A Site Index Formula for Peatland Black Spruce in Ontario

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Abstract

Site index formulas were derived for peatland black spruce (*Picea mariana* [Mill.] B.S.P.) in northern Ontario based on stem analysis of 60 dominant and codominant trees. Non-linear regression analysis and a biological growth function were employed to express both height as a function of site index and stand age and also site index as a function of stand height and age. Analysis of results indicates that peatland black spruce has a different pattern of height growth than that shown by Plonski's site index curves, particularly for site indices less than 8 m and stands older than 80 years.

Résumé

A partir de l'analyse des tiges de 60 arbres dominants et co-dominants, l'auteur a dérivé des formules d'indice stationnel pour l'épinette noire de tourbières (*Picea mariana* [Mill.] B.S.P.) dans le nord de l'Ontario. Il a employé l'analyse de régression non linéaire et une fonction de croissance biologique pour exprimer à la fois la hauteur en fonction de l'indice de station de même que l'âge du peuplement, et l'indice de station en fonction de la hauteur et de l'âge du peuplement. L'analyse des résultats indique que l'épinette noire de tourbières n'a pas la même allure de croissance que celle démontrée par les courbes d'indice de station de Plonski, particulièrement pour les indices de station de moins de 8 m et les peuplements de plus de 80 ans.

Introduction

One of the most common means of estimating the potential productivity of a forest stand is based on height and age of existing stands. Besides identifying potential site productivity, site index curves have been used, in the absence of localized growth data, to estimate stand height growth (Buckman 1962) and also potential height growth of individual trees (Ek and Monserud 1974).

Site index curves applicable to most major Canadian timber species have been prepared (Payandeh 1974a and 1974b). They have been constructed either by the anamorphic method (Bruce 1926, Plonski 1956) or by the stem analysis method (Stage 1963, Curtis 1964, Carmean 1972). Of the two methods stem analysis usually results in a more realistic assessment of potential site productivity. This is partly because more information is obtained from each sample tree — a series of

heights and corresponding ages — and most stem analysis procedures allow for the expression of polymorphic height growth patterns. However, in stem analysis it is assumed that each tree has been dominant or codominant throughout its entire life and this may or may not be true.

Plonski (1956) constructed yield tables and site index curves for black spruce (*Picea mariana* [Mill.] B.S.P.) and other major timber species in Ontario. These have been used in neighboring provinces as well. Heger and Lowry (1971) examined the yield tables and concluded that they are applicable to most of central and eastern Canada. Page and van Nostrand (1971), however, challenged these conclusions and demonstrated that height growth patterns of black spruce in Newfoundland are considerably different from those in Ontario.

Much of Ontario's black spruce grows on peatland sites¹. Growth of this species on organic soils appears to be slower than on mineral soils, perhaps because of excess water, poor aeration and inadequate nutrient availability. For the purpose of this study it was assumed that the height growth pattern of this species might be different on mineral soils than on peatland. In an intensive growth and yield study of peatland black spruce as it is affected by cultural treatments such as drainage and fertilization it is essential to know the exact growth patterns of the natural stands prior to any treatment.

Plonski's (1956) site index curves presumably indicate the average growth patterns of black spruce on both peatland and mineral soils. However, they may not provide sufficiently precise height growth patterns for predicting growth of intensively managed stands of peatland black spruce. This paper reports the results of a study in which preliminary site index formulas were derived for peatland black spruce in northern Ontario. The present site index formulas are also compared with Plonski's.

Methods

A total of 60 dominant and codominant black spruce trees were selected in the Clay Belt area, mainly in the Cochrane District. Most of these trees were adjacent to a set of permanent growth plots established between 1969 and 1973 for growth analysis. They were in even-aged, well stocked stands apparently undisturbed by past cutting, burning, grazing, flooding or other severe disturbance. It was assumed that each tree was

¹A peatland is defined as a lowland site (usually wet) covered by a layer of undecomposed or semidecomposed organic matter deeper than 30 cm.

dominant or codominant throughout its entire life, i.e., relatively free from severe competition for light.

Each tree was felled and sectioned at 1.0 ft. (30 cm) stump height and 4 ft (1.21 m) intervals thereafter up to the growing tip of the tree. Total height was recorded and annual rings were counted in the laboratory using an Addo-X ring counter. Total age for each tree was estimated by extrapolation. Table 1 provides basic statistics on the trees sampled.

In data compilation and analysis, the procedures recommended and used by Johnson and Worthington (1963), Curtis (1964) and Heger (1968) were followed in general. Site indices for the few trees younger than 50 years were estimated by linear extrapolation based on the height growth of the last 10 years.

Analysis and Results

Several mathematical models were considered for expressing height as a function of site index and age. However, because of past experience and the fact that plotting of the data exhibited obvious polymorphisms, the following model was chosen:

where:

- $H = b_1 S^{b_2} (1 - e^{-b_3 A}) b_4 S^{b_5}$ (1)
 H = tree height in metres at any age
 S = site index (height at age 50 years in metres)
 A = tree total age in years
 e = base of natural logarithms
 b, s = constant parameters of the model

This model has the desirable sigmoid and doubly asymptotic properties of a biological growth function (Richards 1959) and allows for polymorphic behavior². In the model above, $b_1 S^{b_2}$ gives the upper asymptote for each curve, b_3 is a rate parameter and $b_4 S^{b_5}$ determines the rate and shape of each curve. The two parameters b_2 and b_5 combined allow for the polymorphic patterns inherent in the site index curves of many tree species, including black spruce.

The data were analyzed, based on the above model, in a non-linear regression analysis (Draper and Smith 1966) in which b_1 parameters were estimated by least-squares approximation techniques. This analysis resulted in the following regression equation:

$$H = 16.2149 S^{.1496} (1 - e^{-0.01326A}) 4.6602 S^{-.5787}, \quad R^2 = .95 \text{ SE} = 1.85 \text{ m} \quad (2)$$

Figure 1 plots the above equation, representing site index curves for peatland black spruce in northern Ontario, and compares it with Plonski's curves (Payandeh 1977) given below for three site classes of 4, 8 and 12 metres:

$$H = 6.183 S^{.515} (1 - e^{-0.0211A}) 5.958 S^{-.5657} \quad (3)$$

Figure 1 indicates that, on the basis of the

Table 1. Basic statistics on a sample of 60 trees used for constructing site index curves for peatland black spruce in northern Ontario

Statistics	Total height (m)	Age (years)	Site index (m)
Mean.....	13.78	132	4.54
Range.....	6.61-21.57	43-287	.67-11.98
Coefficient of variation (%)....	29	37	59

Fig. 1. Site index curves for peatland black spruce in northern Ontario as compared with Plonski's curves for all black spruce in Ontario.

present study, there is a considerable difference between height growth patterns of peatland black spruce and those indicated by Plonski's (1956) site index curves. This is particularly evident for the poorer sites and older stands. The rate of annual height growth (ΔH) may be expressed as the first partial derivative of model (1) with respect to age as:

$$\Delta H \approx \frac{\partial H}{\partial A} = b_1 b_4 S (b_2 + b_5) (b_3 e^{-b_3 A}) (1 - e^{-b_3 A}) (b_4 S^{b_5} - 1) \quad (1a)$$

The solution of the above formula for equations (2) and (3) and for three site indices of $S=4, 8$ and 12 m and for several stand ages is given in Table 2.

Table 2 clearly indicates that Plonski's site index curves underestimate only slightly the height growth of poor sites at younger ages, but they grossly underestimate stand height growth at older ages. Furthermore, as the site index increases the height growth pattern of peatland black spruce approaches that of Plonski's site index curves. In fact Figure 1 indicates that, for a site index of 10 m, the two curves are practically identical but, for site indices greater than 10 m, Plonski's curves overestimate the height of peatland black spruce.

²The condition of $H-S$ at site index age cannot be satisfied with model (1). This is due to the appearance of S twice in the model — the second time as an exponent. The fact that $H-S$ at index age is of little practical significance.

Table 2. Approximate annual height growth (ΔH in metres) calculated for three site indices and several stand ages for peatland black spruce and all black spruce based on equations (2) and (3), respectively.

Age	S Eq.	4		8		12	
		(2)	(3)	(2)	(3)	(2)	(3)
25		.100	.092	.178	.196	.216	.268
50		.129	.121	.158	.170	.165	.196
100		.105	.070	.096	.076	.087	.078
200		.036	.010	.028	.010	.024	.010

As indicated elsewhere (Payandeh 1974b) equations based on model (1) are very difficult, if not impossible, to solve for site index, i.e. for S . Therefore, the data were also analyzed to express site index as a function of stand height and age based on the following model, where symbols are as defined earlier:

$$S = b_1 H^{b_2} (1 - e^{b_3 A}) b_4 H^{b_5} \quad (4)$$

The analysis above resulted in the following regression equation:

$$S = .01835 H^{-.18861} (1 - e^{-.00009A}) - .81174 H^{.1831} \quad R^2 = .93 \text{ SE} = 1.2 \text{ m} \quad (5)$$

The solution of the equation (5) for a given stand height and age will provide an estimate of site index for peatland black spruce in northern Ontario. A similar equation derived for Plonski's data (Payandeh 1977) is given below.

$$S = 0.025 H^{1.7509} (1 - e^{-.00296A}) - 2.0354 H^{-.3212} \quad (6)$$

It should be noted, however, that equation (6) will grossly overestimate site index of peatland black spruce, particularly for shorter and older stands.

Discussion

Site index formulas were derived for peatland black spruce in northern Ontario based on stem analysis of 60 dominant and codominant trees. They show considerable difference between height growth patterns of peatland black spruce and those indicated by Plonski's site index curves, particularly for site indices less than 8 m and stand ages greater than 80 years. Results of this study may have significant management implications in that peatland black spruce stands on poor sites will attain greater heights and therefore greater volumes than are indicated by Plonski's site index curves and yield tables. This in effect

results in a longer optimum rotation for such stands than is indicated by Plonski's yield tables.

Heger and Lowry (1971) examined the applicability of Plonski's site index curves and yield tables for black spruce in regions outside Ontario and concluded that his tables are suitable for central and eastern Canada. Page and van Nostrand (1971), however, questioned these conclusions as they applied to Newfoundland. Results of the present study indicate that, even within Ontario, there is a considerable difference between height growth patterns of black spruce stands grown on peatland (usually on poor sites) and those grown on mineral soils. A more comprehensive study based on larger samples of trees from both peatland and mineral soil sites across the province is suggested to corroborate the results of the present study.

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