SITE INDEX ESTIMATION

FROM ENVIRONMENTAL FACTORS

IN SASKATCHEWAN

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The consultant's report upon which this report is based (Saskatchewan Soil/Site Analysis by James D. Arney) is available upon request from:

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Site Index estimation from environmental factors in Saskatchewan

Introduction:

Saskatchewan has a site capability rating system based on the soil drainage and texture information carried in the forest inventory. One of four productivity classes, based on potential stand volume growth at rotation age, may be assigned to any stand in the inventory, based on the combination of drainage and texture observed. This system provides a sound framework for further site capability studies.

As forest managers in Saskatchewan continue to move from harvesting fire - origin stands towards management of the new forest, there is a growing need for a mappable site productivity system that can be used as the basis for predicting stand growth rates and estimating future timber supplies. The existing system has limited use for these purposes, for reasons discussed within this report.

The present study attempted to build on the existing site matrix approach. The goal was to develop site index prediction models for the major commercial tree species (jack pine, trembling aspen, white spruce and black spruce), based on soil drainage, texture and any other readily available variables.

Background:

The study included data from across the commercial forest zone of North-Central Saskatchewan (Figure 1), roughly corresponding to the "Southern Boreal Ecoregion" (Kabzems et. al. 1986). A wide range of sites is represented in this broad geographic band.

The idea of assigning site productivity ratings based on environmental factors is not new. Many attempts have been made to derive classification systems based on these factors. Gessel et. al. (1987) give a general relationship of forest productivity to environmental factors as:

Productivity = f (climate, time, topography, organisms, soil).

Within this general equation, each of the factors affecting productivity can be broken down into sub-components. For example, "soil" includes available nitrogen, drainage, texture, depth to an impermeable layer, and many other variables that affect the potential growth rate of trees. There are many ways of measuring the dependent variable "Productivity" in the above equation. Some systems use the presence or absence of indicator plant species, while other measures range from total yearly biomass accumulation to attained tree height at a given age (Site Index).

In 1971 Alf Kabzems, building on previous work in the province by such investigators as Losee (1942), Rowe (1956), Kabzems & Kirby (1956), Jameson (1965) and Van Groenewoud (1965), suggested a productivity rating system for Saskatchewan based on an edaphic grid (soil drainage and soil texture), with mean annual increment (m.a.i.) of merchantable volume as the dependent variable. In 1978 the drainage / texture classification was incorporated into the provincial forest inventory, and in 1982-83 the Ecological Site Capability Classification (ESCC) system was formalized by the Provincial Forestry Branch (Liu 1984). ESCC uses the edaphic grid to predict m.a.i. of fully stocked stands at rotation age, as shown in Figure 2.

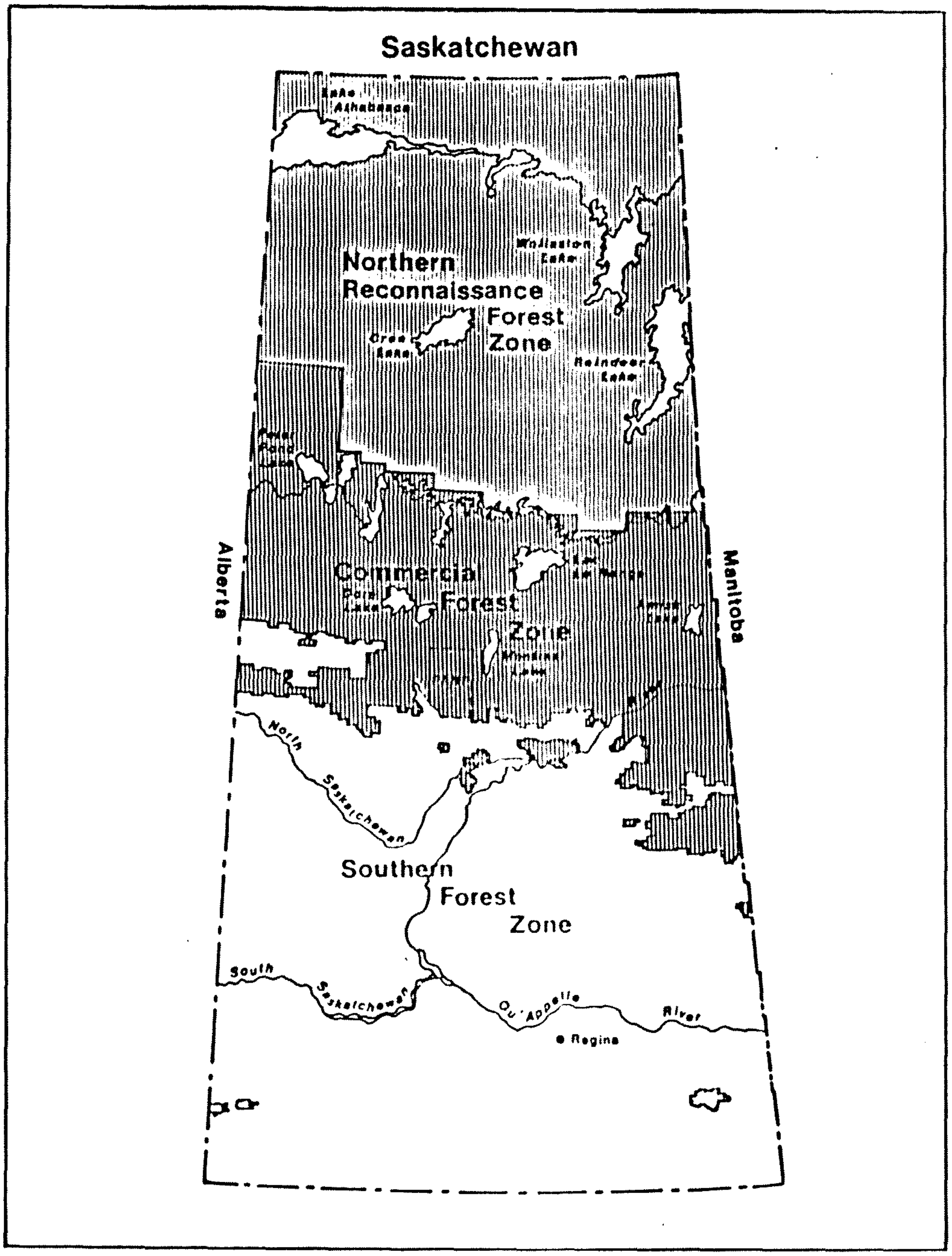

Figure 1. Data from across the Commercial Forest Zone were used.

While cubic volume of wood production is ultimately what foresters want to estimate, there are some practical problems in using volume directly. The main reason for this is that volume is dependent on tree diameter, which in turn is strongly affected by stand stocking (Packee 1988). Therefore observation is limited to stands of a "fully stocked", or "normal" condition. As well, volume cannot be directly measured in the field.

Soil Texture Class	VR	VR-R	R	R-W	W	W-MW	MW	MW-I	I	I-P	P	P-VP
O												bS $\frac{III}{0.8}$
F					wS $\frac{II}{3.1}$	wS $\frac{II-}{3.8}$	wS $\frac{I}{4.3}$	wS $\frac{I+}{5.0}$	wS $\frac{I}{4.3}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
MF-F					wS $\frac{II}{3.1}$	wS $\frac{II-}{3.8}$	wS $\frac{I}{4.3}$	wS $\frac{I+}{5.0}$	wS $\frac{I}{4.3}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
MF					wS $\frac{II}{3.1}$	wS $\frac{II-}{3.8}$	wS $\frac{I}{4.3}$	wS $\frac{I+}{5.0}$	wS $\frac{I}{4.3}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
MC-MF				wS $\frac{II-}{2.6}$	wS $\frac{II}{3.1}$	wS $\frac{II-}{3.8}$	wS $\frac{I}{4.3}$	wS $\frac{I+}{5.0}$	wS $\frac{I}{4.3}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
MC				jP $\frac{II-}{1.6}$	wS $\frac{II}{3.1}$	wS $\frac{II-}{3.8}$	wS $\frac{II+}{3.8}$	wS $\frac{II+}{3.8}$	wS $\frac{II+}{3.8}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
C-MC	jP $\frac{III-}{0.8}$	jP $\frac{III-}{0.8}$	jP $\frac{III}{1.3}$	jP $\frac{II-}{1.6}$	jP $\frac{II-}{1.6}$	wS $\frac{II}{3.1}$	wS $\frac{II}{3.1}$	wS $\frac{II}{3.1}$	wS $\frac{II}{3.1}$	wS $\frac{II-}{2.6}$	bS $\frac{II}{1.4}$	bS $\frac{III}{0.8}$
C	jP $\frac{III-}{0.8}$	jP $\frac{III-}{0.8}$	jP $\frac{III-}{0.8}$	jP $\frac{III-}{0.8}$	jP $\frac{III}{1.3}$	jP $\frac{III}{1.3}$	jP $\frac{III}{1.3}$	jP $\frac{III}{1.3}$	bS $\frac{III}{0.8}$	bS $\frac{III}{0.8}$		

Drainage Class

Figure 2. *The Ecological Site Capability Classification (ESCC) matrix used with the Saskatchewan forest inventory. The lower term indicates potential m.a.i. of merchantable volume at rotation age (m^3/ha/yr) for the indicated species, while the upper term indicates site class (Kabzems et. al. 1986).*

The most commonly accepted method for estimating forest site quality in North America is site index (Hagglund 1981). Site index is defined as the height attained by a specified component of the trees in the stand (e.g. dominant and codominant trees) at a standard age (e.g. 50 years). Height growth is much less dependent on stocking than is diameter growth, so the method can be used across a wide range of stocking levels. Since volume growth in well stocked stands is closely associated with height growth, the ability to estimate site index is a first step to the derivation of volume yields.

Recognizing that the ESCC system had limitations for forest management use, it was decided to investigate the potential for a height - based site capability rating system.

The project was undertaken as a co-operative effort, funded under the 1984-89 Canada - Saskatchewan Forest Resource Development Agreement (FRDA), between the Saskatchewan Department of Parks, Recreation and Culture (SPRC, now the Department of Parks and Renewable Resources), Weyerhaeuser Canada Limited (WCL) and Canadian Forestry Service (CFS, now Forestry Canada). The project leaders for the study were Dr. Jim Arney and Dr. Don Reimer. Data made available to the investigators included SPRC's stem analysis data, Permanent Sample Plot (PSP) data, and 3-P inventory "semi-permanent" plot data.

Methodology:

The project began with conducting a review of past studies, assembling and screening the data, and giving a familiarization tour of the study area to Dr. Jim Arney.

The original intention had been to develop new site index curves, using the stem analysis database. This would have allowed for the expression of polymorphism in the curve shapes. However, while the stem analysis data was generally in good "clean" condition, it was found that the variables of drainage and texture had not been consistently recorded, and could not be readily obtained by linking to the 3-P Inventory files. It was therefore decided to use existing anamorphic height/age curves from the published Growth and Yield reports for jack pine (Kabzems and Kirby 1956), aspen (Kirby et. al. 1957), white spruce (Kabzems 1971), and black spruce (Benson 1973).

The 3-P plot height and age data were used, since drainage and texture had been recorded for all plots. A third predictor variable, incipient solar radiation, was derived from the UTM Northing coordinate of the plot. Therefore, the three predictor variables were defined as:

i. Soil drainage:
   Drainage is used as an indicator of available moisture. Thirteen classes are defined, from 1 (Very Rapidly Drained) to 13 (Very Poorly Drained).

ii. Soil texture:
   Texture is used as an indicator of nutrient availability. Seven classes are defined, from 1 (Coarse) to 7 (Fine).

iii. Solar radiation:
   The project leader had found this factor to be significant in other similar studies. Incipient solar radiation for the month of September in megajoules/m^2/day was derived from the UTM coordinates, grouped into four classes.

With the predictor variables all defined and available, the next data preparation step was to derive the dependent variable, site index at age 50 (SI_{50}) for each dominant and codominant tree height / age recorded in the 3-P data. This was accomplished using the following procedure:

i. The shape of each site index curve (three levels for each species) in the published reports was defined using the Zeide 2-point method. This method, based on the curve heights at ages 40 and 70 years, fits the coefficients of the Chapman-Richards function to each curve, thus reducing the series of curves to a standard equation. Each curve shape is defined by a Growth Type number (or Z-number);
ii. For each 3-P sample tree, the SI_{50} was determined with a computer routine using the measured height / age pair and the curve shape calculated in (i) above;
iii. The average SI_{50} by species per plot was calculated, excluding trees under 30 and over 100 years of age, and any calculated tree SI_{50} under 6 or over 25 m, to exclude possible errors in measurement;
iv. For each cell of the three-dimensional matrix of drainage, texture and solar radiation, the average SI_{50} was calculated. This value was then used in the subsequent regression analysis.

Using the average value per cell as the dependent variable draws out the response surface better than does weighting by number of observations. This technique allows general trends to be defined more obviously than does weighting, which is more confusing and less efficient to apply, and which would probably have resulted in inappropriate conclusions about trends in the data due to the heavy oversampling of some cells. The uneven distribution of plots across drainage / texture classes is readily seen in Table 1. Note that Table 1 gives SI_{50} averages by drainage / texture classes only, but this was further broken down by solar radiation classes for the analysis.

At this point the dependent variable and the three independent variables were all available, so a regression analysis was performed. The procedure used stepwise multiple linear regression to find the "best" equation. An iterative process was followed:

i. Find the independent variable explaining the most variation, test for significance;
ii. Attempt transformations on the variable (using non-linear regression);
iii. Test the effect of the new variable on those variables already included in the equation;
iv. Repeat i-iii for the next variable, etc.

It was found that variation was reduced when the data were stratified into three areas roughly equivalent to UTM Easterly Zones (Zones 12, 13 and 14).

An attempt was made to maintain a consistent equation form for all species. This constrained the results of the above procedure somewhat, i.e. the "best" equation form overall was not the best for some species / UTM zone combinations.

Table 1. Average observed site index value and number of trees for each cell of the site matrix for trembling aspen in UTM Zone 12 (texture classes 6 and 7 had no observations and texture class 9 represents organic soils, not used in this analysis).

Site index in meters (50 yrs)
(number of observations)

Texture	Drainage Code 1	2	3	4	5	6	7	8	9	10	11	12	13	Avr
1				13	14	16								14
				14	*25*	*11*								*50*
2				17	17	16	30	16	16	12	12			17
				11	*137*	*260*	*1*	*11*	*1*	*3*	*3*			*427*
3					14	18	21	23	18	17	17			19
					6	*95*	*3*	*31*	*2*	*14*	*6*			*157*
4				16	15	18	20	22	18	16	10			19
				1	*1*	*547*	*12*	*322*	*63*	*6*	*1*			*953*
5									18					18
									3					*3*
9												13		13
												1		*1*
Avr				15	16	17	21	21	18	16	15	13		18
Sum				*26*	*169*	*913*	*16*	*364*	*69*	*23*	*10*	*1*		*1591*

Results:

The study resulted in a site productivity (SI_{50}) prediction method that is compatible with the existing Provincial forest inventory data and site matrix approach.

The SI_{50} tables obtained with the new equations give site index for all combinations of the independent variables, stratified by UTM zones. Table 2 shows an example. A visual representation of this site index table is given in Figure 3.

Table 2. Example site index table, giving value at each combination of the predictors Drainage (13 classes), Texture (7 classes) and Incipient Solar Radiation (4 classes indicated by UTM Northing).

SASKATCHEWAN SOIL/SITE CLASSIFICATION — SITE INDEX - 50 Year Total Age Basis
Reference: 10-Mar-88 (3A)
UTM - ZONE 12 — Species: ASPEN

UTM-North Texture	Drainage Class 1	2	3	4	5	6	7	8	9	10	11	12	13
590													
1:	7	8	9	10	11	12	12	11	11	10	9	8	6
2:	8	10	11	12	13	13	13	13	13	12	11	10	8
3:	10	11	12	13	14	15	15	14	14	13	12	11	9
4:	10	12	13	14	15	15	15	15	15	14	13	11	10
5:	10	12	13	14	15	15	15	15	15	14	13	11	10
6:	10	11	12	13	14	14	15	14	14	13	12	11	9
7:	8	10	11	12	13	13	13	13	13	12	11	9	8
600													
1:	7	9	10	12	13	13	13	13	12	11	10	8	7
2:	9	10	12	13	14	15	16	15	14	13	12	10	8
3:	10	12	13	15	16	16	16	16	15	14	13	11	10
4:	11	12	14	15	16	17	17	17	16	15	14	12	10
5:	11	12	14	15	16	17	17	17	16	15	14	12	10
6:	10	12	13	15	15	16	16	16	15	14	13	11	10
7:	9	10	12	13	14	15	15	15	14	13	12	10	8
610													
1:	7	9	11	13	14	15	15	15	14	13	11	9	7
2:	9	11	13	15	16	16	17	16	16	14	13	11	9
3:	10	12	14	16	17	18	18	18	17	16	14	12	10
4:	11	13	15	17	18	18	19	18	17	16	15	13	11
5:	11	13	15	17	18	18	19	18	17	16	15	13	11
6:	10	12	14	16	17	18	18	18	17	16	14	12	10
7:	9	11	13	14	16	16	17	16	16	14	13	11	9
620													
1:	8	10	12	14	16	16	17	16	15	14	12	10	7
2:	9	12	14	16	17	18	18	18	17	16	14	11	9
3:	11	13	15	17	19	19	20	19	18	17	15	13	10
4:	11	14	16	18	19	20	20	20	19	18	16	13	11
5:	11	14	16	18	19	20	20	20	19	17	16	13	11
6:	11	13	15	17	18	19	19	19	18	17	15	13	10
7:	9	12	14	16	17	18	18	18	17	15	14	11	9

The final equation form derived to calculate site index, given any values of the independent variables, was:

$$SI_{50} = B0 + B1*TSD + B3*TST + B5*SSD$$

where:

TSD = Sin(DRN/B2)
DRN = Drainage code
TST = Sin(TEX/B4)
TEX = Texture code
SSD = SUN * TSD
SUN = 17.787 - 0.0423 * (UTM - 576)
UTM = Major UTM northern zone
B0 - B5 = Regression coefficients

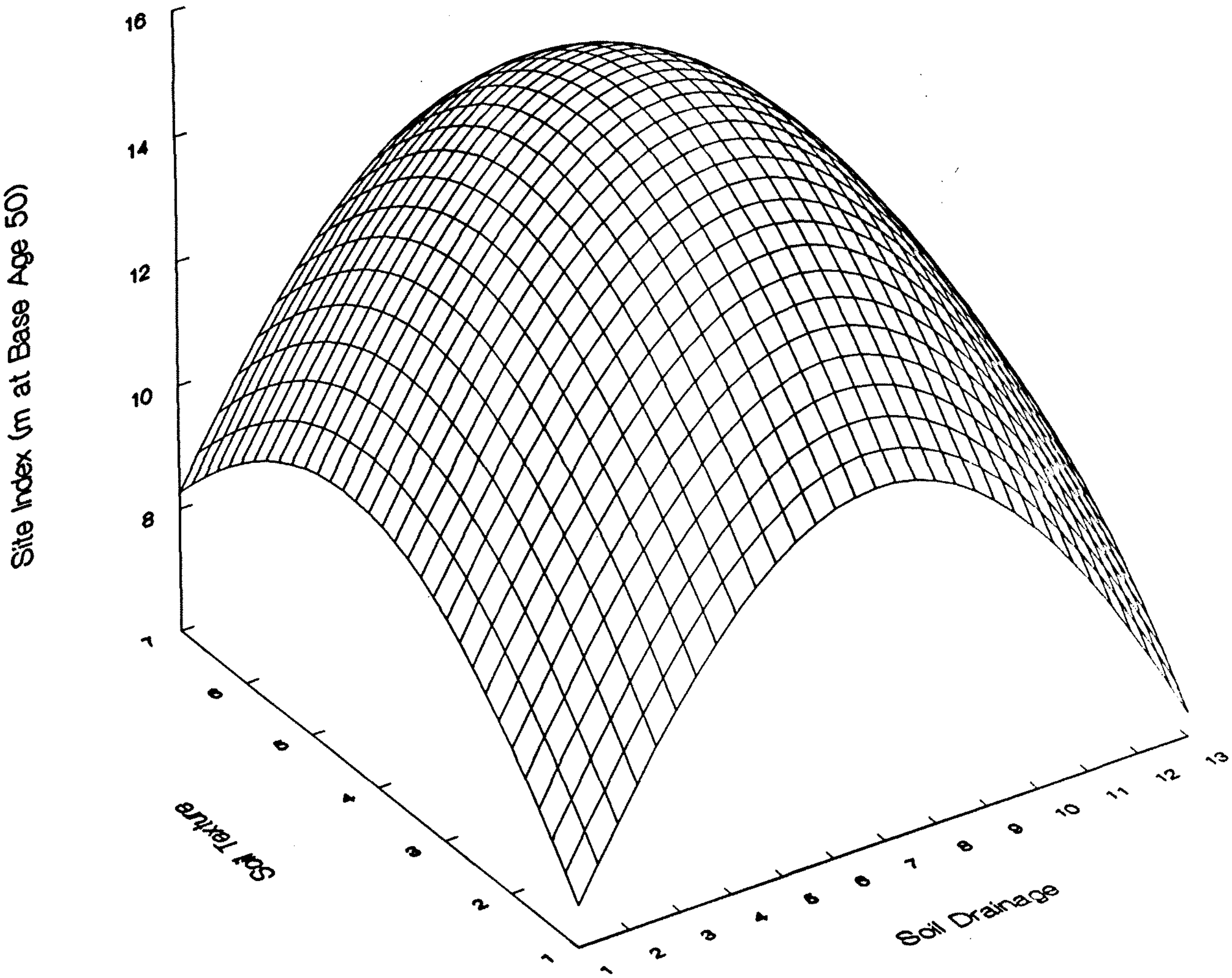

Figure 3. Graphic representation of estimated Site Index for trembling aspen in UTM Zone 12 at Northing 590.

The only exceptions to the above form were for white spruce in Zones 13 and 14:

Zone 13 wS: $SI_{50} = B0 + B1*TEX + B2*SUN + B4*Sin(TEX/2.5)$

Zone 14 wS: $SI_{50} = B0 + B1*Sin(DRN/B2) + B5*SUN*Sin(DRN/B2)$

The regressions generally yielded fairly low correlation values, with R^2 values from .26 to .65. Standard errors range from .92 to 2.31. While the estimates are clearly not very precise, they do show definite trends in tree height growth with varying levels of the predictors. A significant part of the variation in site index is clearly explained by transformations of the predictor variables. In some cases, strictly linear functions gave slightly better regression fits, but do not predict as well at the extremes. Table 3 shows an example of the regression coefficients obtained for one UTM Zone, with associated statistics.

Table 3. Regression statistics for UTM Zone 12. Number of observations is not given, but is equal to the number of sampled matrix cells (see Table 1).

	B_0	B_1	B_2	B_3	B_4	B_5	R^2/SE
		(2nd line:	F-ratio	Statistics	and	Std.Error)	
ASPEN							
	3.240	72.43	4.394	5.676	2.840	-3.834	.45
	0.44	*3.75*	*107.1*	*1.38*	*3.30*	*2.77*	*2.31*
JACK PINE							
	11.80	-25.60	3.500	-1.100	2.500	1.700	.46
	39.9	*1.68*	*18.8*	*0.52*	*1.43*	*2.03*	*1.24*
BLACK SPRUCE							
	2.589	38.15	3.832	6.247	2.241	-2.211	.63
	2.27	*5.95*	*44.4*	*18.6*	*256.2*	*5.10*	*1.09*
WHITE SPRUCE							
	6.411	56.61	4.281	-0.2305	1.866	-2.935	.65
	4.44	*5.22*	*236.8*	*0.33*	*0.31*	*3.79*	*1.26*

Drainage was found to be the most significant predictor, followed by solar radiation, with texture the least significant. This order varied somewhat between species / UTM zone combinations.

The study has yielded a system that can be applied, based on available inventory attributes, without direct measurements of tree height / age pairs. Of course, if direct measurement of height / age for any stand is practicable, then calculation of site index using that information is more reliable than indirect estimation from the predictor variables used in this study.

Discussion:

Other investigators elsewhere have had varying degrees of success in developing indirect site index estimation models based on various combinations of environmental factors such as soil texture, soil drainage, slope, aspect, elevation, available moisture, soil depth, parent material, etc. Payandeh (1986) found that five site factors explained only 22% of the variation in SI, while Carmean (1975) cites studies where the factors explained 65 - 85% of the variation. The present study was limited in the number of predictor variables available in the database. Tree height growth is affected by many environmental factors in addition to drainage, texture and incipient solar radiation, but these variables were chosen because they were already available, while considerable expense and time would be required to measure other factors. The correlations observed could probably be greatly strengthened by extra variable additions.

The equation form used does not fit well at the tails for some combinations of drainage / texture / solar radiation. There are two reasons for this:

i. The trigonometric sine transformations used in the equation gave the best overall statistical fit, but are somewhat limited at the extremes;
ii. Generally, observations are lacking at the tails.

The lack of observations at the tails is due to the fact that inventory plots, originally established to give a representative sampling of cover types, not of drainage / texture combinations, were used. Because of the uneven plot distribution, users of the product should be warned to be very cautious when applying it beyond the range of the data used in developing the equation (Table 1).

Existing published height / age curves, developed using graphical "guide curve" techniques, were used. While some preliminary comparisons with the stem analysis data showed similarities in the height / age trends, it must be recognized that this limitation exists.

Observations of drainage and texture used in this study were obtained from undisturbed forest floors. Users of the product must recognize that site index may be affected by practices such as tree harvesting and road building which can change the values of those variables.

Users should be aware that this rating system is attempting to generalize and simplify a very complex natural system of relationships. Other investigators' experiences in attempting to indirectly estimate site index from similar environmental factors have been considered by them to be unsuccessful. These predictions work best in "ideal" conditions of even-aged, single species stands. The problem increases in complexity with irregular mixed species composition, or multi-aged stands. Also, clonal impacts of aspen and balsam poplar are unknown. It has also been pointed out that the most successful soil-site studies have been done in areas where site index varies widely (Carmean 1975). For example, coastal Douglas fir may have SI_{50} values ranging from less than 18 to over 40 meters. Our range of site indices is narrow in comparison.

<u>Recommendations:</u>

While this project has provided a useable system for assigning site productivity ratings, it is recognized that there are limitations, as outlined above. Several recommendations for future work are given below.

Of utmost importance is the need to identify gaps and overlaps in the existing data. As previously mentioned, the 3-P inventory plots were distributed by forest cover types. Future plot establishments should attempt to cover those matrix cells that are presently unsampled (Table 1). This project can be used in the coordination of efficient additional data collection. Work must be done toward the building of a progressive data base that is continuously improving in distribution, quality and consistency (Curtis and Hyink 1984).

As "better" data becomes available, the system should be "fine tuned". One possible improvement would be the development of new polymorphic site index curves, using the stem analysis database. However, before those data can be used in indirect estimation of site, they must be linked with the predictor variables of drainage and texture.

The product should be subjected to an ongoing validation process using such data as are available. Predicted height / age must be checked against actual conditions on the ground.

While the field measurement of additional environment-based productivity indicators may be prohibitively expensive, it is necessary to review and identify any opportunities that exist to include such factors as mode of origin, landform, slope, aspect, nutrient status, soil rooting depth, annual precipitation, available soil moisture, and others. The analysis could be greatly strengthened by such inclusions.

Conclusion:

The study has produced a site productivity rating system which can be applied to any area where soil drainage and texture are known, whether or not it is presently supporting forest cover. The system has several limitations as mentioned (e.g. data gaps and other non-sampled variables), but is a start and is applicable to the immediate needs in Saskatchewan. Future sampling should include efforts to: fill data gaps; sample other important variables (e.g. slope, soil nutrients, etc.); and incorporate those additional variables into the system.

The ability to predict site index will serve as a starting point for subsequent calibrations of forest growth and yield models. This in turn can give input to forest planning models, to work towards better management of the forests of Saskatchewan.

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