PREDICTABILITY OF SITE INDEX FROM SOIL FACTORS AND LESSER VEGETATION IN NORTHERN ONTARIO FOREST TYPES

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ABSTRACT

Data from 193 and 425 growth plots in the spruce *(Picea* spp.)-fir *(Abies* spp.) and peatland black spruce *(Picea mariana* [Mill.] B.S.P.) forest types, respectively, of northern Ontario were used to establish relationships between site index and some of the soil factors, lesser vegetation and soil nutrient concentration. Stepwise multiple linear regression analysis and dummy variables were employed to express site index as a function of the above variables for each of the two data sets separately.

Results indicated that, for the spruce-fir forest type, five of the site factors and lesser vegetation combined accounted for 22% of the variability in the site index. Inclusion of soil nutrient concentration accounted for an additional 1%. Stand height and age accounted for 72% of the variability, while soil moisture regime and iron concentration accounted for another 2%.

Results from the peatland black spruce data set indicated that two of the categorical variables combined, peat depth and lesser vegetation, accounted for 12% of the total variability in site index. Inclusion of peat pH, nutrient concentration and percent moisture content accounted for another 5% of the variability. In contrast, stand age, average crown width and height to live crown accounted for 63% of the variability, while peatland cover type and peat depth accounted for another 12% of the total variability in the predicted site index.

Results indicate poor correlation between site index and soil factors and lesser vegetation. Consequently, predictive equations based on these variables are of limited use. Many climatic and environmental factors other than soil factors and vegetation affect site productivity and plant growth. In addition, relationships between site productivity and soil factors and vegetation are far too complex and highly variable to be expressed or explained by simplistic relationships. Therefore, soil factors chosen for 'prime site' identification, such as texture, stone content, moisture regime and depth, may be poor predictors of site quality.

RÉSUMÉ

À partir de données provenant de placettes d'échantillonnage permanentes établies dans le nord de l'Ontario, soit 193 dans le type forestier à épinette *(Picea* spp.) et à sapin *(Abies* spp.) et 425 dans le type à épinette noire *(Picea mariana* [Mill.] B.S.P.) de tourbière, on a étudié les rapports entre l'indice de station et certains facteurs édaphiques, la végétation secondaire et les concentrations de certaines substances nutritives dans le sol. Au moyen de l'analyse par régression linéaire multiple pas à pas et de variables factices, on a cherché à exprimer, pour chacun des deux types, l'indice de station en fonction des variables considérées.

Pour la forêt à épinette et à sapin, les résultats indiquent que cinq des facteurs du milieu et la végétation secondaire ensemble contribuent pour 22% de la variabilité de l'indice de station. La contribution des concentrations des substances nutritives dans le sol s'élève à 1%. Par ailleurs, la hauteur et l'âge du peuplement représentent 72% de la variabilité, tandis que le régime hydrique du sol et sa teneur en fer contribuent pour 2%.

Pour le type à épinette noire de tourbière, les résultats indiquent que deux des variables dichotomisées, la profondeur de la tourbe et la végétation secondaire, représentent ensemble 12% de la variabilité totale de l'indice de station. Le pH de la tourbe, les concentrations des substances nutritives et le pourcentage d'humidité fournissent 5% de la variabilité. Par contre, l'âge du peuplement, la largeur moyenne de la cime et la hauteur à la première couronne de branches vivantes expliquent 63% de la variabilité, et le type de couvert de la tourbière ainsi que la profondeur de la tourbe, 12%.

Les résultats indiquent une faible corrélation de l'indice de station avec les facteurs édaphiques et la végétation secondaire. Les équations de prévision reposant sur ces variables sont donc d'une utilité limitée. De nombreux facteurs climatiques et environnementaux autres que les facteurs édaphiques et la végétation influent sur la productivité des stations et la croissance végétale. En outre, les relations entre la productivité des stations et les facteurs édaphiques ainsi que la végétation sont beaucoup trop complexes et variables pour qu'on puisse les exprimer ou les expliquer au moyen d'équations simples. En conclusion, des caractéristiques du sol utilisées pour la détermination des meilleurs emplacements, comme la texture, la teneur en pierres, le régime hydrique et la profondeur, pourraient être, en fait, des indicateurs médiocres de la qualité d'un emplacement.

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INTRODUCTION

In the context of timber management, site quality may be defined as "the production potential of a site for a particular forest type or species." The words "good" and "poor" are frequently used to indicate high or low productive potential of a given site. The proper measurement and interpretation of site quality are important tasks for most forest managers. Product sizes and values at various ages are controlled largely by site quality and stand density. Certain investments that are fully justified on good sites may be uneconomical on less productive sites. Responses of certain silvicultural treatments often differ dramatically among areas of different site quality.

Owing to the great practical importance attached to effective evaluation of site quality, much effort has been devoted to the development of methods for quantifying site quality. Most of these techniques are categorized as direct or indirect. Direct methods include estimation of site quality a) from historical yield records, b) on the basis of stand volume data, and c) on the basis of stand height-age (site index) relationships (e.g., Gevorkiantz 1957, Plonski 1956, Lundgren and Dolid 1970, Monserud 1984a). Indirect methods include estimation of site quality a) from overstory interspecies relationships (e.g., Coile 1948, Olson and Della-Bianka 1959, Doolittle 1958), b) from lesser vegetation characteristics (e.g., Cajander 1926, Ure 1950, Daubenmire and Daubenmire 1968, Hodgkins 1970, Jeglum et al. 1982), and c) from topographic, climatic and edaphic factors (e.g., Coile 1952, Hills 1955, Ike and Clutter 1968, Alban 1976, Carmean 1979, Monserud et al. 1986[1]).

Areas in which site quality is good generally have high rates of height growth. In other words, for these species, volume production potential and height growth are positively and highly correlated. For this reason, the site index method has been the most widely used means of estimating the potential of forest site productivity in North America. Despite the possible shortcomings of site index (Monserud 1984b) it will continue to be used in the foreseeable future. Indirect methods of estimating site quality are applied usually when the species (or forest type) of interest is not present on the land under evaluation or the site index measure is considered unsatisfactory (e.g., in the case of mixed forest types).

In many studies, including some by the above-mentioned authors, attempts have been made to develop regression relationships between site index and soil factors, lesser vegetation and other variables used in indirect estimation of site quality. The purpose of such equations is to predict site quality in the absence of species of interest on the land area of interest. The object of the present paper is to examine the relationship between site quality, as measured by site index, and some of the soil factors, nutrient concentration and lesser vegetation of two of the major forest types in northern Ontario.

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[1] Monserud, R.A., Moody, U., and Breuer, D. 1986. Soil-site relationships for Inland Douglas-fir. USDA For. Serv., Intermount. Res. Stn., For. Sci. Lab., Moscow, Idaho. Submitted for publ. in Forest Science. 42 ms p.

METHODS

Data used in this study were collected as part of two growth and yield projects established in northern Ontario in spruce *(Picea* spp.)-fir *(Abies* spp.) and peatland black spruce *(Picea mariana* [Mill.] B.S.P.) stands, referred to hereafter as data set I and data set II, respectively. Data set I consisted of 193 growth plots (points) established between 1970 and 1974 at three main locations: the Black Sturgeon Lake area northeast of Thunder Bay, the Beardmore area north of Nipigon and the Searchmont area north of Sault Ste. Marie, Ontario. Data set II consisted of 425 sample plots established between 1969 and 1973 in the Cochrane District of northern Ontario. Because of the close similarities between the two data sets, only the first data set is described in detail. Where differences exist they are pointed out for data set II (compare Appendices A and B). All plots were located within stands of 2 ha or more that did not have large gaps in the canopy. The plots covered a wide range of stand age, density, site quality and species composition.

Data gathered on each plot included, among other things, plot number, average stand age, landform (LF), slope percent (SL), position (SLP) and length (SLL), aspect (AS), soil moisture regime (SM) and texture (ST), ground cover (GC) or lesser vegetation (LV) (see Appendices A and B for description and number of classes for each variable). For data set II data recorded included peat characteristics such as peat depth (PD), peat composition (PC), and peat degree of humification (HU), moisture regime (PM) and peatland cover type (CV). For each "in" tree[2] $\geqslant$4 cm DBH (diameter at breast height, i.e., 1.30 m) the data recorded included tree number, species code, and tree status (e.g., pulpwood, saw log, cull, cut or dead, etc.). DBHOB (DBH outside bark) was measured by a diameter tape to the nearest 0.25 mm. In addition, the following data were collected from three to five dominant and codominant trees in each plot. Total height (H) was measured to the nearest 30 cm, with sectional measuring poles for trees less than 10 m and a Speigal relascope for taller trees. Each tree was classified in one of 10 crown classes (CL) and one of the three crown condition classes (CC) (see Appendices A and B for description). Average tree crown width (CW) was estimated visually to the nearest 30 cm. Height to the base of live crown (HTL) (i.e., the general level at which the leaf surface of the crown begins) was measured in a manner similar to that in which tree total height was measured, i.e., with sectional measuring poles or Spiegal relascope. Finally, tree age (A) at stump height, i.e., at 30 cm above ground, was determined on increment cores taken at this level with an Addo-X-Tree Ring Measuring Machine.

A representative soil sample was extracted with a soil sampler from the center of each plot. Samples were oven dried in the laboratory for up to 20 hours at 70°C and analyzed for percent moisture content (MO), total conductivity and pH, and then were chemically analyzed for total N (by a semimicro Kjeldahl procedure), P (by colorimetric method) and K, Ca, Mg, Fe, Mn and Al (by atomic absorption).

Complete measurements were taken on 526 dominant and codominant trees from data set I and 927 trees from data set II, respectively. The data on these

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[2] An "in" tree is one that is included in the sample on the basis of probability proportional to tree size.

trees were used to calculate average plot site index (SI) on the basis of existing site index formulae for major Canadian timber species (Payandeh 1974, 1978). Although several of the site variables and peat characteristics were initially classified in 10 to 12 categories according to Hills (1955), a preliminary screening of the data by means of a multi-way frequency table (Fienberg 1981, Hill 1982) indicated that many classes contained few or no observed data. The initial categories within each variable, therefore, were combined[3] to reduce the number of categories and to avoid classes with low observed frequencies (see Appendices A and B). The variable, percent slope, was also transformed into two categories of slope: 1) slope, if the slope was greater than 5%, and 2) flat, if it was not. It was found that two or three categorical variables conveniently summarized all the observed data as given in Appendices A and B.

Most statistical analyses of categorical variables, particularly regression analysis, require proper transformation, i.e., assigning of dummy variables to various classes of each variable (see Draper and Smith 1966, Cunia 1973, Chatterjee and Price 1977, Sokal and Rohlf 1981). In the present analysis (k-1) dummy variables were used to distinguish k distinct classes.

ANALYSIS AND RESULTS

The summary statistics of the two data sets are given in Table 1. To demonstrate clearly the contribution of each factor, stepwise multiple linear regression analysis was used to establish empirical relationships between site index and soil factors and lesser vegetation, in the following three stages:

A. expressing site index as a function of soil factors or peat characteristics and lesser vegetation (categorical variables only),

B. expressing site index as a function of soil factors, lesser vegetation and soil nutrient concentration (categorical and quantitative variables),

C. expressing site index as a function of soil factors, lesser vegetation, soil nutrient concentration and tree and stand measurements (categorical and quantitative variables).

Table 2 contains the resulting regression equations for data set I. Part A shows stepwise variable selection for the first model, i.e., expressing site index as a function of soil factors and lesser vegetation. In these equations the dummy variables are shown in [ ] to emphasize that each dummy variable takes the value of 1 when the sample element belongs to that class, and 0 otherwise. The first categorical variable included in the regression equation is landform, which accounts for 12.0% of the total variability as indicated by the increase in the value of $\overline{R}^2$ (adjusted for degrees of freedom) shown in Table 2.

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[3] Combining classes of categorical variables because of similarities and/or low frequency is both valid and necessary for regression analysis. Since each class is represented by a dummy variable which carries one degree of freedom regardless of its frequency, classes with low frequencies should be avoided: otherwise, they would influence the resulting regression relationship disproportionately.

Table 1. Summary statistics on 526 dominant and codominant trees and soil nutrient concentration in 193 growth plots in spruce-forest types, and 927 dominant and codominant trees and soil nutrient concentration in 425 growth plots in peatland spruce stands in northern Ontario.

Variable	Mean		Standard deviation		Coefficient of variation (%)	
	I	II	I	II	I	II
Tree height (m)	14.53	11.81	4.28	3.46	29	29
Crown width (m)	3.00	2.28	1.24	0.92	41	40
Height to live crown (m)	6.00	4.34	3.54	2.18	59	50
Tree age (years)	50.29	105.51	23.04	39.85	46	38
Site index (m)	16.36	5.28	3.21	2.69	20	51
Soil moisture contents (%)	41.34	974.97	80.64	800.69	195	82
Conductivity[a]	283.40	419.88	146.39	89.09	52	21
pH[b]	5.04	4.01	0.50	0.86	10	22
N	0.19	1.23	0.25	0.43	133	35
P	0.05	0.06	0.04	0.04	79	78
K	0.98	0.07	0.63	0.21	65	300
Ca	1.56	0.98	1.21	0.93	77	94
Mg	1.10	0.11	0.86	0.12	78	108
Fe	3.67	0.31	2.46	0.44	67	141
Mn	0.09	0.02	0.11	0.06	128	292
Al	5.34	0.27	1.83	0.57	34	214

[a] Measured in µmho at 25°C.

[b] All elements were measured as % of total oven-dry weight.

The first regression equation, i.e.,

$$\hat{SI} = 15.33 + 1.15\ [DLF1] + 2.59\ [DLF2]$$

means that the predicted site index would be 15.33 + 1.15 [1] + 2.59 [0] = 16.48 m if the site is classified as LF1, and it would be 15.33 + 1.15 [0] + 2.59 [1] = 17.92 m if the site is classified as LF2; otherwise, it would be 15.33 + 1.15 [0] + 2.59 [0] = 15.33 m. Similarly, the second equation of part A, Table 2, i.e.,

$$\hat{SI} = 16.15 + 0.7\ [DLF1] + 1.98\ [DLF2] - 1.37\ [DST1] - 0.39\ [DST2]$$

indicates that the predicted site index might take one of the following nine values on the basis of landform and soil texture class combinations (see page 6):

Table 2. Summary of stepwise regression analysis, on data set I, expressing site index as a function of soil factors, lesser vegetation, soil nutrient concentration and stand variables for the spruce-fir forest type of northern Ontario.

Variable in equation	$\bar{R}^2$	Increase in $\bar{R}^2$	F	Regression equation
	A) Soil factors and lesser vegetation			
LF	0.120	0.120	31.6	SI = 15.33 + 1.15 [DLF1] + 2.59 [DLF2]
ST	0.139	0.019	19.0	SI = 16.15 + 0.71 [DLF1] + 1.98 [DLF2] - 1.37 [DST1] - 0.39 [DST2]
GC	0.203	0.064	20.0	SI = 14.70 + 1.10 [DLF1] + 1.77 [DLF2] - 1.78 [DST1] - 0.18 [DST2] + 2.08 [DGC1] + + 1.03 [DGR2]
SM	0.223	0.020	17.2	SI = 13.98 + 0.91 [DLF1] + 1.16 [DLF2] - 1.38 [DST1] - 0.26 [DST2] + 2.24 [DGC1] + 1.43 [DGC2] + 1.06 [DSM1] + 1.27 [DSM2]
SL	0.228	0.005	15.9	SI = 14.28 + 0.71 [DLF1] + 1.27 [DLF2] - 1.32 [DST1] - 0.27 [DST2] + 2.21 [DGC1] + 1.26 [DGC2] + 1.17 [DSM1] + 1.30 [DSM2] - 0.64 [DSL1]
	B) Soil factors, lesser vegetation and soil nutrient concentration[a]			
Fe	0.234	0.006	15.8	SI = 14.47 + 0.82 [DLF1] + 1.18 [DLF2] - 1.38 [DST1] + 0.01 [DST2] + 2.32 [DGC1] + 1.40 [DGC2] + 0.93 [DSM1] + 1.04 [DSM2] - 0.13 Fe
Al	0.237	0.003	14.9	SI = 13.74 + 0.77 [DLF1] + 1.06 [DLF2] - 1.29 [DST1] - 0.10 [DST2] + 2.20 [DGC1] + 1.19 [DGC2] + 0.98 [DSM1] + 0.98 [DSM2] - 0.17 Fe + 0.20 Al
	C) Soil factors, lesser vegetation, soil nutrient concentration and tree and stand data[b]			
H	0.157	0.157	84.4	SI = 10.92 + 0.38 H
A	0.717	0.560	885.2	SI = 10.99 + 0.96 H - 0.17 A
SM	0.726	0.009	289.2	SI = 10.45 + 0.95 H - 0.17 A + 0.11 [DSM1] + 0.88 [DSM2]
Fe	0.733	0.007	246.7	SI = 11.07 + 0.96 H - 0.17 A - 0.09 [DSM1] + 0.68 [DSM2] - 0.14 Fe

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[a] The first four steps in section B) are identical to those in section A). Variable definition: LF = landform, ST = soil texture, GC = ground cover or lesser vegetation, SM = soil moisture, SL = slope, Fe = iron concentration, Al = aluminum concentration, H = stand height in m, A = stand age and [DLF1], [DLF2], etc., indicate dummy variables used for the categorical variables.

[b] See footnote 2 in text.

Landform class (LF)	Soil texture class (ST)	Predicted site index (m)
1	1	15.49
1	2	16.47
1	3	16.86
2	1	16.76
2	2	17.74
2	3	18.13
3	1	14.78
3	2	15.76
3	3	16.15

The second categorical variable entering the regression model increases the value of $\bar{R}^2$ to 0.139, i.e., it accounts for an additional 1.9% of the variability in the predicted site index.

The last equation given in Part A of Table 2 contains three additional categorical variables. Though statistically significant, this regression equation containing five categorical variables accounts for less than 23% of the variability in the predicted site index. The last two variables entering the regression equation account for less than 3% of the total variability. Nevertheless, the corresponding variables in the equation and their estimated parameters may provide some insight into the relationship between site productivity and the predictor variables. For example, the last equation indicates that site productivity is positively and significantly correlated with the three variables of landform, ground cover and soil moisture regime and negatively correlated with the two variables of soil texture and slope. Each dummy variable increases or decreases the predicted site index by its estimated coefficient if the site falls in that category; otherwise, that term of the equation drops out.

Part B of Table 2 contains the resulting stepwise regression equations expressing site index as a function of site factors, lesser vegetation and soil nutrient concentration. The first four equations are identical to those given in Part A, an indication that the four categorical variables LF, GC, ST, and SM are the most significant variables entering the regression model with or without the soil nutrient concentration variables. However, the first equation of Part B indicates that the amount of iron concentration becomes the next significant variable entering the regression model. This variable accounts for an additional 0.6% of total variability (slightly more than the SL variable chosen before) in site productivity. The next variable entering the regression model is the amount of aluminum concentration in the soil, which accounts for an additional 0.3% of the total variability in the site index. This last equation, containing four categorical and two continuous variables, accounts for 23.7% of the total variability in site index. Thus, addition of soil nutrient concentration in this case accounts for about 1% more of the total variability in site productivity as measured by site index.

Part C of Table 2 gives the resulting regression equations expressing site index as a function of soil factors, lesser vegetation, soil nutrient concentration and tree and stand variables. The second equation of Part C indicates that the average height of dominant and codominant trees and stand age together account for nearly 72% of the total variability in site productivity. This is not surprising, of course, as site index is calculated on height-age relationships, although it is not based on a simple linear relationship[4].

The third equation of Part C indicates that, in the presence of stand height and age, the only categorical variable entering the regression as a significant variable is the soil moisture regime, which accounts for an additional 1% of the total variability. Finally, the last equation of this table indicates that the amount of iron concentration in the soil may account for another 0.7% of the variability. Other soil factors, lesser vegetation and soil nutrient concentration become nonsignificant in the presence of the two main stand variables of height and age.

Table 3 gives the resulting equations for the peatland black spruce data set. Part A indicates that the first categorical variable included in the equation is peat depth, which accounts for 10.8% of the variability in site index as indicated by the value of $\overline{R}^2$. The second categorical variable entering the regression model is lesser vegetation. This variable increased the value of $\overline{R}^2$ to 0.116, thereby accounting for an additional 0.8% of the variability.

Part B of Table 3 contains the resulting stepwise regression equations for expressing site index as a function of site factors, lesser vegetation and soil nutrient concentration for the second data set. The first equation of Part B is identical to the first equation of Part A, since peat depth was the most significant variable entering the equation with or without soil nutrient variables. However, the remaining equations of Part B indicate that lesser vegetation became nonsignificant in the presence of soil nutrient variables. The last equation of Part B indicates that one categorical variable and four soil nutrient and moisture-related variables combined accounted for 17% of total variability in site index. The last variable entering the equation, Mn, though statistically significant, accounted for less than 1% of the variability.

Part C of Table 3 presents the resulting regression equations expressing site index as a function of soil factors, lesser vegetation, soil nutrient concentration and stand variables for data set II. The first equation indicates that stand age, the most significant variable, accounts for about 56% of the variability in site index. The variable cover type CT becomes the second most significant variable and accounts for an additional 10.8% of the variability. Average crown width and height to live crown explain another 4% and 3% of the variability, respectively, while peat depth accounts for less than 2%.

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[4] It is known that site index has an inverse sigmoidal relationship with stand height and age. Here, it has been expressed as a linear function of stand height, age and other variables to demonstrate the relative contribution of each variable in predicting site index, and to emphasize that much of the variability accounted for in the few seemingly good site index, soil or habitat relationships obtained to date (e.g., McGee 1961, Monserud 1984a) has been due to stand variables such as height and age.

Table 3. Summary of stepwise multiple linear regression analysis, on data set II, expressing site index as a function of soil factors, lesser vegetation, soil nutrient concentration and stand variables for the peatland black spruce forest types of northern Ontario.

Variable in equation	$\overline{R}^2$	Increase in $\overline{R}^2$	F	Regression equation
	A) Soil factors and lesser vegetation[a]			
PD	0.108	0.108	112.3	$S\hat{I} = 4.54 + 1.59$ [DPD1]
LV	0.116	0.008	61.9	$S\hat{I} = 4.76 + 1.61$ [DPD1] $- 0.48$ [DLV1]
	B) Soil factors, lesser vegetation and peat nutrient concentration			
PD	0.108	0.108	112.3	$S\hat{I} = 4.54 + 1.59$ [DPD1]
PH	0.126	0.018	66.5	$S\hat{I} = 3.17 + 1.64$ [DPD1] $+ 0.33$ PH
MO	0.148	0.022	53.4	$S\hat{I} = 3.12 + 1.55$ [DPD1] $+ 0.47$ PH $- 0.00047$ MO
P	0.162	0.014	15.0	$S\hat{I} = 3.69 + 1.51$ [DPD1] $+ 0.23$ PH $- 0.00071$ MO $+ 9.20$ P
Mn	0.170	0.008	37.71	$S\hat{I} = 3.40 + 1.53$ [DPD1] $+ 0.34$ PH $- .00078$ MO $+ 11.15$ P $- 3.84$ Mn
	C) Soil factors, lesser vegetation, soil nutrient concentration and stand variables[b]			
A	0.556	0.556	1156.7	$S\hat{I} = 10.70 - 0.052$ A
CT	0.664	0.108	611.2	$S\hat{I} = 12.64 - 0.059$ A $- 2.01$ [DCT1] $- .66$ [DCT2]
CW	0.702	0.038	545.3	$S\hat{I} = 11.15 - 0.060$ A $- 1.52$ [DCT1] $- 0.51$ [DCT2] $+ 0.55$ CW
HTL	0.730	0.028	501.7	$S\hat{I} = 10.45 - 0.063$ A $- 1.15$ [DCT1] $- 0.45$ [DCT2] $+ 0.53$ CW $+ 0.22$ HTL
PD	0.749	0.019	461.2	$S\hat{I} = 10.21 - 0.061$ A $- 1.14$ [DCT1] $- 0.51$ [DCT2] $+ 0.44$ CW $+ 0.19$ HTL $+ 0.71$ [DPD1]

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[a] Variable definition: PD = peat depth, LV = lesser vegetation, CT = cover type, MO = % moisture content of peat, P = phosphorus concentration, Mn = manganese concentration, A = stand age, CW = crown width in m, HTL = height to live crown in m and [DPD1], [DLV1], [DCT1] and [DCT2] indicate dummy variables used for the categorical variables.

[b] See footnote 2 in text.

The last equation containing three stand variables and two site or categorical variables accounts for nearly 75% of the total variability in site index.

CONCLUSIONS

Results of the present study indicate that soil factors, lesser vegetation and nutrient concentration are not very good predictors of site quality as measured by site index for the spruce-fir and peatland black spruce forest types of northern Ontario. Although only one of the previous studies (Monserud 1984a) has employed categorical variables, the results of this study are quite similar to those of many of the so-called soil-site index studies carried out elsewhere (e.g., Coile 1948, 1952, Ure 1950, Olson and Della-Bianka 1959, Doolittle 1958, McGee 1961, Daubenmire and Daubenmire 1968, Ike and Clutter 1968, Hodgkins 1970, Alban 1976 and Carmean 1979). For example, McGee (1961) developed a logarithmic regression equation expressing site index (for old-field slash pine *[Pinus elliottii* Engelm.] plantations) as a function of plantation age, thickness of the A horizon and depth to a fine-textured horizon. Although his equation explains 87% of the variability in the logarithm of height, the majority of this variability (69%) is explained by the reciprocal of age, with the soil variables accounting for only 18% of the variation (in logarithmic scale).

Monserud's (1984a) data originated from five, well recognized and ecologically distinct habitat series. Yet, he found that two sets of two of these habitat series were indistinguishable in terms of site quality, i.e., as measured by site index. In addition, he found no apparent difference between the data without habitat series and those of the GR and WRC series (ibid.); thereupon he reduced a six-category habitat series to a three-class categorical variable. Although the habitat-specific site index model developed by Monserud (ibid.) accounted for 92% of the variability in the site index, 80+% of it was due to stand age and height. Less than 12% of the variability was due to habitat.

In a very recent and comprehensive study on soil-site relationship Monserud *et al.* (1986)[1] found that a "large number of measured soil and physiographic factors explained only a trivial amount of the variability in Douglas-fir site index. Only elevation and habitat type were important, and both are easily measured above-ground descriptors. These results do not justify describing and analyzing the soils to predict site index".

As stated by Stone (1978), relationships between yield or site productivity and soil factors such as moisture regime and nutrient concentration are far too complex and too highly variable to be expressed or explained by simplistic models. Many climatic and environmental factors other than soil factors and lesser vegetation affect site productivity and plant growth. Such poor correlation may be at least partly caused by the qualitative nature of the variables, high and subjective variability in data collection, high sampling error, measurement error and often large numbers of classes with low frequencies associated with the categorical variables used. Even with careful data screening, proper model selection and variable transformation, e.g., use of dummy variables, soil-site index regression equations often result in poor fits, i.e., low R^2, and consequently are of limited use.

The results of this study and previous studies (McGee 1961, Stone 1978, Grigal 1984, Monserud 1984b, Monserud *et al.* 1986[1]) should prove useful in developing better criteria for identifying the prime sites for northern Ontario. It is doubtful if soil variables such as texture, stone contents, moisture regime and depth that are currently used (Nicks 1985) are very good predictors of site quality (see Stone 1978, Grigal 1984, Monserud *et al.* 1986[1]). This will be particularly true when the response variable is also expressed as a categorical variable, with three classes of "prime", "intermediate" and "not prime". Direct methods of site quality estimation such as those employing height-age relationships or volume yield of recently cut areas are better predictors of site quality than are soil and vegetation. It is hoped that the results of this study prove useful in developing more efficient criteria for "prime" site determination in northern Ontario.

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APPENDICES

APPENDIX A (cont'd)

Initial codes and description		Final categorial and dummy variables
Code	Description	
	Soil Texture (cont'd)	
3	Silt - particles barely visible, floury; moist, forms spindles, not ribbons; cohesive and not adhesive	Soil texture class 3 [DST1 DST2] = [0 0]
4	Sandy loam - soil squeezed in hand falls apart; when moist forms a cast that breaks if not handled carefully; individual sand grains can be readily seen	
5	Loam - soil slightly plastic when moist, but not greasy; gritty when dry, not floury; brown or dark grey	
6	Silt loam - soil greasy when moist, floury when dry; on wetting it runs together and puddles; light grey to nearly white	
7	Sandy clay loam - individual sand grains can be seen and felt readily; moist soil friable; usually brownish yellow to red	
8	Silty clay loam - soil heavy and greasy when moist; dull grey, sometimes containing iron concretions	

(cont'd)

APPENDIX A (cont'd)

Initial codes and description		Final categorical and dummy variables
Code	Description	
	<u>Soil Texture</u> (cont'd)	
9	Clay loam - soil mellow and greasy when moist; usually yellowish brown to reddish brown	soil texture class 3 [DST1 DST2] = [0 0]
10	Sandy loam - individual sand grains can be seen and felt readily, moist soil somewhat friable; usually bright red or yellow	
11	Silty clay - sand not evident; moist soil plastic; usually grey, sometimes containing iron concretions	
12	Clay - sand not evident; moist soil plastic; usually dark red, often mottled with grey or yellow	
	<u>Slope</u>	
Initially measured in % > 5		slope class 1 DSL1 = [1]
Initially measured in % $\leqslant 5$		slope class 2 DSL2 = [0]
	<u>Ground Cover</u>	
1	shrub	lesser vegetation class 1 [DGC1 DGC2] = [1 0]
2	herb	lesser vegetation class 2 [DGC1 DGC2] = [0 1]
3	moss	lesser vegetation class 3 [DGC1 DGC2] = [0 0]

(cont'd)

APPENDIX A (cont'd)

Initial codes and description		Final categorical and dummy variables
Code	Description	
	Soil Moisture	
1	Dry	soil moisture class 1 [DSM1 DSM2] = [1 0]
2	Moderately dry	
3	Moderately fresh	
4	Fresh	soil moisture class 2 [DSM1 DSM2] = [0 1]
5	Very fresh	soil moisture class 3 [DSM1 DSM2] = [0 0]
6	Moderately moist	
7	Moist	
8	Very moist	
9	Wet	
0	Very wet	
	Soil Texture	
1	Gravel - particle larger than pinhead	soil texture class 1 [DST1 DST2] = [1 0]
2	Sand - particles visible; soil gritty, lacks cohesion and runs free when dry	soil texture class 2 [DST1 DST2] = [0 1]

(cont'd)

APPENDIX A

Initial description and codes for site and soil factors and lesser vegetation and final categorical and dummy variables used for the spruce-fir data set.

Initial codes and description		Final categorical and dummy variables
Code	Description	
	Landform	
1	Glacio-lacustrine plain (sand and gravel)	landform class 1 [DLF1 DLF2] = [1 0]
2	Glacio-lacustrine (silt and clay)	
3	Littoral landscape (dunes, beaches and bars)	
4	Moraine landscape (ground and recessional moraines, drumlins, knob and kettle ridge)	landform class 2 [DLF1 DLF2] = [0 1]
5	Flattened till plain	landform class 3 [DLF1 DLF2] = [0 0]
6	Glacio-fluvial deposits (meltwater stream beds and outwash plains)	
7	Esker and kame landscape	
8	Limestone plain	
9	Other bedrock landscape	
0	Bog and swamp	

(cont'd)

APPENDIX A (concl.)

Initial codes and description		Final categorical and dummy variables
Code	Description	
	Tree crown condition	
1	Good - at least 2/3 filled, with foliage of healthy green color and normal size	crown condition 1 DCC1 = [1]
2	Medium	crown condition 2 DCC2 = [0]
3	Poor - less than 1/3 filled, with foliage of poor color and less than normal size	
	Tree crown class	
1	Dominant	dominant DCL1 = [1]
2	Codominant	nondominant DCL2 = [0]
3	Intermediate	
4	Suppressed	
5	Regeneration (undergrowth)	
6	Understory tree	
7	Understory suppressed	
8	Open grown	
9	Others	

APPENDIX B

Initial description and codes for site factors, peat characteristics, lesser vegetation and final categorical and dummy variables used for black spruce data set.

Initial codes and description		Final categorical and dummy variables
	Landforms	
0	Bog and swamp	landform class 1 DLF1 = [1] (peatland)
1	Glacio-lacustrine plain (sand and gravel)	landform class 2 DLF2 = [0] (upland)
2	Glacio-lacustrine (silt and clay)	
3	Littoral landscape (dunes, beaches and bars)	
4	Moraine landscape (ground and recessional moraines, drumlins, knob and kettle ridge)	
5	Flattened till plain	
6	Glacio-fluvial deposits (meltwater stream beds and outwash plains)	
7	Esker and kame landscape	
8	Limestone plain	
9	Other bedrock landscape	
	Moisture Regime	
1	Oversaturated--water level above surface for six months or more	peat moisture class 1 [DPM1 DPM2] = [1 0] (saturated)
2	Saturated--water level at or above surface	
3	Very wet--water below surface - not lower than 10 cm	
4	Wet--water level 10-19 cm below surface	

(cont'd)

APPENDIX B (cont'd)

Initial codes and description		Final categorical and dummy variables
	Moisture Regime (concl)	
5	Very moist--water level 20-25 cm below surface	peat moisture class 2 [DPM1 DPM2] = [0 1] (very moist)
6	Moist--water level 26-34 cm below surface	peat moisture class 3 [DPM1 DPM2] = [0 0] (fresh)
7	Moderately moist--water level 35-60 cm below surface	
8	Fresh--water level 61-120 cm below surface	
9	Moderately dry--water level 121-180 cm below surface	
0	Dry--water level >180 cm below surface	
	Peat depth	
	Initially measured to nearest 25 mm ⩽30	peat depth class 1 DPD1 = [1]
	" " " " " " >30	peat depth class 2 DPD2 = [0]
	Peat composition	
1	Sphagnum	peat composition class 1 DPC1 = [1]
2	Sphagnum-sedge, sphagnum principally	peat composition class 2 DPC2 = [0]
3	Sphagnum-sedge and wood	
4	Sedge peat	
5	Sedge-sphagnum	
6	Eutrophic sedge-sphagnum peat-extremely rich areas	
7	Sedge-woody peat	
8	Woody-sphagnum and/or sedge peat	
9	Others not specified	

(cont'd)

APPENDIX B (cont'd)

Initial codes and description		Final categorical and dummy variables
	Lesser vegetation	
1	Sphagnum-Chamaedaphne	lesser vegetation class 1 DLV1 = [1]
2	Sphagnum-Ledum-Chamaedaphne	
3	Sphagnum-Ledum-Alnus	lesser vegetation class 2 DLV2 = [0]
4	Sphagnum-Feather moss	
5	Feather moss	
6	Feather moss-Petasites	
7	Feather moss-Cornus	
8	Aster-Cornus	
9	Others not specified	
	Peat degree of humification	
1	Completely unhumified and dye-free peat; when squeezed in hand only clear, colorless water runs between the fingers	humification class 1[DHU1 DHU2] = [1 0]
2	Almost completely unhumified and dye-free peat; when squeezed in hand almost clear; only weakly yellow-brown water runs	
3	Very little humification or very weak dye-yielding peat; with squeezing there is distinctly cloudy brown water, but no peat substance from between the fingers; the remainder is not pasty (viscous)	

(cont'd)

Initial codes and description	Final categorical and dummy variables
Peat degree of humification (cont'd)	
4 Weakly humified or somewhat dye-yielding peat; with squeezing dark muddy water runs, but still no peat substance; the remainder is somewhat viscous	humification class 2 [DHU1 DHU2] = [0 1]
5 Fairly humified or fairly dye-yielding peat; plant structure still evident, but somewhat hazy; with squeezing there is some peat substance, but mainly muddy brown water from between the fingers; the remainder is strongly viscous	humification class 3 [DHU1 DHU2] = [0 0]
6 Fairly humified or fairly dye-yielding peat, with unclear plant structures; with squeezing some 1/3 of the peat substance goes from between fingers; the remainder is viscous	
7 Strongly humified, or strongly dye-yielding peat, of which plant structure is still recognizable; with squeezing some 1/2 of peat substance goes	
8 Very strongly humified or strongly dye-yielding peat with very unclear plant structures; with squeezing 2/3 passes through the fingers; the remainder, mainly from more resistant constituents, persists as root fibers, wood remains, etc.	
9 Almost completely humified or almost wholly dye-yielding peat without recognizable plant structures; nearly the entire peat mass passes from between fingers with squeezing	

(cont'd)

APPENDIX B (cont'd)

Initial codes and description		Final categorical and dummy variables
	Peat degree of humification (concl.)	
10	Completely humified peat or wholly dye-yielding peat without any plant structures; with squeezing the whole peat mass passes out between the fingers	humification class 3 [DHU1 DHU2] = [0 0]
	Peatland cover type	
1	Stagnant black spruce with varying size and density	Cover type class 1 [DCV1 DCV2] = [1 0]
2	Immature black spruce--unmerchantable, but growing at a good rate	Cover type class 2 [DCV1 DCV2] = [0 1]
3	Mature black spruce--merchantable size trees, vigorous	
4	Overmature black spruce--merchantable, but many trees are falling down (20% or more)	
5	Mixed, generally black spruce and balsam fir including white birch growing on shallow peat on slopes or upland	Cover type class 3 [DCV1 DCV2] = [0 0]
6	Open bog--primarily treeless, sphagnum origin	
7	Fen--treeless minerotrophic, sedge predominates	
8	Carr--brushy area--alder, willow, etc.	
9	Marshes--open sedgy areas, water above surface for most of the year	
0	Others--not specified	

(cont'd)

APPENDIX B (concl.)

Initial codes and description		Final categorical and dummy variables
	Tree crown condition	
1	Good--at least 2/3 filled, with foliage of healthy green color and normal size	Condition class 1 [DCN1 DCN2] = [1 0]
2	Medium	Condition class 2 [DCN1 DCN2] = [0 1]
3	Poor--less than 1/3 filled with foliage of poor color and less than normal size	Condition class 3 [DCN1 DCN2] = [0 0]
	Tree crown class	
1	Dominant	Dominant DCL1 = [1]
2	Codominant	Nondominant DCL2 = [0]
3	Intermediate	
4	Suppressed	
5	Regeneration (undergrowth)	
6	Understory tree	
7	Understory suppressed	
8	Open-grown	
9	Others	