild winter and cool summer with high precipitation throughout the year (Klinka *et al.* 1984). Five years after planting, average heights at Holberg and Jeune Landing were 122 and 138 cm, leader elongation 34 and 42 cm (better than any of the 12 sites), and survival 95 and 94%, respectively (Stump 1989). These sites were comparable to the most vigorous site in site group I, lending further evidence to show that noble fir is adapted to the coastal maritime climate.

These results support the view that the failure of noble fir to expand its natural range farther north is not due to environmental constraints or poor biological adaptability, but rather to lack of long-distance seed dispersal capacity, poor competition ability (shade intolerance), and other factors that may have prevented its northern migration (Franklin 1964; Sorensen *et al.* 1990). The results also support the conclusion of Sorensen *et al.* (1990) that cold intolerance probably sets the species' upper elevational limit, and low competitive ability — particularly slow initial growth rates and inability to reproduce under a forest canopy — limits its expansion to low elevations.

Clustering analyses divided the 12 sites into four groups based on height and leader growth (Figure 3) which are statistically satisfactory (Appendix 5a,b,c). Is this grouping also ecologically satisfactory? In other words, are there common site and ecological factors which differentiate the site groups? Apparently, the degree of maritime influence is the major determining factor; the three most productive sites in site group I are all located within strongly maritime BEC variants (the Mt. Cain site located at the lower end of MH zone, climatically similar to CWH), whereas the least productive sites in site group III are mostly in the submaritime BEC variants (Appendix 2). Also, the three sites in site group I are on warm south facing slopes (Appendix 2).

Noticeable exceptions to this general trend also occur; both maritime and submaritime sites were grouped in the same site groups (indicating similar productivity) e.g., the Englishman R. and Mt. Washington E. sites in site group III and Joffre Cr. site in site group II (Appendix 2). These exceptions suggest the strong modifying effect of local topography, soil or harvest operations. For example, both Duncan and Englishman rivers are located in the same BEC variant (Appendix 2), but noble fir grew nearly twice as tall at the former than at the latter (Table 1). Apparently, the steep westerly slope at Englishman R. contributing to growing season soil moisture stress affected noble fir growth. Similarly, noble fir grew significantly taller at Mt. Cain than at Mt. Washington W. and E. (Table 1), although all three sites occupy the same BEC variant (Appendix 2). Poor growth of noble fir at Mt. Washington E. could be attributed to its cool northerly aspect, and at Mt. Washington W. to massive decaying wood which covers about 70% of the site (Appendix 2). Site variability could also bias the estimate of site mean height, (e.g., Joffre Cr.). This lack of correspondence between environmental commonality of test sites (delineated according to tree growth) and BEC units suggests that site environments within these BEC variants are far from uniform, and BEC units alone are not adequate to guide the planting of noble fir.

Provenance Effect

Provenance differences in growth were large, particularly at productive sites (Tables 2 and 8a), but neither cluster analysis (Figures 4a,b,c) nor correlation and regression analyses strongly related the differences to provenance latitude, longitude or elevation of origin.

The lack of a discernible pattern of geographic variation observed in this study is consistent with the results of other studies (Maze and Parker 1983; Sorensen *et al.* 1990), and also of provenance tests involving the same IUFRO collections in Europe (Fletcher and Samuel 1990; Ruetz *et al.* 1990). However, the tests in this provenance trial are still young. Trees at many sites are still protected by snow cover. A discernible pattern might emerge as the trees grow taller.

Maze and Parker (1983) suggest that selection occurring as a result of site disturbance is the major factor contributing to population differentiation of noble fir. Sorensen *et al.* (1990) indicate that population differentiation of noble fir may be related to its adaptability to the local environment, but not necessarily to latitude, longitude and elevation. Efficacy of natural selection in differentiating natural population may be overemphasized in explaining adaptative provenance variation of tree species; this uninterpretable variation could be a random occurrence rather than an adaptation in nature (Lewontin 1978; 1982).

Practical Application

The three high-vigor sites in site group I (Duncan, Bigtree and Mt. Cain) are located in the warmer variants of the moist and dry maritime CWH subzones and the wetter variant of the moist maritime MH subzone. Sites occupying warm aspects and windward slopes in the montane and submontane region within these BEC units apparently favor the growth of noble fir. Planting noble fir at these sites involves very low risk. Species trials (Bower 1983; Arnott *et al.* 1989) and experiences from small-scale operational planting indicate similar conclusions, as do results from European trials (Fletcher and Samuel 1990).

The present species selection guidelines in British Columbia recommend that noble fir be planted in the warmer moist variant of the maritime MH subzone, and in the leeward montane variant of the moist maritime CWH subzone (R.N. Green, pers. comm., 1992), which is approximately from 600 to 1200 m in elevation and south of 50° latitude. The test results suggest that noble fir's planting can be extended farther north of 50° latitude in both the leeward and windward submontane variants of the moist maritime CWH subzone, at least on Vancouver Island (Stump 1989). Noble fir can also be expected to grow well at sites in the dry maritime CWH subzone. However, planting at sites in the submaritime/subcontinental climate zones (Figure 2) should only be on a trial basis at present.

Since no apparent pattern of geographic variation can be established, selection of productive and adapted seed sources has to be provenance-specific. Sixth-year testing results suggest the following:

- Provenances originating from French Butte (No. 16), McKinley Lake (No. 18) and Stevens Pass (No. 21) of Washington, and Laurel Mt. (No. 8) of Oregon, were relatively fast growing, particularly at high-vigor sites. These should be considered as primary seed sources for introduction (Figure 1; Appendix 1). Some of these provenances also grew fast at European trials (Fletcher and Samuel 1990; Ruetz, *et al.* 1990).
- Provenances Nos. 3 and 4 of coastal Oregon and No. 14 from Red Mt. of Washington were among the poorest at most sites (Table 2) and should be avoided for seed collection. Provenances of Oregon coast origin suffered high mortality and were slow growing at most European trials (Fletcher and Samuel 1990; Ruetz *et al.* 1990).

Annually poor cone crops (Franklin 1974) and rapid loss of seed viability in storage (Edwards 1982) can hamper the scheduling of reforestation with noble fir. Furthermore, the productivity of noble fir plantations using wild seed can be substantially lower than expected because a high proportion of seeds from wild collections may be self-pollinated; post-embryonic lethals may be lacking, rendering nursery culling relatively ineffective; and inbreeding depression may hamper growth after outplanting (Sorensen *et al.* 1976; Sorensen and Miles 1982). To ensure a long-term supply of quality seeds and overcome some of the disadvantages of wild seeds, the establishment of seed production plantations and seed orchards should be seriously considered in British Columbia.

APPENDIX 1. Geographic origin of the seed sources

Prov. No.	Origin	Lat.°N	Long.°W	Elev. (m)
Noble fir				
1[a]	Odell Butte, Oregon	43° 27′	121° 52′	1950
2[a]	Juniper Ridge, Oregon	44° 35′	122° 20′	1700
3	Grass Mountain, Oregon	44° 26′	123° 40′	1060
4	Marys Peak, Oregon	44° 30′	123° 33′	1065
5	Fisher Point, Oregon	44° 33′	122° 02′	1220
6	Snow Peak, Oregon	44° 39′	122° 35′	1060
7	Elk Lake, Oregon	44° 49′	122° 06′	1200
8	Laurel Mountain, Oregon	44° 56′	123° 35′	975
9	One Hundred Road, Oregon	45° 06′	122° 18′	1130
10	Elk Mountain, Oregon	45° 20′	121° 39′	1220
11	Larch Mountain, Oregon	45° 32′	122° 06′	975
12	Mount Defiance, Oregon	45° 38′	121° 44′	1125
13	Larch Mountain, Washington	45° 43′	122° 17′	975
14	Red Mountain, Washington	45° 56′	121° 50′	1220
15	Hungry Peak, Washington	46° 07′	121° 54′	1280
16	French Butte, Washington	46° 20′	121° 57′	1300
17	Mud Lake, Washington	46° 24′	121° 37′	1425
18	McKinley Lake, Washington	46° 35′	122° 08′	900
19	Corral Pass, Washington	47° 01′	121° 28′	1615
20	Stampede Pass, Washington	47° 14′	121° 22′	1065
21	Stevens Pass, Washington	47° 43′	121° 08′	1000
22	Overgaard Forest Estate, Denmark	-	-	-
812	Green Timbers Nursery, British Columbia	-	-	-
813	Goat Mountain, Washington	46° 11′	122° 19′	970
815	Johnston Ridge, Washington	47° 47′	121° 15′	1220
Pacific silver fir				
594	TFL 38, British Columbia	50° 06′	123° 10′	1250
606	Silver River, British Columbia	49° 40′	121° 50′	900
631	Strathem, British Columbia	49° 28′	125° 15′	615
Mountain hemlock				
146	Beaufort River, British Columbia	48° 55′	124° 05′	823

[a] Excluded because of poor germination.

APPENDIX 2. Summary of ecological site diagnosis for the 12 noble fir provenance trials. (Trial sites have been arranged according to the site groups (Figure 3) – approximately from most to least productive based on average leader elongation and tree height).

Site and stratum number ···>	< ····· SITE GROUP I······>				< ············ SITE GROUP II ············>						< ········ SITE GROUP III·········>					
	BT-1	DU-1	MC-1	MC-2	GL-1	GL-2	WW-1	JF-1	JF-2	JF-3	EM-1	LG-1	WE-1	VH-1	MP-1	UZ-1
Biogeoclimatic zone	CWH	CWH	MH	MH	MH	MH	MH	<--CWH (ESSF-->			CWH	CWH	MH	ESSF	CWH	ESSF
Subzone/Variant/Phase[a]	xm2	mm2	mm1	mm1	mm1	mm1	mm1	ms1 mw)			mm2	ms1	mm1	mw	ms1	mw
								(borderline to ESSFmw)								
Project name	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857	EP 857
Location	BIGTREE	DUNCAN	MT. CAIN	MT. CAIN	GUYLINE	GUYLINE	MT. WA. W.	JOFFRE	JOFFRE	JOFFRE	ENGLISH	LOG CR.	MT. WA. E.	VAN HOR.	MASELPA.	UZTLIUS
No. ecological strata identified	1	1	2	2	2	2	1	3	3	3	1	1	1	1	1	1
Stratum no.	1	1	1	2	1	2	1	1	2	3	1	1	1	1	1	1
Elevation (m.a.s.l.)	550	795	1035	1035	1035	1035	1035	1030	1130	1130	915	1050	1160	1280	1430	1280
Slope gradient (%)	55	40	50	50	55	35	27	58	45	40	58	58	35	55	50	7
Aspect (degrees)	130	230	140	140	85	85	255	230	230	230	285	10	40	50	95	350
Slope position[b]	MD	UP	MD	MD	UP	MD	MD	MD	MD	MD	MD	LW	LW	LW	MD	CR
Surface shape[c]	ST	ST	ST	ST	CV	ST	CC	ST	ST	ST	ST	ST	CC	ST	ST	ST
Actual SMR[d]	SDF	F	F	MVM	F	M	F	SDF	F	W	SDF	FM	MVM	SD	F	MD
Relative SMR (hygrotope)[e]	3.5	3	4	5.5	4	5	4	3.5	4	7	2-3	4.5	5.5	3.5	4	2.5
Trophotope[f]	C	C	B	B	C	C	C	B	B	C	C	C	C	B	C/D	B
SNR (Trophotope)[g]	M	M	P	P	M	M	M	P	P	M	M	M	M	P	M/R	P
***** Soil features *****																
Humus form order	MOR	MOR	MOR	MOR	MOR	MOR	MOR	MOR	MOR	YR	MOR	MOR	MOR	MOR	MOR	MOR
Forest floor thickness (cm)	4	5	8	15	6	12	10	8	8	25	7	4	5	6	10	0.5
Ah horizon thickness (cm)	1															10
Ae horizon thickness (cm)		1	3		4	4	1	12	12		1	3	1	5	5	
Soil depth (cm)	60+	60	60	60	40	50	45+-	50+	50+	20+	50+	60+	45	50+	65	50+
Rooting depth (cm)	55+	50	40	20+	40	40	35	50+	50+	17	50+	60	30	40	55	45
Seepage (Y/N) depth (cm)	N	N	N	5+	N	N	N	N	N	5	N	N	N	N	N	N
Gleyed horizons (Y/N) depth (cm)	N	N	N	5+	N	N	N	N	N	0	N	45	13	N	N	N
Flooding (Y/N)	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N
Soil colour (Light, Med., Dark)	M	M	M		M	M	M	M	M	L	M	L	M	M	M	M
***** Soil discontinuities *****																
Depth range (cm)	0-60	0-60	0-60	0-50	0-40	0-45	0-35	0-50+	0-50	0-20	0-50+	0-60	0-30	0-30	0-25	0-50
Soil texture	LS	SL	SL	SL	LS	LS	SL	S	S	S	L	S	SL	S	SL	S
Coarse fragments (>2mm) (%)	60	60	45	45	30	30	20	60	60	30	40	40	45	30	25	20
II Layer depth range						45+								30-50+	25-60	
Soil texture						S								S	S	
Coarse fragments (>2mm) (%)						30								65	50	
III Layer depth range															60+	
Soil texture															SL	
Coarse fragments (>2mm) (%)															40	
Coarse frag./bedrock lithology[h]	VOLCAN.	VOLCAN.	GR(VOL)	GR(VOL)	GR-VOL	GR-VOL	VOLCAN.	GR	GR	GR	VOLCAN.	GR	VOLCAN.	GR-MF	MIXED	GR
***** Surface substrate *** Ground cover %**																
Decaying wood	10	30	30	30	20	35	70	30	35	20	25	40	30	40	15	5
Bedrock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cobbles & stones	5	2	0	0	10	5	0	20	10	5	5	5	5	3	2	2
Mineral soil	40	18	0	0	10	5	0	20	10	0	1	0	0	7	20	80
Forest floor	45	50	70	70	60	55	30	30	45	75	69	55	65	50	63	13

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[a] Biogeoclimatic Units of British Columbia. Unpub. mimeo, February 1992. B.C. Min. For., *Forest Science Research Branch.*

[b] MD = mid slope, UP = upper slope, LW = lower slope, CR = crest.

[c] ST = straight, CV = convex, CC = concave.

[d] SDF = slightly dry to fresh, F = fresh, MVM = moist to very moist, M = moist, W = wet, FM = *fresh to moist, MD = moderately dry, SD = slightly dry.*

[e] 0-8 = very xeric to hydric.

[f] b = submesotrophic, c = mesotrophic, d = permesotrophic.

[g] M = medium, P = poor, M/R = medium to rich.

APPENDIX 3. Format of ANOVA[a] for combined analyses of all sites (only the 18 provenances common to all sites considered)

Source	Df	Expected mean square[b]
Subzone	4	$\sigma^2 + b\sigma^2 p.s(z) + b.s_1\sigma^2 p.z + b.p\sigma^2 s(z) + b.p.s_1\ \theta_z$
Site (subzone)	7	$\sigma^2 + b\sigma^2 p.s(z) + b.p\ \sigma^2\ s(z)$
Block (site, subzone)	126	$\sigma^2 + p\theta b(s)(z)$
Provenance	17	$\sigma^2 + b\sigma^2 p.s(z) + b.s\ \sigma^2 p$
Prov. x subzone	68	$\sigma^2 + b\sigma^2 p.s(z) + b.s_1\ \sigma^2 p.z$
Prov. x site (subzone)	118	$\sigma^2 + b\sigma^2 p.s(z)$
Error	2097	σ^2

[a] Biogeoclimatic subzone considered fixed effect, and site and provenance random effect.

[b] Satterthwaite's approximate F-test to test the effect of subzone; b (harmonic mean of blocks per site per subzone = 11.08; s_1 (harmonic mean of sites per subzone) = 1.94.

APPENDIX 4. Format of ANOVA for each site group, assuming random effect of all factors

Source	Df	Expected mean square
Site	s-1	$\sigma^2 + b\sigma^2 sp + bp\ \sigma^2 s$
Block (site)	s(b-1)	$\sigma^2 + sp\ \theta b(s)$
Provenance	p-1	$\sigma^2 + b\sigma^2 sp + sb\ \sigma^2 p$
Site x provenance	(s-1)(p-1)	$\sigma^2 + b\sigma^2 sp$
Error	s(p-1)(b-1)	σ^2

APPENDIX 5a. Mean squares, variance components (percent of all components), and probability level of significance in F-test derived from the combined ANOVA of site group I (Figure 3) for 3rd-year leader elongation and 6th-year height (cm), and 1st- and 6th-year survival (%)

Source	Df	Leader			Height			Survival (%)					
								1st-year			6th-year		
		MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P
Site	2	2107	23	.00	4452	3	.00	4791	11	.00	1468	5	.00
Block (site)	33	69	6	.00	3461	28	.00	136	0	.76	149	1	.16
Provenance	17	136	6	.00	3013	11	.00	274	1	.14	204	0	.41
Site x provenance	34	40	3	.03	612	3	.01	176	0	.37	188	4	.02
Error	561	26	62		348	55		166	87		119	90	

APPENDIX 5b. Mean squares, variance components (percent of all components), and probability level of significance in F-test derived from the combined ANOVA of site group II (Figure 3) for 3rd-year leader elongation and 6th-year height (cm), and 1st- and 6th-year survival (%)

Source	Df	Leader			Height			Survival (%)					
								1st-year			6th-year		
		MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P
Site	2	405	11	.00	4487	6	.00	84667	47	.00	6340	10	.00
Block (site)	33	54	14	.00	1538	23	.00	427	1	.23	172	0	.92
Provenance	17	37	4	.00	659	5	.00	1973	3	.05	346	1	.26
Site x provenance	34	12	1	.35	116	0	.98	1001	6	.00	271	0	.37
Error	560	11	70		208	66		363	43		254	89	

APPENDIX 5c. Mean squares, variance components (percent of all components), and probability level of significance in F-test derived from the combined ANOVA of site group III (Figure 3) for 3rd-year leader elongation and 6th-year height (cm), and 1st- and 6th-year survival (%)

Source	Df	Leader			Height			Survival (%)					
								1st-year			6th-year		
		MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P	MS	VC(%)	P
Site	4	319	18	.00	7126	21	.00	137332	60	.00	454	0	.41
Block (site)	49	15	5	.00	373	7	.00	655	1	.00	341	2	.05
Provenance	17	25	3	.03	600	5	.00	2389	2	.02	730	2	.08
Site x provenance	68	12	5	.00	157	2	.06	1123	6	.00	452	0	.00
Error	800	7	69		121	65		393	36		250	96	

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