THE RANGE-WIDE BLACK SPRUCE STUDY: RESULTS FROM 12 EXPERIMENTS IN THE NORTHEAST

E.K. Morgenstern, M. Villeneuve, and R.B. LeBlanc[1]

Abstract.--Analysis of 34 provenances common to 12 locations and from 50 to 99 provenances at individual locations revealed that a weak clinal pattern of variation in height growth is found. Variation in survival was less well differentiated. Because of great regional differences, very few provenances are well adapted to more than one location. Tentative recommendations for provenance selection are made.

Additional keywords: Height growth, survival, test site variability, variation pattern, contour plotting.

A range-wide study of black spruce (*Picea mariana* [Mill.] B.S.P.) was initiated by the Canadian Forestry Service in 1967 in cooperation with several other organizations in North America (Morgenstern 1971). More than 200 provenances across the range were sampled and field experiments established between 1973 and 1977. Early results from these experiments and from two smaller, more regionally oriented trials indicated: (1) strong clinal trends in phenology and growth in Ontario nursery experiments (Morgenstern 1969, 1978); (2) a weakening of this trend in field experiments, with much more variation within regions, at the age of 15 years from seed (Boyle 1985); (3) the absence of clinal variation in Newfoundland presumably due to complex temperature patterns and maritime influences in general (Khalil 1975, 1981, 1984); (4) clinal patterns of variation in the Maritime Provinces (Fowler and Park 1982).

This report is based on the height and survival of provenances tested in Maine, New Brunswick, eastern Quebec, Nova Scotia, Prince Edward Island, and Newfoundland. Its objectives are to examine the variation pattern, relate this to factors at the place of seed origin, and to determine trends that might be useful for provenance selection.

MATERIALS AND METHODS

Between 1967 and 1970, seed collections were made across the range from Newfoundland to Alaska by the Canadian Forestry Service, the U.S. Forest Service, and some universities and wood-using industries. More than 200 provenances were included. This report is based primarily on the 34 provenances (Table 1) well represented in 12 northeastern experiments and on all provenances at each location for some analyses. These experiments were established between 1973 and 1977 and ranged over 8 degrees of latitude and 14 degrees of longitude (Table 2). Most experiments were visited by us and mea-

[1] Professor and Research Assistants, respectively Dept. of Forest Resources, Faculty of Forestry, University of New Brunswick, Fredericton, N.B. E3B 6C2. Canada.-The authors gratefully acknowledge Drs. P. Hall, D.P. Fowler, and A. Corriveau of the Canadian Forestry Service, and R. Wilkinson of the U.S. Forest Service, who provided the data for this report.

Table 1.--List of provenances common to 12 test locations

No.[a]	Place of Origin	Latitude °N	Longitude °W	Elevation[b] m
1	Holyrood, Nfld.	47.3	53.1	90
2	Jeffrey's, Nfld.	48.2	58.9	60
3	Bishop's Falls, Nfld.	49.0	55.4	60
6	Chignecto, N.S.	45.5	64.5	50
7	Bengal Road, N.S.	45.9	60.2	60
10	Guysborough Shore, N.S.	45.4	61.4	50
13	South Side Harbour, N.S.	45.7	61.9	20
14	North Gut, St. Ann's, N.S.	46.2	60.6	80
23	Geary, N.B.	45.7	66.5	20
25	William's Brook, N.B.	47.5	66.9	440
26	Gagetown, N.B.	45.6	66.5	90
28	Simpson's Field, N.B.	47.6	66.4	370
33	Tweedie Brook, N.B.	46.8	65.2	60
35	Black River, N.B.	46.9	65.1	30
42	Acadia Forest Exp. Sta., N.B.	46.0	66.3	40
45	Somerset County, Me.	45.5	70.0	300(est)
46	Somerset County, Me.	46.5	69.9	370
56	Chandler, Que.	48.4	64.9	120
65	Peribonka, Que.	49.6	71.3	400(est)
77	Senneterre, Que.	48.4	77.0	370
82	Causapscal, Que.	48.5	67.1	240
85	Blandford, Que.	46.3	72.0	90
93	Bancroft, Ont.	45.2	77.2	350
95	Chalk River, Ont.	46.0	77.4	160
97	Nipissing Game Preserve, Ont.	46.9	79.7	330
99	Timmins, Ont.	48.5	81.4	310
103	Massey, Ont.	46.3	82.8	240
105	Goulais River, Ont.	46.7	84.4	210
124	Shebandowan, Ont.	48.7	90.2	450
136	Oscoda County, Mich.	44.6	84.3	300(est)
138	Mackinac County, Mich.	46.1	84.8	300(est)
141	St. Louis County, Minn.	47.5	92.0	300(est)
142	Oconto County, Wis.	45.3	88.5	300(est)
149	Virginia, Minn.	47.7	92.5	300(est)
150	Itasca County, Minn.	47.5	93.7	300(est)

[a] Provenance numbers correspond to those in the common register prepared by Selkirk (1974).

[b] Elevations estimated when not given in original collection record.

surements of total height and survival were supplied by the cooperators in 1985.

All analyses are based on age 15 years from seed. Survival percentages were transformed by arcsin (Steel and Torrie 1980). General linear models were used for analysis of variance and correlation (SAS Institute 1982).

To determine optimum combinations of provenances and plantation location, contour plotting was attempted. The calculations are based on multiple regressions (Kung and Clausen 1984). Several different sets of data were used: all 12 test locations, all 8 Maritime locations, and the 4 New Brunswick locations.

RESULTS

General trends

Survival was high, ranging from 69% at Lac St. Ignace in Quebec to 91% at East Bideford, Prince Edward Island (Table 2), with many other locations exceeding 80%.

Table 2.--Test locations, with height and survival based on all provenances present at each location

Location	Lat. N	Long. W	Elevation m	Mean Height cm	Mean Survival %
Millertown, Nfld.	49°03'	56°15'	100	179	84
Roddickton, Nfld.	51°00'	56°10'	70	189	90
Acadia For. Exp. Sta., N.B.	46°00'	66°24	110	258	90
Black Brook, N.B.	47°18'	67°30'	430	379	80
Dromore, P.E.I.	46°18'	62°48'	40	308	90
East Bideford, P.E.I.	47°42'	64°00'	10	253	91
Cape Breton Highlands, N.S.	46°24'	60°48'	460	168	89
Pleasant Valley, N.S.	45°06'	62°42'	170	315	78
Stanley, N.S.	45°06'	63°54'	30	185	83
East Dalhousie, N.S.	44°42'	64°48'	230	312	79
Lac St-Ignace, Que.	49°00'	60°20'	500	220	69
Alfred, Me.	43°39'	70°43'	150	315	75

Height development, too, was satisfactory in general. Lowest values were measured on Cape Breton Highlands, N.S. (168 cm), a very cool environment, and at Millertown, Nfld. (179 cm), one of the northernmost test locations. The southernmost test at Alfred, Me. was not the tallest (315 cm); Black Brook in northern New Brunswick was in the first position (379 cm). Variation in the intermediate position of the remaining test locations can often be explained by soil fertility and local climate. For example, the relatively low height at Stanley, N.S. (185 cm) is the result of excessive moisture, low fertility, and competition from ericaceous species, while the moderate height at East Bideford, P.E.I. (253 cm) on a good site is probably related to excessive winds near the Atlantic Coast.

There was no clear trend with regard to the performance of the local provenances. While growing or surviving better than the mean of all provenances at some locations, there are also cases of performance below the mean. No location existed where the local provenance was best.

Correlations

The results of the correlations between factors of the place of seed origin including geographic variables (latitude, longitude, elevation) and climatic variables (growing season and day length) are summarized in Table 3. Correlations with latitude of origin were significant at 9 of the 12 locations for height and of both response variables with longitude and elevation were significant less frequently (1 to 4 times). Correlations with temperature (here expressed in terms of the growing season based on a threshold temperature of 5.6°C or 42°F) were also noticeable (2 to 6 times). Correlations with day length on the 21 June again were strong: 9 and 3 times out of 12 for height and survival, respectively. Overall, the correlations with height were stronger.

Table 3.--Number of significant correlations (at least 5% level) between height and survival and geographic and climatic variables of the place of seed origin, based on all provenances present at each location[a/]

Variable	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1, height	5	9	4	4	6	5	9
X_2, survival	-	3	3	1	2	4	3

a/ Remaining variables are as follows:

X_3, latitude

X_4, longitude

X_5, elevation

X_6, start of growing season based on 5.6°C (42°F)

X_7, length of growing season based on 5.6°C (42°F)

X_8, day length on 21 June

Rank correlations calculated for height and survival for measurements at age 9 reported by Fowler and Park (1982) and measurements made available by them for this study showed that, for three typical test locations, correlations are significant (Table 4).

Table 4.--Spearman's rank correlation coefficients between heights at 9 and 15 years, and survival between 9 and 15 years, for selected locations. All coefficients are significant at the 1% level

Location	Height	Survival
Black Brook, N.B.	0.94	0.66
Dromore, P.E.I.	0.90	0.93
East Dalhousie, N.S.	0.78	0.74

Contour plotting

The correlation analysis indicated that latitude of origin was the most important variable related to height and survival (Table 3). On this basis contour plotting was attempted to determine optimum combinations of proven ances and plantation locations, but the results were not encouraging. All r values were relatively low (highest value 0.38) and the trends changed with the set of data used. There was no overlap in the response surfaces of height and survival, hence clearcut conclusions could not be drawn.

Analysis of variance

The analysis of variance (Table 5) reflected the large effect of test locations and provenances within regions, both of which were significant at the 1% level. The error component for height was relatively small (8.1%) while that for survival was substantially larger (51.5%).

Table 5.--Analysis of variance for height and survival, including variance components (V.C.)

		Height		Survival	
Source	d.f.	M.S.[b]	V.C.%	M.S.[c]	V.C.%
Location	11	112,113**	87.2	25.619**	39.1
Region of origin[a]	2	2,211	0.0	6.974	1.9
Provenance in region	31	2,798**	4.6	3.212**	7.5
Location x region	22	475	0.1	0.848	0.0
Error	256	449	8.1	1.378	51.5

a/ Regions distinguished are Acadian, Great Lakes-St. Lawrence, and Boreal (Rowe, 1972). United States places of origin were grouped with the Acadian or Great Lakes-St. Lawrence Forest Region.

b/ F-tests are approximate due to unequal coefficients of expected mean squares. All those marked by ** are significant at the 1% level.

c/ Mean squares coded by 100 for simplication.

The large variation among provenances within regions suggests opportunities for provenance selection. To illustrate this possibility from the results at four locations, the five best provenances in height and survival are listed in Table 6. The list includes provenances not given in Table 1 but further details on their origin can be obtained from the register prepared by Selkirk (1974).

Table 6.--The five best provenances at four locations

Location	Prov. No.	Origin	Height (m)	Prov. No.	Origin	Survival (%)
Roddickton	26	N.B.	219	69	Que.	100
	20	P.E.I.	213	99	Ont.	100
	28	N.B.	207	24	N.B.	98
	24	N.B.	206	41	N.B.	98
	82	Que.	206	129	Ont.	98
Black Brook	44	Me.	411	74	Que.	98
	60	Que.	409	32	N.B.	95
	136	Mich.	403	35	N.B.	95
	85	Que.	398	70	Que.	95
	22	P.E.I.	397	20	P.E.I.	92
Lac St. Ignace	26	N.B.	269	62	Que.	93
	33	N.B.	269	156	Man.	91
	86	Que.	265	60	Que.	89
	81	Que.	262	68	Que.	86
	90	Que.	260	56	Que.	84
Alfred	136	Mich.	376	56	Que.	93
	122	Ont.	362	2	Nfld.	89
	97	Ont.	356	206	Conn.	89
	123	Ont.	349	10	N.S.	86
	149	Minn.	346	1	Nfld.	86

For Newfoundland (Roddickton), for height, three provenances came from New Brunswick and one each from Prince Edward Island and Quebec. Only one of these was also superior in survival; the remaining are from New Brunswick, Quebec and Ontario.

For New Brunswick (Black Brook), for height, the top group includes one each from Maine, Michigan, and Prince Edward Island and two from Quebec. None of these was also superior in survival.

For Quebec (Lac St. Ignace), height includes two from New Brunswick and three from Quebec. For survival, all of the top provenances differ from those listed for height.

For Maine (Alfred), the best provenance for height is from Michigan and of the remaining, one is from Minnesota and three from Ontario. For survival, the best provenances come from Quebec.

Overall, it seems that height growth is better in provenances from more southerly areas while survival exceeds in more northerly or continental (inland) provenances. There is very little agreement between height and survival, which was also indicated by the contour plotting exercise.

DISCUSSION

The genetic variation of any species can be influenced by the processes of mutation, migration, natural selection, introgressive hybridization, inbreeding and random genetic drift. In widely distributed forest tree species, with great differences in temperature and photoperiod across the range, there is no doubt that natural selection and migration are the dominant processes, giving rise to clinal variation patterns in certain characteristics. In addition, particularly within regions, the processes of inbreeding, random genetic drift, and introgressive hybridization are at work, and there is also natural selection in response to local factors, e.g. soil moisture and local climate. Therefore, superimposed on a clinal pattern, we can expect variation that could be ecotypic (i.e. related to local selective forces) or simply deviates from the broad clinal trends (Stern and Roche 1974).

The results of the experiments reported here demonstrated only weak clinal trends (Table 3). For Newfoundland provenances, this is not surprising in view of Khalil's (1981) observations. The variation of Maritime provenances is probably influenced by introgressive hybridization with red spruce (*Picea rubens* Sarg.), but only in a minor way (Manley 1975). The decline of clinal trends has also been observed by Boyle (1985) at age 15 in Ontario. Perhaps a plausible explanation for this phenomenon is the much greater diversity of field environments as compared to the nursery environments where the early studies were made. Nevertheless, as older European studies with Norway spruce (Picea *abies* (L.) Karst.) demonstrate, broad, general relationship of growth and hardiness to latitude and elevation persist (Schmidt-Vogt 1977), and should therefore be expected in black spruce as well, particulary in continental climates where temperature gradients are regular.

Judging from the results of these experiments, therefore, the task of provenance selection is not easy. One of the problems is the lack of agreement between height and survival; only at Roddickton was there a provenance (No. 24) that was in the top group for both characteristics. If survival is compared alone, No. 56 was in the top group at two locations. However, survival differences are not yet serious; there is generally high survival at all locations at this stage. A longer observation period is needed to see whether survival will differentiate more.

Among the provenances with superior height is No. 97 from Nipissing, Ontario, which was among the best at Alfred, and was also identified as a leading provenance in Ontario (Boyle 1985). No. 26 from Gagetown, New Brunswick, was among the best both at Roddickton and Lac St. Ignace. Beyond these two cases, there are no provenances superior at two test locations, but this number will increase if the list is expanded, say to the upper 10% or upper quartile of those tested at each location.

If the four test locations are representative for their regions, then the following general recommendations can be made to increase productivity:

1. In Newfoundland, use selected provenances from New Brunswick, Prince Edward Island, or Quebec.
2. In New Brunswick, use selected provenances from New Brunswick, Maine, or Quebec.
3. In eastern Quebec, use selected provenances from southern Quebec or New Brunswick.
4. In southern Maine, use south-central Ontario or Lake States provenances.

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