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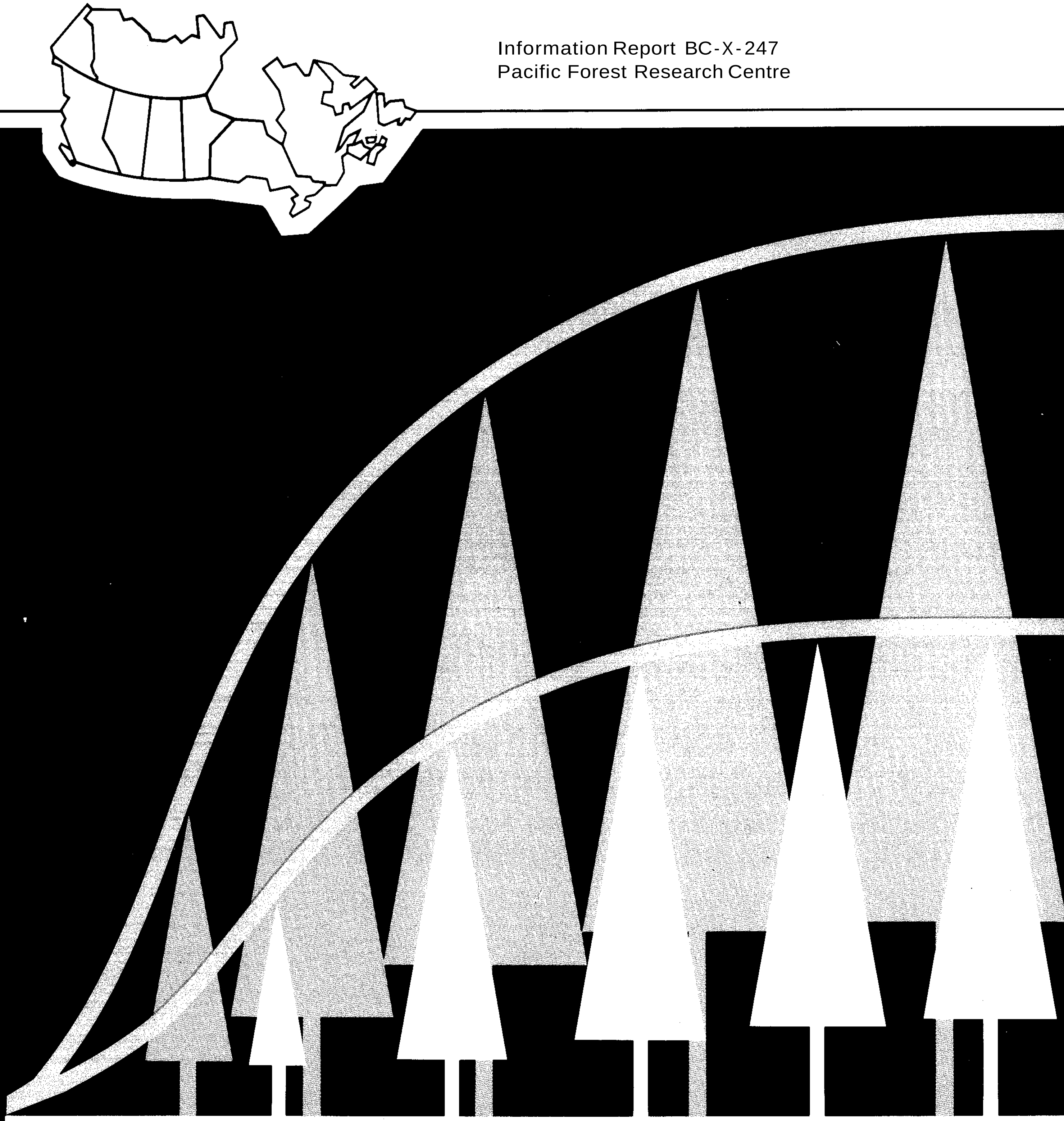

Site index curves for lodgepole pine from the southeastern Yukon

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ABSTRACT

Stem analysis data from 86 destructively sampled lodgepole pine *(Pinus contorfa* Dougl.) trees from ecoregions **2, 4** and 5 of the Yukon Territory was used to develop a site index equation for the grouped ecoregions. The formula utilized was:

$$Z = a + b(\text{age}) + c(\text{age})^2, \text{ where } Z = \text{age}^2/\text{ht}.$$

Curves were plotted (index age = 100) for 2 metre site classes.

RÉSUMÉ

Les ésulta s de l'analyse de la ige, echar illonnee de facon destructive, de 86 pins tordus *(Pinus contorfa* Dougl.) des ecoregions 2, 4 et 5 du Yukon ont servi a etablir une equation de l'indice de station pour les groups d'ecoregions. En voici la formule:

$$Z = a + b(\hat{a}\text{ge}) + c(\hat{a}\text{ge})^2, \text{ oh } Z = \hat{a}\text{ge}^2/\text{hauteur}.$$

Des courbes ont été tracees (Age type = 100) pour les classes de stations de 2 mètres.

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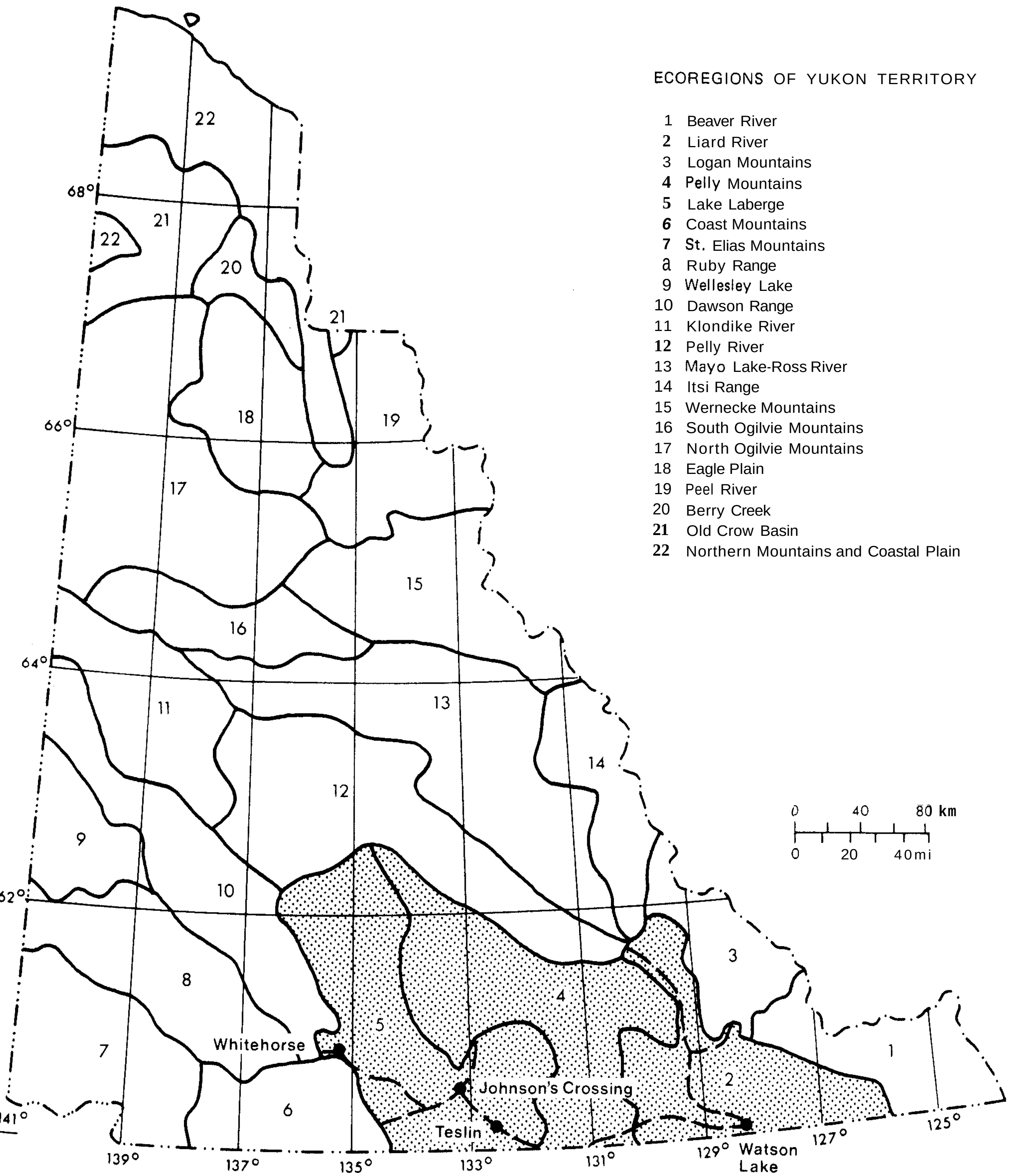

Aher: Oswald dnd Senyk (1977)

FIGURE 1. Sampled ecoregions.

INTRODUCTION

Productive capacity of a forest site is a determinant of the site's total volume and rate of growth and is usually quantified as site index: a measure of the height of the dominant and codominant trees at a specific age. The purpose of this report is to present site index curves for lodgepole pine (*Pinus contorta* Dougl.) for Yukon ecoregions 2, 4, and 5 (Oswald and Senyk 1977). Tree samples were taken on plots along the Alaska Highway from near Watson Lake (at 1050.0 km) west to a point southeast of Whitehorse (at 1356.0 km), and along the Robert Campbell highway north of Watson Lake to km 153.15. These samples cover the range of lodgepole pine accessible by road in the three ecoregions (Fig. 1).

METHODS

Between 1980 and 1981, 108 plots were randomly established in the Yukon Territory as part of the Canadian Forestry Service Energy From the Forest (ENFOR) program. Data from these plots, collected on contract by Nawitka Renewable Resource Consultants Ltd., Victoria, B.C., were intended for the development of biomass prediction equations (Massie 1983). Thirty of the 108 biomass plots contained lodgepole pine. All but three of these plots were located in ecoregions 2, 4 or 5. The three plots located in ecoregion 12 were dropped from the analysis because of insufficient sample size. In addition, all trees in the suppressed and intermediate crown classes included in the original biomass study were eliminated, thus reducing the sample from the original 149 trees to 86 dominant and codominants for use in the site index study (Table 1).

All trees were marked, felled and sectioned, with discs removed at stump height (0.3 m), breast height (1.3 m), and every 2 metres thereafter. Annual growth along two radii of average (Chapman and Meyer 1949) length was measured using an ADDO-X tree ring measuring instrument. To determine tree age, a correction factor of 3 years, obtained from a subsample of tree stumps, was added to the stump age. Annual volume, volume growth, DBH, and height at decadal intervals were calculated for each tree from stem analysis data using the computer program VOLCHA. The VOLCHA output was separated by ecoregion for independent testing. Several equations commonly used in site index studies were tested for each ecoregion and groups of ecoregions using the multiple linear regression (P1R) package available in BMDP (Dixon and Brown 1979). A summary of the results may be found in Appendix A.

Table 1. Summary statistics of sample trees

Ecoregion	No. of Plots	No. of Trees	Average Tree Age (yrs)	Range (yrs)	Average Tree Height (m)	Range (m)	Average Tree DBH (cm)	Range (cm)	Average Tree Volume (m^3)
2	8	32	94	19-147	13.4	5.7-19.1	12.8	6.2-26.2	0.119
4	4	17	87	17-151	10.6	3.6-15.4	12.5	4.6-22.9	0.102
5	5	37	68	45-160	12.2	5.1-22.7	13.0	4.3-30.3	0.141
Total	17	86	80						

RESULTS AND DISCUSSION

The data from ecoregions 2, 4 and 5 were combined. Covariance analysis indicated that ecoregions *2* and 5 were not significantly different, but that ecoregion 4 differed from ecoregions *2* and 5 (Fig. *2)*. However, because of a significant overlapping of the respective scatter plots and because all three curves show a similar pattern (Fig. 2), these differences may be attributed to differences in site quality (lower quality in the sample from ecoregion 4) and, therefore, departures from a common mean. For these reasons, data from ecoregions 2, 4, and 5 are considered as a single group.

Average age, height, volume, and dbh of the sample trees are summarized in Table 1. Given the relatively high average age of sample trees (80 years) and the slow growth of lodgepole pine in the Yukon, an index age of 100 years was chosen. The site index curves for grouped ecoregions *2*, 4, and 5 are presented in Figure *3* and in tabular form in Table 2. These curves were developed as indicated in Appendix B.

Alemdag (1971, 1976) presented preliminary site index curves for the upper Liard River drainage of the Yukon Territory for lodgepole pine. Differences in methodology, and a different range for sample areas make strict comparisons between results not particularly meaningful. Alemdag's samples are from ecoregion *2* only, and he used breast-height age and standing height, whereas our samples are from ecoregions 2, 4 and 5, and our procedures are those of destructive sampling and stem analysis as generally described in Curtis (1964) and Herman *et al.* (1975). However, overlay of the plots of site index curves from the two studies shows a relatively good correspondence. Further work for other ecoregions and for other species is required.

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We thank Dr. C. Simmons for his assistance in the statistical analysis.

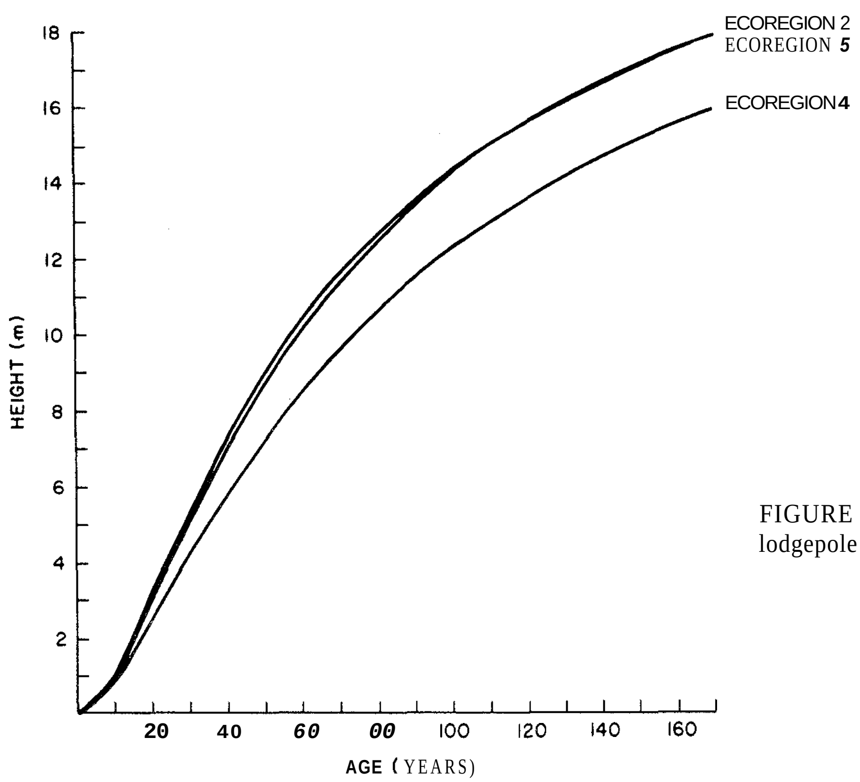

FIGURE 2. Height vs age curves for lodgepole pine for sampled ecoregions.

Table 2. Average height of dominant and codominant trees by age and site index

Age	Site Index								
	8	10	12	14	16	18	20	22	24
1	0.65	0.77	0.89	0.99	1.09	1.18	1.26	1.34	1.41
15	1.15	1.43	1.69	1.96	2.22	2.47	2.72	2.96	3.20
20	1.68	2.12	2.58	3.04	3.52	4.01	4.51	5.03	5.56
25	2.20	2.82	3.47	4.15	4.88	5.64	6.45	7.31	8.22
30	2.71	3.50	4.34	5.24	6.21	7.25	8.38	9.60	10.92
35	3.20	4.15	5.17	6.27	7.47	8.77	10.18	11.73	13.44
40	3.67	4.77	5.95	7.23	8.62	10.14	11.81	13.64	15.66
45	4.13	5.36	6.68	8.12	9.67	11.37	13.23	15.27	17.52
50	4.56	5.91	7.36	8.93	10.62	12.45	14.46	16.64	19.04
55	4.98	6.43	'1.99	9.66	11.46	13.40	15.50	17.78	20.26
60	5.38	6.93	8.58	10.34	12.22	14.23	16.39	18.71	21.21
65	5.76	7.39	9.12	10.95	12.89	14.95	17.13	19.47	21.96
70	6.12	7.83	9.62	11.51	13.49	15.57	17.77	20.08	22.53
75	6.47	8.24	10.09	12.02	14.02	16.12	18.30	20.59	22.98
80	6.80	8.63	10.53	12.48	14.51	16.60	18.76	21.00	23.31
85	7.12	9.00	10.93	12.91	14.94	17.02	19.14	21.33	23.57
90	7.42	9.35	11.31	13.31	15.33	17.38	19.47	21.60	23.76
95	7.72	9.69	11.67	13.67	15.68	17.71	19.76	21.82	23.90
100	8	0	12	14	16	18	20	22	24
105	8.27	0.30	12.31	14.31	16.29	18.26	20.21	22.15	24.07
110	8.53	0.58	12.60	14.59	16.56	18.49	20.39	22.27	24.12
115	8.78	0.85	12.88	14.86	16.80	18.69	20.55	22.37	24.14
120	9.02	1.11	13.14	15.11	17.02	18.88	20.69	22.44	24.16
125	9.25	11.36	13.38	15.34	17.22	19.05	20.81	22.51	24.16
130	9.48	11.59	13.61	15.55	17.41	19.20	20.91	22.56	24.15
135	9.69	11.81	13.83	15.75	17.58	19.33	21.00	22.60	24.13
140	9.90	12.03	14.04	15.94	17.74	19.46	21.09	22.64	24.11
145	10.10	12.23	14.23	16.12	17.89	19.57	21.16	22.66	24.09
150	10.30	12.43	4.42	16.28	18.03	19.67	21.22	22.68	24.06
155	10.48	12.62	4.60	16.44	18.16	19.77	21.28	22.69	24.03
160	10.67	12.80	4.77	16.59	18.28	19.86	21.33	22.70	23.99
165	10.84	12.97	4.93	16.73	18.39	19.94	21.37	22.71	23.96
170	11.01	13.14	5.08	16.86	18.50	20.01	21.41	22.71	23.92
175	11.18	13.30	5.23	16.99	18.60	20.08	21.45	22.71	23.89
180	11.34	13.45	15.37	17.11	18.69	20.14	21.48	22.71	23.85
185	11.49	13.60	15.50	17.22	18.78	20.20	21.51	22.71	23.82
190	11.64	13.75	15.63	17.33	18.86	20.26	21.53	22.70	23.78
195	11.79	13.88	15.75	17.43	18.94	20.31	21.56	22.70	23.75
200	11.93	14.02	15.87	17.53	19.01	20.36	21.58	22.69	23.71

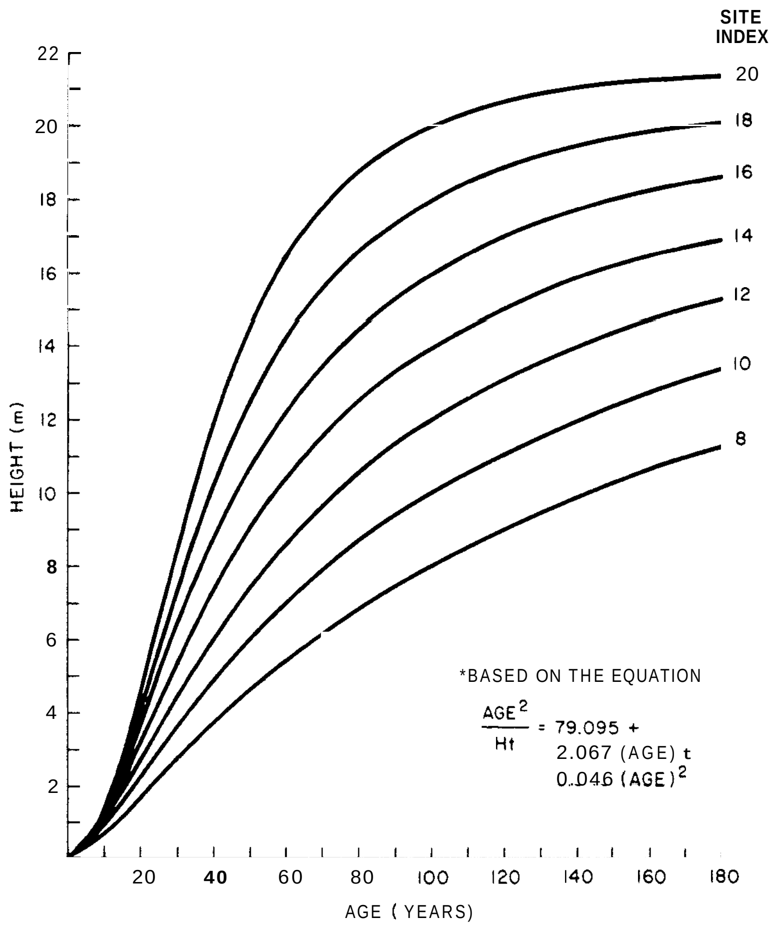

FIGURE 3. Site index curves for lodgepole pine—Yukon Territory, Ecoregions 2, 4 and 5.

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APPENDIX A

Regression Analysis

The equations that best fit the data are:

Equation 1: $Z = a + b(\text{age}) + c(\text{age})^2$

where $Z = \frac{(\text{age})^2}{\text{ht}}$ (Prodan 1951)

Equation 2: $\text{ht} = a + b(\text{age}) + c(\text{age})^2$
(Kirby 1975)

Equation 3: $\text{ht} = a + b(\text{age}) + c(\text{age})^2 + d\left(\frac{1}{\text{age}}\right)$
(Hegyi *et al.* 1979)

Equation 4. $\log(\text{ht}) = a + b\left(\frac{1}{\text{age}}\right)$
(Avery and Burkhart 1983)

Coefficients of determination and standard errors are shown in Table A1.

Equation 1, which best fits the data, was developed by Prodan (1951) and has been used recently by King (1966), Demars and Bell (1970), and Wiley (1978). The values for the coefficient of determination are consistently higher than those obtained using any other equation. This, combined with randomly distributed residuals, made this the equation of choice.

Equation 2 provides a random distribution of residuals and fits the data quite well, except at higher ages. Because this equation is parabolic, it tended to underestimate tree heights of older trees. If this equation were used, further data collection from higher age groups would be required.

Equation 3 was used in the development of the latest British Columbia Ministry of Forests site index equations (Hegyi *et al.* 1979). However, we found that the inverse of age term is not significant in the case of Yukon lodgepole pine. For this reason, the r^2 values and coefficients of equations 2 and 3 are identical (Table **A1**).

Equation **4** is the standard model for height versus age (Avery and Burkhart 1983). This model, although easy to fit, did not describe the data well. Examination of a plot of residuals showed that the model consistently underestimated tree height at low ages and overestimated tree height at higher ages. This, along with low r^2 values, lead to the elimination of this equation.

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Because linear transformations were used to fit the coefficients to Prodan's (1951) non-linear equation, the multiple correlation coefficient (r) should be considered to be an approximation.

Table A.1. Equations tested and statistics obtained

Equation	Ecoregion 2	Ecoregion 4	Ecoregion 5	Ecoregion 12	Ecoregions 2, 4, 5	Ecoregions 2, 4, 5, 12
1. $Z = a + b(age) + c(age)^2$, where $Z = \frac{(age)^2}{ht}$*						
	r = 0.928	r = 0.990	r = 0.916	r = 0.957	r = 0.947	r = 0.945
	r^2 = 0.862	r^2 = 0.979	r^2 = 0.838	r^2 = 0.917	r^2 = 0.896	r^2 = 0.892
	Se = 108.72	Se = 57.66	Se = 101.99	Se = 66.00	Se = 102.004	Se = 101.240
	a = 65.240	a = 78.876	a = 76.697	a = 64.282	a = 79.095	a = 76.894
	b = 2.330	b = 3.395	b = 2.281	b = -0.394	b = 2.067	b = 1.737
	c = 0.042	c = 0.041	c = 0.041	c = 0.065	c = 0.047	c = 0.050
2. $ht = a + b(age) + c(age)^2$**						
	r = 0.897	r = 0.974	r = 0.836	r = 0.934	r = 0.874	r = 0.873
	r^2 = 0.804	r^2 = 0.947	r^2 = 0.699	r^2 = 0.873	r^2 = 0.764	r^2 = 0.761
	Se = 2.227	Se = 1.066	Se = 3.082	Se = 1.863	Se = 2.536	Se = 2.559
	a = -0.752	a = -0.537	a = -1.107	a = -1.235	a = -0.864	a = -0.819
	b = 0.250	b = 0.182	b = 0.272	b = 0.368	b = 0.249	b = 0.259
	c = -0.001	c = -0.0005	c = -0.001	c = -0.002	c = -0.001	c = -0.001
3. $ht = a + b(age) + c(age)^2 + d(\frac{1}{age})$*** — coefficient d for $\frac{1}{age}$ term in this equation was not significantly different from zero, therefore this equation became equal to equation No. 2, above.						
4. $\log(ht) = a + b(\frac{1}{age})$****						
	r = 0.883	r = 0.929	r = 0.888	r = 0.902	r = 0.895	r = 0.891
	r^2 = 0.780	r^2 = 0.863	r^2 = 0.789	r^2 = 0.814	r^2 = 0.801	r^2 = 0.794
	Se = 0.184	Se = 0.169	Se = 0.222	Se = 0.157	Se = 0.199	Se = 0.198
	a = 1.140	a = 1.081	a = 1.110	a = 1.208	a = 1.119	a = 1.131
	b = -8.676	b = -9.433	b = -8.902	b = -8.104	b = -8.963	b = -8.867

* Prodan (1951), King (1966), Wiley (1978)
** Kirby (1975).
*** Hegyi *et al.* (1979).
**** Averyand Burkhart (1983).

Appendix B

Derivation of lodgepole pine site index equations using anamorphic curves

Regression analysis indicated that equation 1 best fits the stem analysis data (see Table A.1).

$$\frac{A^2}{ht} = a + bA + cA^2 \qquad (1)$$

where: ht = height in metres
A = age in years
a = 79.095
b = 2.067
c = 0.046
r^2 = 0.896

By the definition of site index, at index age the site index must equal the height. Thus, substituting index age (Ai) for age (A) and site index (SI) for height (ht) into equation 1, one gets:

$$\frac{Ai^2}{SI} = a + bAi + cAi^2 \qquad (2)$$

solving for b:

$$b = \frac{Ai}{SI} - \frac{a}{Ai} - cAi \qquad (3)$$

Substituting equation (3) into equation (1), one obtains (4):

$$ht = \frac{A^2}{a + \left(\frac{Ai}{SI} - \frac{a}{Ai} - cAi\right)A + cA^2} \qquad (4)$$

By algebraic rearrangement, one arrives at the equation relating SI to age and height:

$$SI = \frac{AiA}{A\left(\frac{A}{ht} + \frac{a}{Ai} + c(Ai - A)\right) - a} \qquad (5)$$

where: a = 79.095
c = 0.046
Ai = 100