CALIBRATING ONTWIGS FOR DRAINED AND FERTILIZED PEATLAND AND BLACK SPRUCE STANDS IN NORTHERN ONTARIO

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ABSTRACT

"ONTWIGS," an adaptation of the "LSTWIGS" growth and yield projection system developed for the Lake States, has been partially calibrated for boreal mixedwood in Ontario. This report describes its calibration for a treated peatland black spruce stand in northern Ontario. Precalibration analysis of variance indicated significant differences due to distance to drainage ditches. Model calibration was carried out separately and in stages for plots with different distances to the ditch. This was accomplished by adjusting tree survival and potential diameter growth coefficients of "ONTWIGS" equations, so as to reduce the prediction errors to within ±5% over a 5-year period. The final calibration resulted in average prediction errors for number of trees/ha (NTH), quadratic mean diameter (QMD), and basal area/ha (BAH) of: -2.3, 1.4, 0.4%; -1.9, -0.3, -2.2%; 0.4, -0.3, -0.4% for plots located at 9 m, 15 m, and 46 m from the drainage ditch, respectively.

Results indicate that "ONTWIGS" can be locally calibrated in order to increase its prediction accuracy to ±5%, averaging less than 2%, so as to account for variabilities due to drainage and fertilization of peatland black spruce in northern Ontario. Therefore, the model can be used as a growth and yield projection system for both natural and managed stands in Ontario for short to medium projection periods.

RÉSUMÉ

«ONTWIGS», une version modifiée du modèle de prévision de la croissance et du rendement «LSTWIGS» mis au point pour les États des Grands Lacs, a été partiellement adapté à la forêt mixte boréale de l'Ontario. Le présent rapport décrit l'adaptation de ce modèle à un peuplement d'épinettes noires à tourbière traité dans le nord de l'Ontario. Les analyses préalables de la variance ont révélé des différences significatives attribuables à l'éloignement des fossés de drainage. Le modèle a été adapté par étapes à différentes parcelles selon leur distance par rapport aux fossés. Pour y arriver, on a ajusté les coefficients de survie et de croissance potentielle en diamètre des équations de «ONTWIGS» de façon à réduire les erreurs de prévision à ±5 % sur une période de 5 ans. Cette démarche a permis d'obtenir les erreurs de prévision moyennes suivantes dans les parcelles situées respectivement à 9, 15 et 46 m des fossés de drainage: -2,3, 1,4 et 0,4 % pour le nombre d'arbres par hectare (NTH); -1,9, -0,3 et -2,2 % pour le diamètre de la tige de surface terrière moyenne (QMD); et 0,4, -0,3 et -0,4 % pour la surface terrière par hectare (BAH).

Les résultats montrent que «ONTWIGS» peut être adapté localement afin d'accroître le degré de précision à ±5 %, avec une moyenne inférieure à 2%, de façon à tenir compte de la variabilité attribuable au drainage et à la fertilisation des peuplements d'épinettes noires à tourbière dans le nord de l'Ontario. Par conséquent, ce modèle peut servir de système de prévision de la croissance et du rendement, tant en forêt naturelle que dans des peuplements aménagés de l'Ontario, pour des périodes de prévision variant de brèves à moyennes.

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cover photo:
A black spruce stand near Cochrane, Ontario,
which was drained in late 1940s (via a highway
drainage ditch) and fertilized in 1970.

INTRODUCTION

Black spruce (Picea mariana [Mill.] B.S.P.) is the most important pulpwood species in Ontario. About 50% of Ontario's black spruce sites are poorly drained peatlands (Ketcheson and Jeglum 1972) where the growth rate is slow due to excess water in the substrate, poor aeration, and lack of available nutrients (McEwen 1946, Payandeh 1973). However, productivity can be improved by drainage, fertilization, and/or thinning (Stanek 1968, 1977; Payandeh 1973, 1981).

Given the extent and economic importance of peatland black spruce in Ontario, it is essential to examine its growth response to drainage and fertilization and to attempt projections of these responses for areas with similar growing conditions. The purpose of this report is to describe the procedures used to calibrate the ONTWIGS model with the existing experimental data and to discuss the projections made with respect to growth response of drained and fertilized black spruce on peatland in northern Ontario.

GROWTH PROJECTION SYSTEMS

Over the past three decades, about 50 growth simulation models have been developed for North American forests and tree species. Such models may be divided into two general categories: stand models and individual tree models (Munro 1974).

Stand models simulate the growth and yield of a forest as a whole while using stand variables and associated factors such as stand density, basal area, height, and site productivity to predict the growth and yield of a forest stand. Individual tree models simulate the growth of single trees as affected by other trees competing for light, soil moisture, and nutrients. Individual tree models are further divided into two types: distance dependent and distance independent models.

The distance dependent models are driven by the density, i.e., number of trees /ha and spatial pattern of trees. In general, spatial patterns vary from clustered (aggregated) to random or uniform patterns. Distance dependent models may provide the most reliable growth and yield information because they are based on individual trees and their interactions with other neighboring trees. However, such models are expensive to develop, calibrate, and apply. In distance independent models, growth and development of individual trees are not affected by spatial patterns. The majority of stand and individual tree models developed to date are for single species, even-aged forest stands. However, several stand and individual tree models have also been developed for mixed species and/or uneven-aged stands.

STEMS (Stand and Tree Evaluation and Modelling System) and TWIGS have been developed at the North Central Forest Experiment Station in St. Paul, Minnesota (Holdaway and Brand 1983, Miner et al. 1988). TWIGS, the microcomputer version of STEMS, was initially developed for those who do not have access to a mainframe computer system. Developed as an individual tree growth and yield model, LSTWIGS is the version developed specifically for the Lake States of Michigan, Wisconsin, and Minnesota. Other versions have been developed for use in the central, as well as northeastern, states. As a result of interest shown by the Ontario Ministry of Natural Resources and the Ontario forest industry, Payandeh and Huynh (1991) adapted LSTWIGS to accommodate Ontario's urgent need for growth and yield projection systems.

The adaptation and calibration of ONTWIGS has been accomplished through: (1) input/output metrification, i.e., converting species specific coefficients from imperial units to metric units; (2) species code substitution; (3) model validation (Goulding 1972), i.e., how closely ONTWIGS predicts Ontario growth conditions; (4) model calibration, i.e., modifying model coefficients to bring prediction errors to within an acceptable level, say ± 10 %; and (5) development of new submodels based on local data so as to represent Ontario's growth conditions based on new functional relationships, if necessary. Payandeh and Huynh (1991) have successfully completed the first two steps while Payandeh and Papadopol (1994) described the results of partial validation and calibration of the model for boreal mixedwood. Payandeh et al.[1] produced a users' manual for the model and included simple procedures for its local calibration. The objective of this paper is to present the results of ONTWIGS calibration for an experimental drained and fertilized peatland black spruce site in northern Ontario.

MATERIALS AND METHODS

Data came from 48 (0.02 ha or 1/10 acre) circular growth plots established in 1970 as part of a drainage and fertilization experiment along existing drainage ditches located about 30 km southeast of Cochrane, Ontario (Payandeh 1982). The site is classified as a tree bog (Jeglum 1975) containing stagnant, unmerchantable black spruce. These stands average about 95 years in age and have an average SI_{50} of 3 m. According to Plonski (1974), this is well below Site Class 3.

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[1] Payandeh, B.; Papadopol, P.E.; Wang, Y. Users' manual for "ONTWIGS": A forest growth and yield projection system adapted for Ontario. Nat. Resour. Can.,Canadian Forest Service–Ontario, Sault Ste. Marie, ON. Inf. Rep. (In prep.).

Plots were established in two rectangular blocks, measuring 61 m by 244 m (200 ft by 800 ft), on each side of a highway drainage ditch dug in late 1940. In each block three rows of eight plots, positioned parallel to the ditch, were established at 9, 15, and 46 m (30, 50, and 150 ft) from the centre of the drainage ditch. Each circular plot was approximately 200 m² in area and had a radius of 8 m. Each set of three plots was randomly assigned to one of several fertilization treatments consisting of varying amounts of ammonium nitrate (AN), triple superphosphate (TSP), and potash(KC):

1. AN 84 kg/ha, TSP 84 kg/ha, KC 42 kg/ha,
2. AN 168 kg/ha, TSP 168 kg/ha, KC 84 kg/ha,
3. AN 112 kg/ha, TSP 112 kg/ha, KC 66 kg/ha,
4. AN 224 kg/ha, TSP 224 kg/ha, KC 112 kg/ha.

In June 1970, fertilizers were broadcasted manually, as uniformly as possible, in each plot. Treatments were replicated twice (4 treatments x 2 replications = 8 plots along one row, for one distance from the ditch).

All trees with a diameter at breast height (DBH) >1.5 cm (0.6") within each plot were marked and tagged. Height and DBH were measured and recorded for all trees. Tree diameters were measured with a diameter tape to the nearest 0.25 cm. The height of trees taller than 10 m was measured with a Spiegel Relaskop; shorter trees were measured to the nearest 30 cm with sectional tree height measuring poles. Detailed individual tree data such as height, age, crown class, crown condition, distance to nearest tree, etc., were measured and recorded for 3–4 dominant and codominant trees as part of the permanent growth plot located at the centre of each fertilization plot (Payandeh 1982). Subsequently, DBH and heights were measured for each tree with a diameter greater than 2.5 cm in 1970, 1972, 1975, 1985, and 1991.

Data from each plot constituted a tree list for input to ONTWIGS, where the information was expanded to a per hectare basis. The initial number of live trees, their diameters, and species codes were entered in the tree list. Ingrowth trees were added and cut or dead trees were removed from the plot tree list at the appropriate date during the projection period.

Prior to the calibration of ONTWIGS, two-way analysis of variance was performed on the 1991 measurements to determine the effects of drainage and/or fertilization on the growth and yield of the experimental plots.

The procedures employed, and stand attributes considered, were similar to those of Kowalski and Gertner (1989) and employed by Payandeh and Papadopol (1994). The three stand attributes: number of trees per hectare (NTH), quadratic mean diameter (QMD), and basal area per hectare (BAH) were chosen to represent tree survival, growth, and overall system performance, respectively. Prediction errors were calculated using all live trees

> 2.5 cm in diameter. The model was evaluated using the following statistics:

$$\text{percent error} = 100 \frac{\sum_{i=1}^{n} \frac{\hat{Y}_i - Y_i}{Y_i}}{n}$$

$$\text{standard deviation of error} = \sqrt{\frac{\sum_{i=1}^{n} (e_i - \bar{e})^2}{n-1}}$$

$$\text{mean error} = \frac{\sum_{i=1}^{n} (\hat{Y}_i - Y_i)}{n}$$

where: $\hat{Y}_i$ and Y_i are, respectively, the predicted and observed stand NTH, QMD, or BAH; e_i is the difference between $\hat{Y}_i$ and Y_i; and n is the number of plots.

For the sake of uniformity, the resulting errors were tabulated on a 5-year basis. The calibration process began with the initial parameter estimates. The objective was to adjust the most sensitive coefficients and reduce the magnitude of the errors to within ± 5 %. Since the models' original coefficients resulted in overprediction in nearly all cases, reduction in survival rate seemed to be the first logical step. The survival function is somewhat complex, as given below:

$$S = b_1 - \frac{1}{(1 + e^n)}$$

where: S = tree annual probability of survival, $n = b_2 + b_3 DGR^{b4} + b_5 D^{b6} e^{-b7D}$, D = current diameter, DGR = predicted annual diameter growth, and b's = species specific coefficients.

To adjust the above function to reduce probability of survival or to increase mortality across the board, b_1 should be reduced in simple local calibration. Similarly, coefficients b_1 and b_2 of the potential diameter growth (given below) can be adjusted:

$$PG = b_1 + b_2 D^{b_3} + b_4 SI\, CRD^{b_5}$$

where: PG = potential annual diameter growth, D = current tree diameter, SI = site index (height in meters at a base age of 50 years); CR = tree crown ratio code; and b_1, b_2, b_3, b_4, b_5 = species specific coefficients.

Local calibration was accomplished by adjusting the above coefficients, for tree survival and potential diameter growth, for the data set. Work began with the initial coefficients of ONTWIGS, which were then adjusted iteratively until satisfactory results were obtained. Due to the magnitude of the variability in growth, as a result of drainage and fertilization treatments, model calibration was accomplished in three stages in order to reduce the prediction error to ± 5 % for all plots within the experimental area.

ANALYSIS OF RESULTS

Analysis of Variance

Two-way analysis of variance was performed on the 1991 remeasurement data to determine whether there were significant differences due to drainage, fertilization, and their interactions. Results of such analysis for the three stand attributes, i.e., NTH, QMD, and BAH, listed above are summarized in Tables 1–3.

Examination of Tables 1, 2, and 3 indicates that distance from the drainage ditch has produced a highly significant difference over the 21 year period only in the case of BAH ($F = 6.348$, $P = 0.005$ %). For the other two stand attributes the distance from the ditch was less significant, i.e., at about a 7% level. Fertilization does not appear to have had any significant influence on these attributes. Such findings, although contrary to some other studies, agree with an earlier report (Payandeh 1982). This may be due to stand age, excessive moisture, and/or shortness of the growing season.

Figure 1 indicates that NTH clearly decreases with the distance from the ditch. However, Figure 2 shows that the average diameter of surviving trees did not decrease to a great extent. On the other hand, Figure 3 shows that BAH is significantly affected by the improved drainage as shown by the ANOVA results mentioned above. As a result, a larger number of trees with equal or larger diameter growth are yielding a greater BAH.

The high variability in basal area growth due to

Table 1. Summary of a two-way ANOVA for stand density (NTH) of drained peatland black spruce 21 years following fertilization.

Source of variation	df[a]	Sum of squares	Mean square	F-ratio	P
distance from ditch	2	4.15e+006	2.08e+006	2.945	0.068[b]
fertilization	5	4.46e+006	892349.49	1.265	0.305
distance x fert	10	1.76e+006	176197.13	0.250	0.987
residual	30	2.12e+007	705320.97		
TOTAL	47	3.15e007	671014.40		

[a] Degrees of freedom.
[b] Significant at the 7% level.

Table 2. Summary of a two-way ANOVA for quadratic diameter mean (QDM) of drained peatland black spruce 21 years following fertilization.

Source of variation	df[a]	Sum of squares	Mean square	F-ratio	P
distance from ditch	2	24.57	12.25	2.905	0.070[b]
fertilization	5	32.47	6.49	1.540	0.207
distance x fert	10	3.44	0.34	0.082	0.999
residual	30	126.57	4.21		
TOTAL	47	187.01	3.97		

[a] Degrees of freedom.
[b] Significant at the 7% level.

Table 3. Summary of a two-way ANOVA for basal area (BAH) of drained peatland black spruce 21 years following fertilization.

Source of variation	df[a]	Sum of squares	Mean square	F-ratio	P
distance from ditch	2	693.82	346.91	6.348[b]	0.005
fertilization	5	381.38	76.28	1.396	0.254
distance x fert	10	154.96	15.50	0.284	0.980
residual	30	1639.45	54.65		
TOTAL	47	2869.61	61.06		

[a] Degrees of freedom.
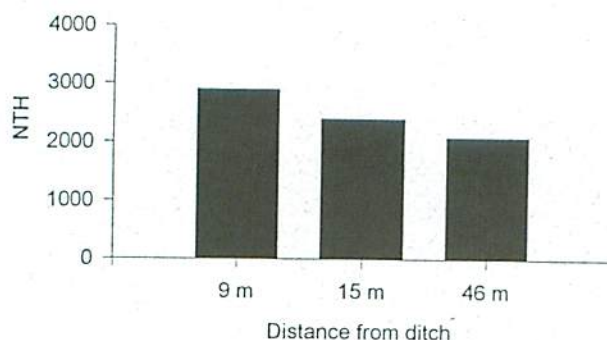[b] Significant at the 1% level.

Figure 1. Bar charts indicating average number of trees/ha by distance from the ditch.
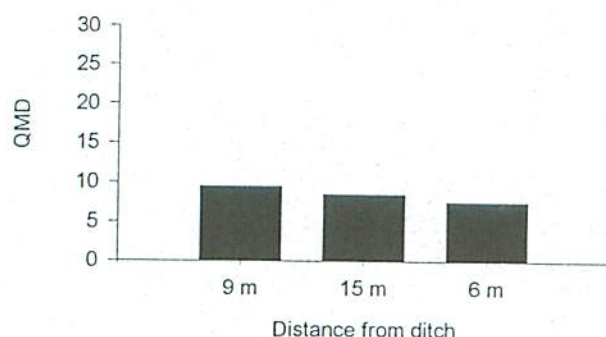

Figure 2. Bar charts indicating average quadratic mean diameter by distance from the ditch.
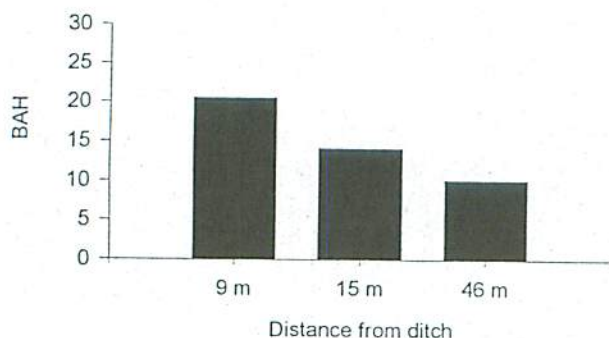

Figure 3. Bar charts indicating average basal area/ha by distance from the ditch.

improved drainage suggests that the calibration of ONTWIGS for such a situation would have to deal with significantly different growing conditions. Therefore, it is postulated that no single set of coefficients may adequately describe such conditions.

Empirical Calibration of ONTWIGS

Results of the partial calibration of the model based on the data sets described are summarized in Table 4. The results calculated in terms of 5-year percent differences are given by distance from the ditch. Although most of the results given should be self explanatory, a brief explanation may be helpful.

In the initial stage, the first set of coefficients that were modified were b_1 and b_2 of the survival equation. These predict the probability of annual survival for each tree. It should be noted that such empirical calibration may not reveal any cause and effect relations, i.e., the magnitude and direction of change in coefficients are not necessarily biologically meaningful or cause and effect related. Using the original (validation coefficient) values for b_1 and b_2 as a starting point, the program was run several times, applying different values for each coefficient via binary search,[2] until the mean of projected attributes (NTH, QMD, and BAH) fell within ±5 % of the observed means for the majority of plots. Although adjusting the b_1 and b_2 of survival coefficients was adequate for most of the plots, it did not satisfy the allowable error for the plots located farthest from the ditch. Perhaps this was because they were under different growing conditions. With b_1=0.9999 and b_2=13.408, the average 5-year percent error ranged from -1.6 to 6.0%, with an overall average of -0.2, 2.8, and 4.4% for NTH, QMD, and BAH, respectively. (*see* Table 4)

In the second stage, coefficient b_1 of the potential diameter growth equation was adjusted to 0.12711 while b_1 and b_2 of survival were kept constant at 0.9999 and 13.408, respectively. Such adjustment reduced the overprediction of basal area for plots 238, 240, 244, and 248 from 12.9%, 18.2%, 13.4%, and 26.0% to -2.0%, 4.4%, -2.0%, and 1.2%, respectively. As a result, the 5-year average percent errors ranged from -4.8 to 0.4%, with an overall average of -1.2, -0.7, and -2.4% for NTH, QMD, and BAH, respectively.

In the third stage, with the b_2 coefficient of potential diameter growth increased from 0.12711 to 0.20711 and survival coefficients kept constant, the underprediction for basal area of plots 237 and 243 located at a distance of 9 m from the ditch changed from -5.3% and -5.5% to 0.2% and 0.6%, respectively.

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[2] Payandeh, B.; Papadopol, P.E.; Wang, Y. Users' manual for "ONTWIGS": A forest growth and yield projection system adapted for Ontario. Nat. Resour. Can.,Canadian Forest Service–Ontario, Sault Ste. Marie, ON. Inf. Rep. (In prep.).

Table 4. Five year percent error for attributes of peatland black spruce drainage x fertilization experiment near Cochrane, Ontario, for varying potential diameter growth and survival coefficients for calibrating the "ONTWIGS".

				Submodel coefficients for the three phases of model calibration								
	Validation Survival (b1) 0.9946 (b2) 4.3155 P growth[a] (b1) 0.27211			Phase I Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.2721			Phase II Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.12711			Phase III Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.20711		
plot	NTH	QMD	BAH	NTH	QMD	BAH	NTH	QMD	BAH	NTH	QMD	BAH
						distance from the ditch = 9m						
225	-6.9	2.4	-3.4	-1.1	1.9	2.8						
230	-11.3	2.4	-8.6	-2.9	1.1	-0.9						
231	-10.8	3.0	-7.3	-0.3	0.7	1.1						
236	-10.8	2.4	-8.0	-1.3	0.8	0.4						
78	-10.5	-1.2	-11.8	-3.3	3.6	-4.8						
79	-10.4	2.2	-7.9	-2.4	1.2	-0.2						
80	-9.5	3.0	-5.7	-0.9	1.7	2.5						
81	-9.9	5.4	-2.9	-2.2	4.3	6.4	-2.5	-1.1	-4.4			
249	-9.1	4.4	-3.1	-0.5	3.2	6.0	-0.6	-2.3	-4.9			
237	-13.3	5.3	-1.3	-3.1	4.7	6.4	-4.1	-0.9	-5.3	-4.9	2.7	0.2
242	-12.0	6.4	1.6	-2.8	6.0	9.6	-3.1	-0.4	-3.7			
243	-10.5	4.3	-0.9	-0.4	3.6	7.1	-0.2	-2.8	-5.5	0.4	0.1	0.6
69	-6.3	3.5	0.3	-2.1	-0.1	-2.0						
68	-6.8	3.5	-0.6	-0.9	-0.5	-1.8						
67	-9.9	0.2	-9.7	1.6	-2.1	-2.5						
66	-13.0	-0.3	-13.2	0.4	-2.4	-4.5						
Sum	-161.0	46.9	-82.5	-22.2	27.7	25.6	-10.5	-7.5	-23.8	-4.5	2.8	0.8
Average	-10.1	2.9	-5.2	-1.4	1.7	1.6	-2.1	-1.5	-4.8	-2.3	1.4	0.4
						distance from the ditch=15m						
70	-7.2	5.5	4.2	-2.9	2.4	1.5						
71	-5.7	5.3	6.2	-1.2	2.1	2.9						
72	-6.7	3.0	-1.4	-0.5	-0.7	-1.8						
73	-8.0	0.8	-6.8	-1.7	-1.5	-4.4						
226	-9.2	1.5	-7.4	-0.8	1.0	1.2						
229	-9.5	3.9	-4.3	-2.5	3.3	3.8						
232	-8.4	4.2	-2.3	-2.7	3.8	4.6						
235	-8.5	3.2	-4.0	-1.5	2.7	3.8						
85	-9.3	1.8	-7.1	-1.0	1.0	0.9						
84	-9.5	3.9	-4.4	-2.6	3.4	3.8						
83	-10.0	4.5	-4.4	-0.4	2.9	5.8	-0.8	-2.1	-4.9			
82	-8.9	6.5	0.3	-0.6	5.4	11.1	-1.0	-0.5	-2.0			
248	-6.8	9.3	9.0	-0.2	10.8	26.0	-0.6	1.0	1.2			
238	-11.2	8.4	5.8	-4.1	8.7	12.9	-4.2	1.2	-2.0			
241	-7.8	7.4	8.5	-1.2	7.0	10.6	-3.3	-0.8	-3.4			
244	-8.9	7.2	4.9	-1.1	6.8	13.4	-1.4	-0.3	-2.0			
Sum	-135.6	76.4	-3.2	-25.0	59.1	96.1	-11.3	-1.5	-13.1			
Average	-8.5	4.8	-0.2	-1.6	3.7	6.0	-1.9	-0.3	-2.2			

(cont'd)

Table 4. Five year percent error for attributes of peatland black spruce drainage x fertilization experiment near Cochrane, Ontario, for varying potential diameter growth and survival coefficients for calibrating the "ONTWIGS". (concl.).

	Submodel coefficients for the three phases of model calibration											
	Validation Survival (b1) 0.9946 (b2) 4.3155 P growth[a] (b1) 0.27211			Phase I Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.2721			Phase II Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.12711			Phase III Survival (b1) 0.9999 (b2) 13.408 P growth[a] (b1) 0.20711		
plot	NTH	QMD	BAH	NTH	QMD	BAH	NTH	QMD	BAH	NTH	QMD	BAH
	distance from the ditch = 46m											
77	-6.4	7.8	14.4	-3.0	6.3	9.6	-3.7	0.4	-4.2			
76	-5.0	6.7	12.7	-0.3	4.1	8.5	4.0	-2.7	-1.8			
75	-7.1	4.0	0.5	-0.5	-0.1	-0.7						
74	-6.3	3.8	0.9	-0.7	0.2	-0.3						
227	-1.3	3.3	5.3									
228	-0.4	3.7	7.6	0.5	4.4	10.4	-1.1	-0.9	-2.8			
233	0.0	3.0	6.5				-0.8	-1.5	-3.6			
234	-0.8	3.6	6.8				-1.2	-1.0	-3.1			
247	2.2	5.7	15.8				-0.6	0.7	0.3			
86	-0.9	2.6	4.3									
87	-2.2	3.2	3.9									
88	0.3	3.0	6.8				-0.3	-1.5	-3.2			
89	0.0	4.6	10.0				-0.7	-0.2	-1.1			
239	-0.9	6.0	12.0				-0.1	1.2	2.3			
240	0.0	8.1	18.2				-0.5	2.5	4.4			
245	-2.3	7.5	13.3				8.9	-0.2	8.4			
Sum	-31.1	76.6	139.0	-4.0	14.9	27.5	3.9	-3.2	-4.4			
Average	-1.9	4.8	8.7	-0.8	3.0	5.5	0.4	-0.3	-0.4			
Overall average	-6.8	4.1	1.1	-1.2	2.8	4.3	-1.2	-0.7	-2.4			

[a] Potential diameter growth.

DISCUSSION

Numerous swamp drainage and/or fertilization experiments conducted in Finland, Sweden, Russia, and other European countries have proven that such treatments can significantly improve the growth and yield of peatland forest stands. Large-scale application of such treatments has also been shown to be both practical and economical under the socioeconomic conditions of both Finland and Russia. Thus, large areas of swampy forests are being drained and/or fertilized annually in both countries.

In the case of Canadian peatland forests in general, and those of black spruce stands in northern Ontario in particular, no concrete recommendations can be made regarding the magnitude of growth and yield improvement due to drainage and/or fertilization mainly because of a lack of sufficient information. Only a few small-scale forest drainage and/or fertilization experiments have been conducted in Canada to date. Unless a series of long-term, well designed, and well replicated experiments are carried out to determine the effects of such treatments on growth and yield of peatland black spruce, no definite recommendation can be made regarding the practicality and economic feasibility of such stand improvements under Canadian economic conditions. Results of this study indicate that "ONTWIGS" may be locally calibrated so as to project with reasonable accuracy the growth and yield of drained and/or fertilized peatland black spruce stands in Ontario. Nevertheless, it is perhaps safe to say that unless the economic conditions in general, and the wood supply situation in particular, changes drastically in the near future, application of such silvicultural treatments to peatland black spruce stands may not be economically justified.

SUMMARY AND CONCLUSIONS

Results of this study, summarized in Table 4, indicate that with simple local calibration the prediction accuracy of "ONTWIGS" can be improved considerably to account for variabilities due to changes in soil hydrology or nutrient content induced by drainage and/or fertilization. Therefore, the model can be used as a practical growth and yield projection system for both natural and managed stands in Ontario, for short to medium projection periods. However, further calibration of the model on larger, well designed experiments and more representative data sets is recommended to insure increased model accuracy and reliability.

REFERENCES

Goulding, C.J. 1979. Validation of growth models used in forest management. New Zealand Jou. of Forest Science. 24:108–124.

Holdaway, M.R.; Brand, G.J. 1983. An evaluation of the STEMS tree growth projection system. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN. Research Paper NC-234. 20 p.

Jeglum, J.K. 1975. Classification of swamp for forestry purposes p. 227–238. in J.W. Fraser and C.F. Robinson, eds. Proceedings, Black Spruce Symposium. 23–25 September, Thunder Bay, Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O–P–4.

Ketcheson, D.E.; Jeglum, J.K. 1972. Estimates of black spruce and peatland areas in Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O–X– 172. 29 p.

Kowalski, D.G.; Gertner, G.Z. 1989. A validation of TWIGS for Illinois forests. Northern Journal of Applied Forestry 6:154–156.

McEwen, J.K. 1946. An effect of sphagnum on the growth of black spruce. For. Chron. 42(2): 175–183.

Miner, C.L.; Walters, N.R.; Belli, M.L. 1988. A guide to the TWIGS for the north central U.S. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. Technical Report. 105p.

Munro, D.D 1974. Forest growth models - a prognosis. p.7-21 in J. Fries, ed. Growth Models for Tree and Stand Simulation. Swedish Royal College of Forestry, Stockholm, Sweden. Res. Note No. 30.

Payandeh, B. 1973. Analyses of a forest drainage experiment in northern Ontario. I: Growth analysis. Can. J. For. Res. 3(3):387–398.

Payandeh, B. 1982. Five-year growth response of northern Ontario peatland black spruce to fertilization and drainage. Environ, Can., Can. For. Serv., Sault Ste. Marie, ON. 31 p.

Payandeh, B.; Huynh, L.N. 1991. ONTWIGS" A stand growth projection system adapted for Ontario. For. Can., Ontario Region, Sault Ste. Marie, ON. Inf. Rep. 0–X–412. 16 p.

Payandeh, B.; Papadopol, P.E. 1994. Partial calibration of "ONTWIGS" for several species of boreal mixedwood in Ontario. Northern J. Appl. For. 11(2): 41–46.

Plonski, W.L. 1974. Normal yield tables (metric) for major forest species of Ontario. Ontario Ministry of Natural Resources, Div. of Forests, Toronto, ON. 40 p.

Stanek, W. 1968. A forest drainage experiment in northern Ontario. Pulp and Paper Magazine of Canada. 69: 58–62.

Stanek, W. 1977. Ontario clay belt peatlands - are they suitable for forest drainage? Can. J. For. Res. 7(4):656–665.