Performance of Lodgepole Pine Provenances at Sites in Southwestern British Columbia

By C. C. Ying

B. C. Ministry of Forests, Research Branch, 31 Bastion
Square, Victoria, B. C., V8W 3E7, Canada

(Received 2nd January 1991)

Abstract

Testing of 58 seed sources of *Pinus contorta* Dougl. at three locations over a 15-year period revealed the impact of both seed source and planting site, and their interaction. Site differences in total height varied from 270 cm to 493 cm, and 63% of trees at one site suffered snow damage. The local environment due to topography and soil conditions had significant impact on the quality of the lodgepole pine plantation. Provenance performance, in terms of growth, mortality and snow damage showed a broad regional differentiation; provenances of coast-interior transition origin were susceptible to winter injury and those from the Rocky Mts. (U.S.) were slow growing. Genetic differentiation among provenances from interior British Columbia, the Yukon Territory, and Alberta followed a northwest-southeast trend with a strong modifying effect of provenance elevation. Regression models relating provenance performance to geographic variables accounted for 52% to 73% of the among-provenance variation. Increasing winter hardiness and tolerance of snow damage was associated with decreasing growth potential from south and east to north and west, and from low to high elevation. Elevational differentiation at high latitudes was not as evident. Practical implications in terms of seed transfer and selection of seed sources are discussed.

Key words: Lodgepole pine, provenance, geographic variation, growth, survival, snow damage.

Introduction

Taxonomically, lodgepole pine (*Pinus contorta* Dougl.) is considered a complex of four subspecies, but is commonly accepted as consisting of an inland variety latifolia, and a coastal variety *contorta*, sometimes called shore pine (Critchfield, 1980). Results from provenance tests in the Yukon Territory and British Columbia have shown a sharp differentiation from coast to interior; seed sources with a trace of coastal influence were vulnerable to cold injury at sites with continental climate (Ying et al., 1985; Ying and Illingworth, 1986a); interior seed sources, on the other hand, were susceptible to diseases in the coastal environment (Hunt, 1981). These results suggest strong adaptive genetic differentiation from the maritime coast to the continental interior.

Provenance research with the inland variety has demonstrated a steep elevational cline (Rehfeldt, 1988; Ying et al., 1989). However, evidence also suggests that elevational genetic differentiation is not as clear among populations north of latitude 56° (Ying and Illingworth, 1986a). Lindgren (1983) and Fries and Lindgren (1986) reported that elevational differentiation among high latitude populations has a thresholds provenances from about 800 m grow faster than those from either below or above this elevation. Narrow elevational distribution (Koch, 1987) may have effectively prevented elevational differentiation in the species' northern range.

Shore pine, due to its stunted growth and scrubby form. is not a commercially important species. On the other hand, the inland variety is a major timber species in the interior region of British Columbia (B.C.). For this reason, lodgepole pine provenance research in B.C. is directed mainly towards the operational use of this species east of the Coast Mountains where an extensive series of trials were planted from 1973 to 1975 (Ying and Illingworth, 1986a).

Lodgepole pine, however, is known to be able to grow well at difficult sites. These difficult sites include the extensive area of exposed south aspects at medium to high elevations in the coastal-interior transition zone in southwest B. C. and of the dry high-elevation sites on the Chilcotin Plateau (*Fig. 1*). In the former, lodgepole pine is not an important component species of the forests, and

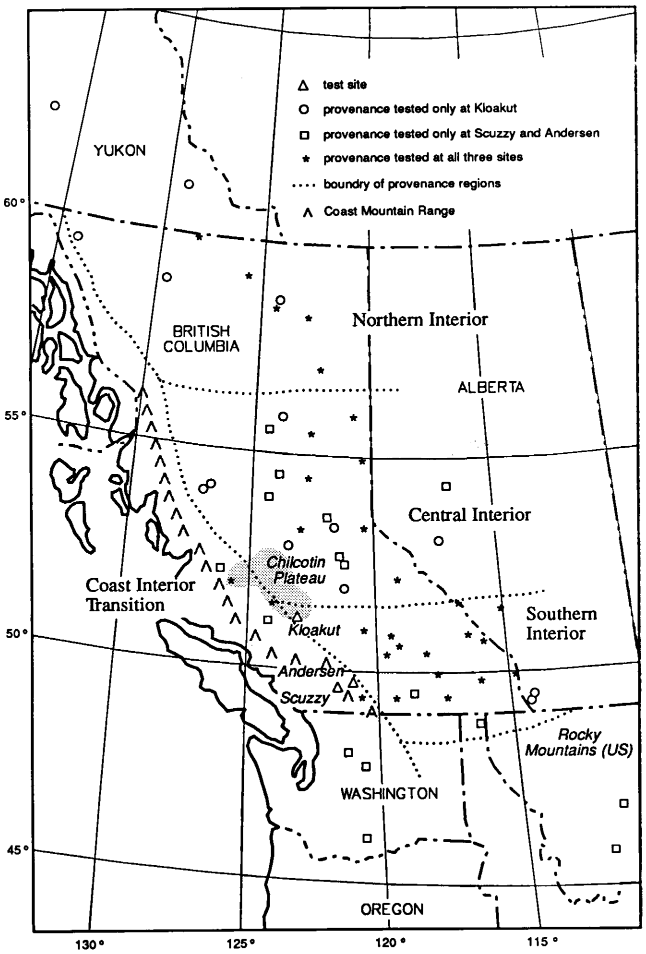

Figure 1. — Location of provenance samples, division of provenance regions (see *Table 1* for elevational ranges within each region), and test sites.

2A. 2B. 2C.

Figure 2. — Illustration of trees suffering different degrees of snow damage at Anderson and Scuzzy: A. severely damaged trees; B. moderately damaged trees which may recover and grow to harvestable timber; C. healthy and vigorous trees with no or minor injury.

cone crop is not frequent. Planting of this species may have to depend on non-local seed sources. It was recognized that selection of suitable seed sources may be critical for successful planting at these difficult sites, if non-local seeds have to be used. At the time when this study was initiated, it was conceived that interior lodgepole pine may be a potential seed source. To test this assumption, it was decided to establish provenance tests in this region.

Lodgepole pine is extensive on the Chilcotin Plateau (*Fig. 1*) and regenerated naturally. However, once the regeneration method changes, selection of seed sources becomes important. For this reason, the Chilcotin Plateau was included in this study.

Eventually, provenance tests were established in 1973 at three locations, one on the Chilcotin Plateau and two in the coast-interior transition zone in southwestern B. C. A sample of 58 seed sources covering the natural range of the subspecies *latifolia* in British Columbia, western Alberta and northern Cascades (CRITCHFIELD, 1980) were tested. The test plantations have been carefully maintained and provenance performance was assessed five times over a period of 15 years.

This paper reports geographic variation of provenance performance in growth, mortality and snow damage, and its practical implications on seed transfer and selection of seed sources.

Table 1. — Number of provenances and their elevational ranges in each region.

Region	Plantation[1]	No. of provenances	Elevational range (m)
N. Interior	K	10	457-1173
	S & A	5	457-1173
	common	5	457-1173
C. Interior	K	13	518-1204
	S & A	14	671-1280
	common	7	697-975
S. Interior	K	17	579-1661
	S & A	16	579-1661
	common	14	579-1661
C.-I. Transition	K	3	1059-1128
	S & A	8	1059-1128
	common	3	1059-1128
Rocky Mts. (US)	K	-	-
	S & A	2	2134-2134
	common	-	-

[1] K = Kloakut; S & A = Scuzzy and Anderson; common = provenances tested at all sites.

Table 2. — Format of combined ANOVA of Kloakut and Scuzzy.

Source	Df	EMS[1]
Site	1	$\sigma^2 + K_1\sigma^2 sp + 28K_1\sigma^2 s$
Blocks in Site	14	$\sigma^2 + 28\sigma^2 b(s)$
Provenance	27	$\sigma^2 + K_1\sigma^2 sp + 2K_1\sigma^2 p$
Region	3	$\sigma^2 + K_1\sigma^2 sp(r) + 2K_1\sigma^2 p(r) + 2K_1K_2\Theta$
Prov. in Region	24	$\sigma^2 + K_1\sigma^2 sp(r) + 2K_1\sigma^2 p(r)$
Site x Provenance	27	$\sigma^2 + K_1\sigma^2 sp$
Site x Region	3	$\sigma^2 + K_1\sigma^2 sp(r) + K_1K_2\sigma^2 sr$
Site x Prov. in Region	24	$\sigma^2 + K_1\sigma^2 sp(r)$
Error	377	σ^2

[1] K_1 = 7.5 and K_2 = 4.4, harmonic means of number of replications per site and number of provenances per region, respectively.

Materials and Methods

The 58 provenance samples (*Fig. 1*) span 18° of latitude, 25° of longitude and 1,200 m of elevation, and were divided into five regions (*Fig. 1*) according to the geographic patterns observed in other studies (YING and ILLINGWORTH, 1986a; YING et al., 1989). The number of provenances and elevational ranges of provenance samples in each region are given in *table 1*; elevational ranges of the provenance samples reflect the declining elevational distribution of natural lodgepole pine from low to high latitude (KOCH, 1987). Forty-five of the 58 provenances were tested at two sites (Scuzzy and Anderson), and 43 at a third (Kloakut) with 28 provenances common to all three sites. Each provenance consisted of bulked seeds from 10 to 15 parent trees, with a majority represented by seeds from 15.

The original plan was to establish two long-term field tests, one on the Chilcotin Plateau and one in the coast-interior transition in southwestern British Columbia, with 10 replications in each. Because of the difficulty of finding a site in the mountainous coast-interior transition which was large and uniform enough to accommodate the test, it was laid out at two locations, Scuzzy and Anderson, approximately 18 kms apart (*Fig. 1*) with 6 blocks at Scuzzy and 4 at Anderson. Due to differences in local topography and soil, growth was much more vigorous at Scuzzy than at Anderson. The sites were therefore treated as two separate tests. The Kloakut (Chilcotin Plateau) site was planted in May, and Scuzzy and Anderson in June, 1972. Provenances were planted in randomized complete blocks of 8-tree row-plots, spaced 2.5 m within and 3 m between rows. The test stock were 2+1 transplants grown at Red Rock Research Station (interior) for Kloakut, and at Cowichan Lake Research Station (coast) for Scuzzy and Anderson. They were grown in three replications at both nurseries.

Kloakut (latitude 51°38'; longitude 123°27'; elevation 1520 m) is a flat and dry, high elevation site; annual precipitation is about 400 mm and the frost free period is less than 50 days (ANNAS and COUPÉ, 1979). Due to a history of fire, the soil is exposed with very little organic material. Lodgepole pine dominates the natural forest. Both Scuzzy (latitude 49°49'; longitude 121°38'; elevation 950 m) and Anderson (latitude 49°52'; longitude 121°24'; elevation 1010 m) are located in the wet submaritime/subcontinental climatic zone with 1500 mm annual precipitation (half of it snowfall) and approximately 150 frost free days (KLINKA et al., 1984). Natural lodgepole pine only occurs scattered. The Anderson site is a northeast facing, narrow slope with gradients varying from 5% to 35%; parts of the four blocks extend over the ridge crest. Shallow stoney loam characterizes the soil of the Anderson site. The Scuzzy site is southeast facing with four blocks located on a steep (25% to 50%), but relatively uniform middle slope, and two blocks on a lower slope of irregular shape. The soil is deep sand, mostly over 50 cm in depth. Both sites are nutrient poor with humus layers mostly less than 5 cm.

Height growth and survival were recorded after 1, 3, 6, 10 and 15 growing seasons in the field (ages 4, 6, 9, 13, and 18 from seed) and diameter was measured only at Scuzzy and Anderson at the end of the 15th growing season. Tree age from here on means the number of years in the field. Height:diameter ratio was calculated as an indicator of stem taper. Volume was estimated according to the formula of KOVATS (1977). Tree injury and damage occurred extensively at Anderson and were assessed at both Anderson and Scuzzy in 1987 (age 16). Trees were classified into three categories according to the severity of damage, mainly by snow: a) severely damaged trees including those toppled, severely crooked, or with broken trunk, that probably will never recover and grow to harvestable timber (*Fig. 2A*); b) moderately damaged trees that may recover and grow to harvestable timber (*Fig. 2B*); c) healthy and vigorous trees uninjured or with minor injury (*Fig. 2 C*).

Analysis of the test results emphasized those traits that were not seriously confounded with other traits and also reflected the differentiating power of the test environment. For example, the extensive snow damage at Anderson seriously affected height but provided the environment to differentiate provenances in their ability to whithstand snow press. Therefore, at Anderson, snow damage was the only variable chosen as an indicator of provenance performance. For the same reason, total height, diameter and volume at Scuzzy, and height and survival at Kloakut were chosen as indicators of provenance performance at these two sites.

Data were subjected to analysis of variance (ANOVA) with provenance effect further subdivided into components of geographic regions and provenance-within-region. Combined ANOVA were done only for height and survival at Scuzzy (Transition) and Kloakut (Chilcotin). The main interest in combined ANOVA was site-provenance interaction. To reduce the scale effect of site difference (mean height at Scuzzy twice that at Kloakut) which could mask the variance of site-provenance interaction, plot means were adjusted by subtracting site means before the analyses. Survival percent was transformed to angular scale before ANOVA. Both site and provenance effects were considered random, and region fixed (*Table 2*); sites were treated as random because these sites are quite typical of the environmental conditions in Chilcotin and Transition.

For simplifying variance component estimate and F-test, provenance-within-region was used as the error term to asses the effect of provenance region (*Table 2*). It is equivocal statistically that interaction between site (a random factor) and provenance region (a fixed factor) be a component of the provenance region mean square (*Table 2*), which renders both variance component estimate and F-test an approximation. However, since interpretation of the variance component emphasized its age trend rather than its magnitude at a particular age, this simplification should not be critical. Results of ANOVA were presented as a percentage of variance components including the fixed factor.

Multiple regression was used to develop response models relating provenance performance to latitude, longitude, elevation, their quadratic forms and products, and geographic region of provenance origin; geographic region was treated as a set of qualitative variables coded as 1 or 0. Independent variables which significantly reduced the sum of squares in dependent variables were selected according to a stepwise method for maximizing R^2 (SAS Institute, Cary, NC, USA). To avoid over-fitting, only independent variables with partial regression coefficients statistically significant at the 0.05 or higher probability level were included in the model. Adequacy of the models were judged by the coefficient of determination (R^2), residual mean squares, and structure displayed by residuals. Patterns of geographic variation depicted by the regression models were then graphically presented. The purpose of the regression analyses is descriptive (depicting trend of geographic variation), not predictive (predicting provenance performance). To facilitate the comparison of geographic variation between sites and with the results of other studies, only provenances from Northern, Central and Southern Interior (*Fig. 1, Table 1*) were included in regression analyses. The lodgepole pine within this vast area is the most valuable genetic resource for silviculture and tree improvement in British Columbia.

Results

Site differences in height, survival, and the potential to produce high quality timber were large. Trees at Scuzzy grew 83% taller than those at Kloakut, and produced nearly twice the volume as those at Anderson (*Table 3*). The poorest provenance at Scuzzy grew faster than the best at Kloakut. Differences in survival among the three sites were not as striking as growth (*Table 4*). However, 36% of the living trees at Kloakut suffered winter injury (*Table 4*) suggesting substantial increase of mortality in the future at this site. High mortality occurred in the first three years after planting, 21% at Kloakut, 13% at Scuzzy, and 12% at Anderson.

At Anderson, 63% of the trees suffered various degrees of snow damage compared to 26% at Scuzzy; the percentage of severely damaged trees at Anderson was three

Table 3. — **Mean difference among provenances from different geographic regions in 15-year height, stem taper (height:diameter ratios), and volume at the three test sites.**

	Height (cm)			Stem taper		Volume (m^3)[1]	
Region	Anderson	Scuzzy	Kloakut	Anderson	Scuzzy	Anderson	Scuzzy
N. Interior	315	424	240	52	64	5.2	8.8
C. Interior	348	503	275	52	65	7.3	14.2
S. Interior	369	529	286	51	65	8.8	16.7
Coast/Interior Transition	344	453	263	50	62	8.0	12.0
Rocky Mt. (U.S.)	330	435	-	53	61	6.4	11.1
Site mean	350	493	270	52	64	7.7	14.0
LSD (.05)	37	44	20	3	2	2.0	2.5
LSD (.01)	50	59	26	4	3	2.7	3.4

[1] **Individual tree volume x 1000.**

Table 4. — Mean differences among provenances from different geographic regions in 15-year survival and 16-year snow damage at the three test sites.

	Survival (%)			(Survival[1] - W.I.) (%)	Snow damage (%)			
					Severe		Moderate	
Region	Anderson	Scuzzy	Kloakut	Kloakut	Anderson	Scuzzy	Anderson	Scuzzy
N. Interior	78	84	88	60	24	12	40	16
C. Interior	80	84	80	51	33	11	28	14
S. Interior	76	84	68	42	41	13	30	14
Coast/Interior Transition	81	82	67	37	27	10	27	14
Rocky Mt. (U.S.)	75	84	-	-	21	8	29	19
Site mean	79	84	76	49	33	11	30	15
LSD (.05)	13	10	12	9	17	6	10	6
LSD (.01)	18	13	16	12	23	8	14	8

[1] W. I.: Winter injured trees.

times higher than at Scuzzy (*Table 4*). Such trees likely will never recover and grow to harvestable timber (*Fig. 2A*). Greater stem taper at Anderson than at Scuzzy (*Table 3*) probably was the result of the cumulative effect of snow damage to height at the former.

Differences among provenances from different geographic regions were also large. Provenances originating from the southern and central interior, the southern interior ones in particular, were superior to those from other regions in growth, and this superiority was most obvious at Scuzzy (*Table 3*). At Scuzzy, the southern interior provenances grew 40% more volume and had significantly more slender stem form than those from the coast-interior transition (*Table 3*) where the Scuzzy and Anderson tests are located (*Fig. 1*), and none of the provenances from outside the central and southern interior grew above plantation mean in total height, diameter or volume. On the other hand, trees from the southern and central interior suffered the most severe snow damage at Anderson, higher than trees from other regions (*Table 4*). Observation suggests that fast growing trees with both long internodes and branches were susceptible to snow damage.

Table 5. — ANOVA by individual test site for height and survival. Variance components presented as intra-class correlations (percent of the total of all components).

Source	Df	Ht1	Ht3	Ht6	HT10	HT15	Surv. 15
		Trait[1]					
		Scuzzy					
Blocks in Site	5	22**	4**	5**	10**	16**	0^N
Region	4	25**	27**	23**	19**	22**	0^N
Prov. in Region	40	20**	12**	0^N	0^N	0^N	4^N
Error	211	33	57	72	71	62	96
Error MS		8	52	613	2583	7763	233
		Kloakut					
Blocks in Site	9	7**	22**	25**	27**	24**	14**
Region	3	21**	16**	0^N	8**	18**	20**
Prov. in Region	39	19**	8**	13**	7**	4**	13**
Error	377	53	54	62	58	54	53
Error MS		7	26	121	711	1866	222

[1] Htl: 1st:-year height, etc.; Surv. 15: percent of 15-year survival in angular scale. N: not significant; *) significant at 0.05 level; **) significant at 0.005 level or higher.

Regional differences in survival were small (not statistically significant) at Scuzzy and Anderson, but were large and highly significant at Kloakut (*Tables 4* and *5*). Provenances from the central and northern interior tolerated the harsh environment at Kloakut significantly better than those from the southern interior or coast-interior transition (*Table 4*).

ANOVA for individual sites (*Table 5*) confirmed the strong regional influence on height (*Table 3*), and this influence, relative to the component of provenance-within-region, increased after age 6. The error component for height increased rapidly from age 1 to 3 to 6 and then leveled off at Scuzzy, but was about the same magnitude at all ages at Kloakut (*Table 5*). A sudden drop in the regional component from age 3 to 6 at Kloakut was intriguing (*Table 5*). To aid the interpretation of this age trend in variance components, height increments between measurements were analyzed in the same manner as total height. The results showed a similar age trend as total height, that is, the ratio of region to provenance-within-region components increased with age except from age 1 to 3. The data also revealed that a dramatic convergence of regional means occurred at age 6 (1977) at Kloakut; the range in regional mean 6-year heights was only 4% of the site mean compared to about 14% at other years. No such convergence occurred at Scuzzy. Weather records at a station near Kloakut showed no unusual climatic event during the period of testing. Unstable pattern of variance in growth before age 6 was also observed at other test sites in interior British Columbia (Ying et al., 1989). This unstable pattern of variance in growth before age 6 was probably a natural phenomenon of lodgepole pine adjusting to the new environment after planting. The large 2+1 planting stock might have prolonged recovery from planting shock and also contributed to this unstable pattern of growth.

Survival was strongly associated with provenance origin at Kloakut, but not at Scuzzy where the error variance component accounted for over 90% of the total variation (*Table 5*). Kloakut with its harsh climate exposed the regional differences in hardiness (*Table 4*). The percentage of total variance associated with different sources changed very little after age 3 at both sites.

At Anderson, differences in percent of severely damaged trees among regions and among provenances within regions were highly significant, accounting for 3% and 27% of the variation respectively. Regional differences in stem taper (height : diameter ratio) were significant at Scuzzy, although they accounted for only 8% of the variation.

Combined ANOVA of Scuzzy and Kloakut for height showed a similar age trend as at individual sites, a steady increase in the regional component accompanied by a decrease in the provenance-within-region component from age 6 on (*Table 6*). This age trend can be expected if regional variance reflects natural selection of climatic adaptation. The components for the interaction terms showed no apparent age trend (*Table* 6). Combined ANOVA for survival showed significant effect of provenance region, but not provenance-within-region (*Table 6*); interactions of site with provenance origin were statistically significant at all ages. This reflects essentially the influence of the result at Kloakut, since provenance variation in survival at Scuzzy was small and not statistically significant (*Table 5*). The relative magnitude of variance components varied very little from age to age (*Table 6*), as was observed at individual sites.

The "best" regression models relating provenance performance to geographic variables of the seed source are given in *table 7*, and graphically illustrated in *figures 3* to *8*. The models accounted for 52% to 73% of the among-provenance variation (*Table 7*). The pattern of geographic and elevational variation depicted by regression models can be simply described as clinal from northwest to southeast with elevation imposing a strong modifying effect. This northwest-southeast trend reflects essentially a latitudinal (north-south) cline because of the geographical orientation of British Columbia. The modifying effect of provenance elevation seems to become weaker at high latitude, probably due to the narrow elevational range of lodgepole pine at high latitude (*Table 1*) (Koch, 1987). The qualitative variables representing geographic regions were not selected by the stepwise procedure in any of the regression models (*Table 7*), although ANOVA indicated a significant effect of region on growth at Scuzzy, and growth and survival at Kloakut (*Table 5*). High correlation of qualitative variables with latitude (r = 0.8) may have caused them to be eliminated.

Table 6. — Combined ANOVA of Kloakut and Scuzzy for height[1]) and survival. Variance components derived according to the format in *Table 1*, and presented as intra-class correlations (percent of the total of all components).

Source	Df	Years after planting				
		1	3	6	10	15
1				Height		
Site	1	-	-	-	-	-
Blocks in Site	14	18**	15**	9**	16**	16**
Region	3	13*	9*	2*	7**	14**
Prov. in Region	24	11*	9*	0^N	0^N	0^N
Site x Region	3	4^N	3^N	19**	5^N	7*
Site x Prov. in Region	24	10**	4^N	7**	3^N	3^N
Error	377	44	60	62	68	59
Error Ms		8	37	323	1524	4439
				Survival		
Site	1	8**	11**	10**	6*	7**
Blocks in Site	14	8**	8**	10**	11**	10**
Region	3	7*	7*	7*	7*	8*
Prov. in Region	24	0^N	3^N	4^N	5^N	6^N
Site x Region	3	13*	9*	9*	10*	11**
Site x Prov. in Region	24	11**	10**	7**	7**	5*
Error	377	52	51	52	54	53
Error Ms		208	228	239	233	225

[1]) Adjusted to site mean height before analysis. N: not significant; *) significant at 0.05 level; **) significant at 0.01 or higher level.

Table 7. — Summary of regression analysis for height (cm), survival (%), and percent of severely snow damaged trees.

Site	Dependent variable	Independent variable	Partial coefficient	Standard error	F-test p<	R^2
Kloakut	Ht. 15	Lat.	7.0542	1.8916	.0007	.732
		Long.	-0.2157	0.0881	.0194	
		Lat.^{2}	-0.0667	0.0174	.0005	
		Constant	-132.1555	53.2460	.0179	
Kloakut	Surv. 15	Lat.	69.6183	16.1390	.0001	.667
		Elev.	0.7123	0.1549	.0001	
		Long. x elev.	-0.0058	0.0013	.0001	
		Long.^{2}	0.1403	0.0333	.0002	
		Lat. x long.	-0.5419	0.1323	.0002	
		Constant	-2202.1776	493.4835	.0001	
Scuzzy	Ht. 15	Elev.	-0.0078	0.0018	.0002	.660
		Lat.^{2}	-0.0132	0.0016	.0001	
		Constant	97.9312	5.8499	.0001	
Anderson	Snow damage	Lat.	-73.3863	31.9389	.0290	.519
		Long.	-30.2290	13.6268	.0345	
		Elev.	-0.4049	0.1411	.0076	
		Lat. x elev.	0.0070	0.0027	.0134	
		Lat. x long.	0.5333	0.2538	.0444	
		Constant	4192.0977	1106.3089	.0204	

Elevational trends for height at Scuzzy, snow damage at Anderson, and survival at Kloakut are illustrated in *figures 3, 4* and *5*, respectively. The higher the elevation of seed origin of the provenances, the lower the growth potential (*Fig. 3*), the lower their susceptibility to damage caused by snow press (*Fig. 4*), and the higher their tolerance to harsh environments (*Fig. 5*), although elevational

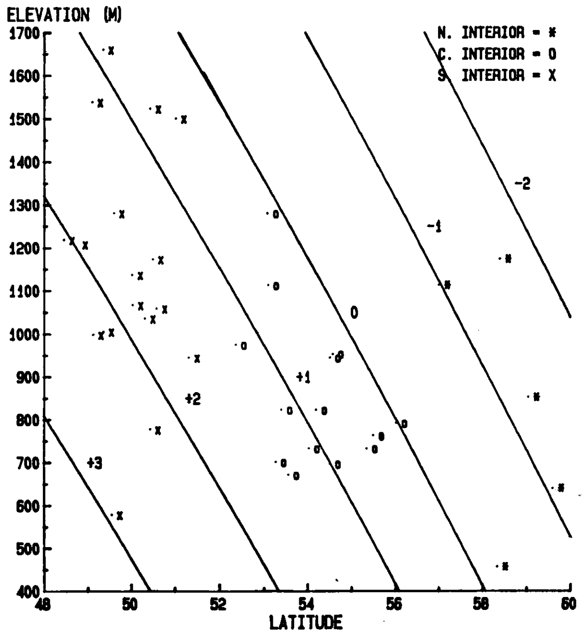

Figure 3. — Latitudinal and elevational trend in predicted 15-year height at Scuzzy derived from regression model in *Table 7*. Distance between lines is equivalent to one standard error of provenance means (e.g. +2 = 2 standard errors above mean).

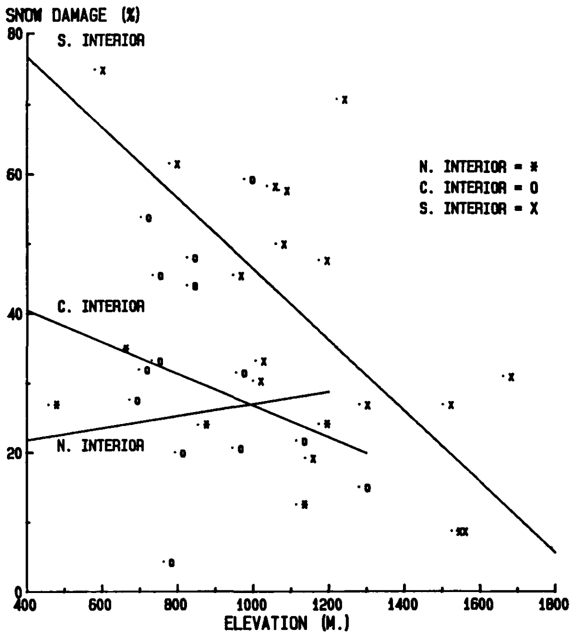

Figure 4. — Elevational trend in predicted percent of severely damaged trees (*Fig. 2A*) at Anderson derived from regression model in *Table 7*, at average latitude and longitude of southern, central and northern interior provenances (*Fig. 1*).

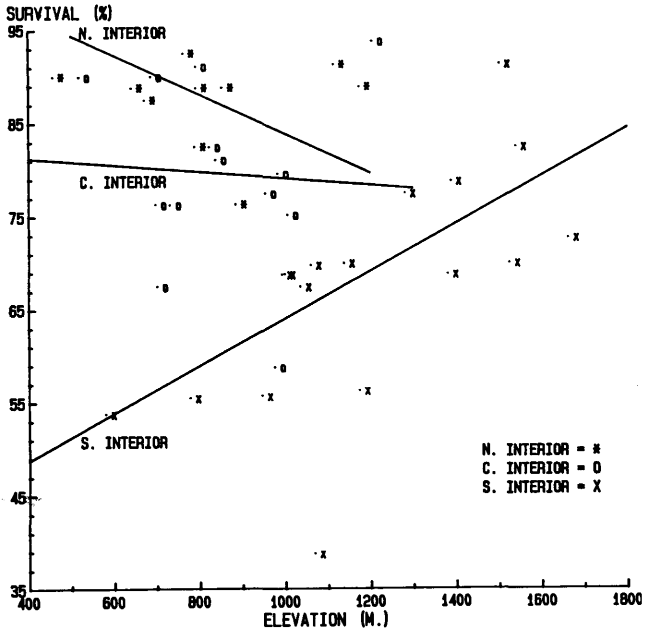

Figure 5. — Elevational trend in predicted 15-year survival at Kloakut derived from regression model in *Table 7*, at average latitude and longitude of southern, central and northern interior provenances (*Fig. 1*).

cline becomes less evident from southern to northern interior.

The northwest-southeast (north-south) trend in geographical patterns is shown for height at Scuzzy (*Fig. 3*) and Kloakut (*Fig. 6*), snow damage at Anderson (*Fig. 7*), and survival at Kloakut (*Fig. 8*). Volume and diameter at Scuzzy had the same pattern as height. At a constant elevation, the farther north and west the provenance origin, the lower their growth potential at both Scuzzy and Kloakut (*Figs. 3* and *6*), the higher their survival at Kloakut (*Fig. 8*), and the lower their vulnerability to snow damage at Anderson (*Fig. 7*).

Between-age correlations in height were much lower, on average, at Kloakut than at Scuzzy (*Table 8*). There were no major rank changes in total height at Scuzzy after 6 years, but at Kloakut relative ranking only became stable after 10 years. Correlations were based on the 28 common provenances.

Discussion

The different performance of lodgepole pine provenances at Scuzzy and Kloakut (*Figs. 3, 6 and 8; Tables 3* and *4*) is rather expected because of the very different environments at these two sites. But Scuzzy and Anderson are located within 18 km of one another and in the same climatic zone, and lodgepole pine is the recommended species for both sites according to the species selection guideline (KLINKA et al., 1984); the excessive snow damage at Anderson demonstrates the importance of local environment affecting the quality of a lodgepole pine plantation (*Table 4*).

The Scuzzy plantation is located on a southeast facing, mostly steep and long slope, whereas Anderson sits on a northeast facing, narrow, and gentle slope. The long, steep slope plus warm aspect may have prevented excessive accumulation of snow and thus reduced the incidence of damage at Scuzzy. The shallow and rocky soil at Anderson could also impair the development of a sound root system and thus render the trees vulnerable to snow press (31% of trees toppled).

Seed transfer in British Columbia is guided by limiting the distance of allowed transfer from origin (floating principle) and by zones of fixed boundary (Anon. 1989). However, a mosaic pattern of environmental variation as illustrated in the situation of Scuzzy and Anderson can render this traditional approach less effective. A site specific

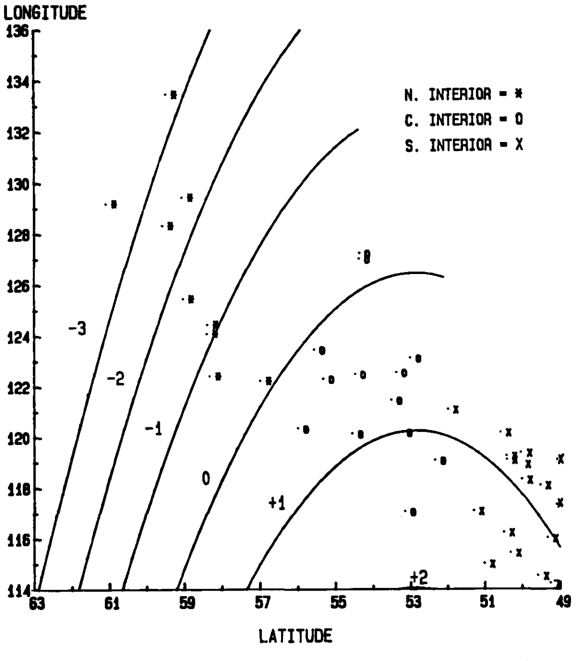

Figure 6. — Latitudinal and longitudinal trend in predicted 15-year height at Kloakut derived from regression model in *Table 7*, at average provenance elevation (900 m). Distance between lines is equivalent to one standard error of provenance means (e. g +2 = 2 standard errors above mean).

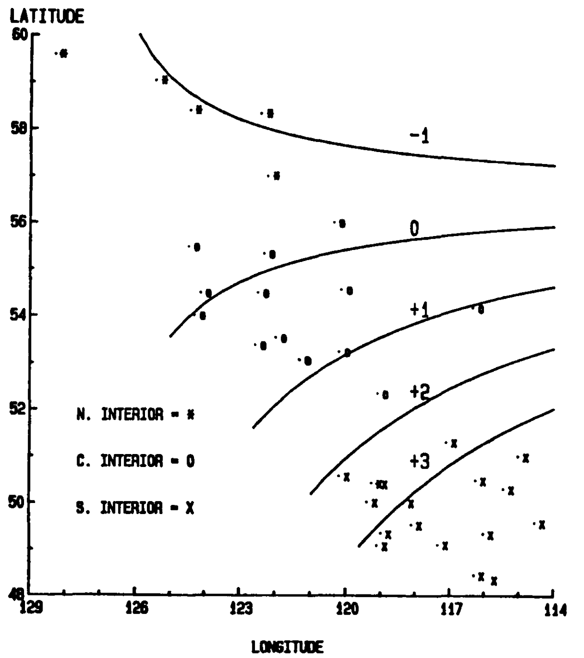

Figure 7. — Latitudinal and longitudinal trend in predicted percent of severely damaged trees (*Fig. 2A*) at Anderson derived from regression model in *Table 7*, at average provenance elevation (900 m). Distance between lines is equivalent to one standard error of provenance means (e.g. +2 = 2 standard errors above mean).

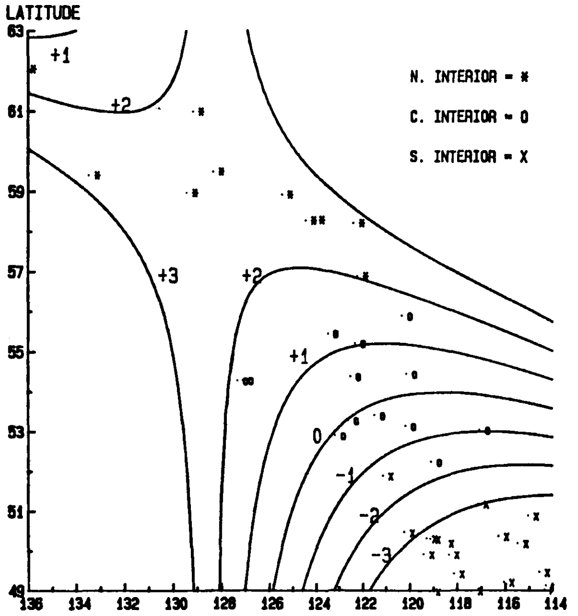

Figure 8. — Latitudinal and longitudinal trend in predicted 15-year survival at Kloakut derived from regression model in *Table 7*, at average provenance elevation (900 m). Distance between lines is equivalent to one standard error of provenance means e.g. +2 = 2 standard errors above mean).

transfer (based on biotic and abiotic characteristics of the sites rather than distance) can remedy this deficiency. However, this requires testing in diverse sites representing a good sample of the target environments. In the interior region of British Columbia, the network of lodgepole pine provenance trials (Ying and Illingworth, 1986a) may provide such an opportunity.

Table 8. — Correlation matrix of between-age height growth based on means of the 28 common provenances (*Fig. 1*), at Kloakut (above diagonal)and Scuzzy (below diagonal) (correlation coeff. = 0.37 and 0.48 significant at 0.05 and 0.01 level respectively).

Height[1]	Ht1	Ht3	Ht6	Ht10	Ht15
Ht1		.90	.03	.32	.43
Ht3	.93		.13	.47	.58
Ht6	.75	.85		.70	.43
Ht10	.56	.67	.91		.90
Ht15	.63	.70	.90	.95	

[1]) Ht1 = total height after one growing season, etc.

The broad regional pattern of geographic variation observed in this study is in agreement with the results of tests in the interior B. C. (Ying et al., 1985; YIng and Illingworth, 1986a; Ying et al., 1989), that is, provenances with coastal influence are less hardy and thus susceptible to winter injury at sites with continental climate, e. g. the poor performance of coast-interior transition provenances at Kloakut (*Table 4*). Also, provenances from the U. S. Intermountain/Rocky Mountains region are slow-growing (U.S.), e. g. the performance of Rocky Mts. (U.S.) provenances at Scuzzy (*Table 3*).

The commercially most valuable types of lodgepole pine exist in the vast interior of British Columbia, Alberta, and the Yukon (Koch, 1987), and in this area, the variation pattern of provenance performance in growth, mortality and snow damage was clinal along environmental gradients with latitude and longitude (southeast to northwest), and elevation (*Table 7*, *Figs. 3* to *8*). This northwest-southeast clinal pattern also has been reported in wood density (Yanchuk, 1986), reproductive growth and shoot morphology (O'Reilly and Owen, 1988 and 1989), cone production (Ying and Illingworth, 1986b), and resistance to needle cast (Hunt et al., 1987; Ying and Hunt, 1987).

The elevational cline in lodgepole pine has been well documented. Elevation was the single most important geographic variable affecting population differentiation of lodgepole pine from the Rocky Mountains of the United States in growth potential and freezing tolerance (Rehfeldt, 1988), and resistance to needle cast (Hoff, 1985; Rehfeldt, 1987). Similar elevational differentiation was also observed in this and a number of other studies in British Columbia, e. g. in needle-cast resistance (Hunt et al., 1987; Ying and Hunt, 1987), growth potential (Ying et al., 1985; Ying et al., 1989), and frost injury (M. Carlson, personal communication). The slow growth of provenances from the northern Cascades and Rocky Mountains (U. S.) (*Fig. 1*) in this (*Table 3*), and in other studies in British Columbia (Ying et al., 1985; Ying et al., 1989), can also be attributed to their high-elevation origin.

The elevational influence on population differentiation, however, seems to decrease with increase of latitude (*Figs. 4* and *5*). Ten-year height and volume among populations from north of latitude 53^{0} at two trials in the Yukon were not related to elevation of provenance origin (Ying and Illingworth, 1986a). Both Lindgren (1983) and Fries and Lindgren (1986) reported a threshold elevational effect of provenances from the same region; trees originating from below 800 m were of higher growth potential than those from above this elevation. Since the elevational range of natural lodgepole pine decreases with increasing latitude (Koch, 1987), less elevational differentiation at high latitude would be expected.

Strong site-and-provenance interaction on survival (*Table 6*) suggests the necessity of limiting seed transfer. Planting of lodgepole pine from southern interior (south of latitude 52^0) (*Fig. 1*) at dry high elevation sites in the Chilcotin Plateau is undesirable, in view of their high mortality and susceptibility to cold injury at Kloakut (*Table 4*, *Fig. 8*). Interior provenances from latitude 53^0 to 57^0 are expected to have above average survival (*Fig. 8*) and height growth (*Fig. 6*). Although these central interior provenances may be able to tolerate cold temperatures, their ability to cope with drought stress in the long run is unknown. It seems to be prudent to use local seeds at these harsh dry sites.

On the other hand, the 15-year testing results clearly indicated the potential of interior sources of lodgepole pine for reforestation at sites similar to Scuzzy in the coast-interior transition of the Lower Coast. There was no evidence that the closest provenances are optimal, i.e. provenances from the same climatic region where the tests are located did not survive or grow better (*Tables 3* and *4*). At Scuzzy, of the 10 most productive provenances, seven were of southern interior origin and three from the central interior which outgrew the "local" provenances (Coast/Interior Transition) by an average of 40% in volume. But snow damage to trees from these productive provenances occurred more than twice as often than to "local" ones at Anderson. Therefore, selection of planting sites to minimize the impact of snow damage or other potentially damaging events is equally important in order to capitalize on this potential for increased growth.

In addition to winter injury and snow damage, lodgepole pine can be very susceptible to various diseases, insect and rodent damage at some sites (Ying et al., 1985). This species is becoming increasingly important in reforestation in B.C., and planting of genetically improved trees will rapidly increase in the next decade. Unless we understand the nature of its genetic interaction with ecological factors of planting sites which accounts for these biotic and abiotic hazards to lodgepole pine plantation, projected gain in productivity from its intensive silviculture cannot be certain.

Acknowledgements

Doug Ashbee provided technical assistance, and L. McKnight conducted data analysis. I would like to thank Drs. R. K. Campbell, F. S. Sorensen and G. E. Rehfeldt for their thorough review of this paper.

Literature Cited

Annas, R. M. and Coupe, R.: Biogeoclimatic zones and subzones of the Cariboo Forest Region. B. C. Ministry of Forests, Victoria, B. C. (1979). —— Anon.: Interior seed transfer guidelines for cone collection planning and seedlot selection. B. C. Ministry of Forests (1989). —— Critchfield, W. B.: Genetics of lodgepole pine. USDA For. Serv. Res. Pap. No. 37 (1980). —— Fries, A. and Lindgren, D.: Performance of plus tree progenies of *Pinus contorta* originating north of latitude 55 °N in a Swedish trial at 64 °N. Can. J. For. Res. 16: 427—437 (1986). —— Hoff, R. J.: Susceptibility of lodgepole pine to the needle cast fungus *Lophodermella*. USDA For. Serv. Res. Note INT-349 (1985). —— Hunt, R. S.: Trisetacus (Acarina: Eriophyoidea) on *Pinus contorta* in British Columbia: distribution, symptoms, and provenance effect. Can. J. For. Res. 11: 651—653 (1981). —— Hunt, R. S., Ying, C. C. and Ashbee, D.: Variation in damage among *Pinus contorta* provenances to the needle cast *Lophodermella concolor*. Can. J. For. Res. 17: 594—597 (1987). —— Klinka, K., Green, R. N., Courtin, P. J. and Nuszdorfer, F. C.: Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest Region. B. C. Ministry of Forests and Lands, Victoria, B. C. Land Management Rep. 25 (1984). —— Koch, P.: Growth characteristics of lodgepole pine trees in North America. USDA For. Serv. General Tech. Pap. INT-227 (1987). —— Kovats, M.: Estimating juvenile tree volumes for provenance and progeny testing. Can. J. For. Res. 7: 335—342 (1977). —— Lindgren, K.: Provenances of Pinus contorta in northern Sweden. Department of Forest Genetics and Plant Physiology. The Swedish University of Agricultural Sciences, Umea, Sweden (1983). —— O'Reilly, C. and Owens, J. N.: Reproductive growth and development in seven provenances of lodgepole pine. Can. J. For. Res. 18: 43—53 (1988). —— O'Reilly, C. and Owens, J. N.: Polycyclis and branching in the upper crown in provenances of lodgepole pine. Can. J. For. Res. 19: 78—87 (1989) —— Rehfeldt, G. E.: Components of adaptive variation in *Pinus contorta* from the Inland Northwest. USDA For. Serv. Res. Pap. INT-375 (1987). —— Rehfeldt, G. E.: Ecological genetics of *Pinus contorta* from the Rocky Mountains (USA): a synthesis. Silvae Genet. 37: 131—135 (1988). —— Yanchuk, A. D.: Variation of genetic parameters of *Pinus contorta* var. *latifolia* (Engelm.) in central British Columbia: some evolutionary implications for multiple-trait selection. Ph. D. Thesis, Department of Forest Sciences, University of Alberta, Edmonton, Alta. (1986). —— Ying, C. C. and Hunt, R. S.: Stability of resistance among *Pinus contorta* provenances to *Lophodermella concolor* needle cast. Can. J. For. Res. 17: 1596—1601 (1987). —— Ying, C. C. and Illingworth, K.: Lodgepole pine provenance research in northwestern Canada with particular reference to the Yukon Territory. In: Provenances and Forest Tree Breeding for High Latitude. Proceedings of The Frans Kempe Symposium. (D. Lindgren [ed.]). Department of Forest Genetics and Plant Physiology. Swedish University of Agricultural Sciences, Umea, Sweden, Rep. No. 6, pp. 189—218 (1986a). —— Ying, C. C. and Illingworth, K.: Variation in number of seeds per cone, seed weight, and seed- and pollen-cone production in lodgepole pine natural stands, a wind-pollinated progeny plantation, and grafted clonal banks. In: Conifer Tree Seed in the Inland Mountain West. Symposium proceedings. (Compiled by R. C. Shearer). USDA For. Serv. Gen. Tech. Rep. INT-203, pp. 191—199 (1986b). —— Ying, C. C. Illingworth, K. and Carlson, M.: Geographic variation in lodgepole pine and its implications for tree improvement in British Columbia. In: Lodgepole Pine: The Species and its Management, Symposium Proceedings. (D. M. Baumgartner, R. G. Krebill, J. T. Arnott and G. F. Weetman [eds.]). Washington State University Cooperative Extension Service, Pullman, WA, pp. 45—53 (1985). —— Ying, C. C., Thompson, C. and Herring, L.: Geographic variation, nursery effect and early selection in lodgepole pine. Can. J. For. Res. 19: 832—841 (1989).