

Spatial Accuracy Assessment: Land Information Uncertainty in Natural Resources

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CHAPTER 50

Mapping Forest Site Potential at the Local and Landscape Levels

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INTRODUCTION

In 1996, the Canadian Forest Service initiated the ECOLEAP project, a research initiative whose objective is to develop a spatialized model for predicting the net primary productivity of forest ecosystems both at the regional and the local scales for applications in forest management. The spatialization is based on the numerical description of elevation, slope, aspect, slope shape, slope position, and climate, as well as on the use of satellite images to capture data defining the state of the vegetation cover. The present work is an intermediate step in the derivation of this spatialized, process-based simulator of forest productivity, and is aimed at the development of a biophysically sound empirical methodology for mapping forest site potential. Biophysical variables retained are related to climate and topography. In this work, site potential is defined as the maximum height reached by a tree species on a site. In grid-based geographic information systems, the topographic, climatic, and edaphic variables may be available for every grid cell of a forest stand, whereas in current forest inventories this information is available from only a small sample of cells.

MATERIAL AND METHODS

Plot Data

The data used to develop the forest site potential model come from 46,000 temporary plots measured by the Quebec Ministry of Natural Resources as part of its ongoing forest inventory program (Figure 50.1). The plots are arranged along 5-plot 1 km transects.

Transect orientation is selected to maximize along-transect variability in forest types. The transect themselves are distributed in most of the forest types of the province according to a sampling scheme designed to characterize all forest strata. Within each plot, collected information includes variables related to the site, the trees, and the stand. Site-related variables measured are topography (elevation, slope, aspect, topographic type), drainage class, and soil characteristics, particularly texture. Drainage classes vary from 0 (excessive or dry) to 6 (poor or wet). Tree-related variables are the diameter at 1.3 m (dbh) of each stem with a dbh greater than 9 cm within a 400 m²-circular plot, dbh of all stems smaller than 9 cm within a 40 m² plot, and age of three dominant trees per plot as determined by ring count at stump height. Data on the forest stand relate to its canopy cover and its developmental stage. Measurements of those plots was carried out between 1992 and 1997.

Biophysical Variables

Independent or explanatory variables were chosen to explain maximum tree height (H) so that we could capture local site and climate characteristics. The variables were selected based on their functional relationship to tree growth, and on the possibility of computing their value for any point using numerical topographical and soils information, and regional climatic data. The variables had to be as independent from one another as possible.

Soil fertility potential was expressed as the sum of the percent silt and clay fractions (SC). Drainage

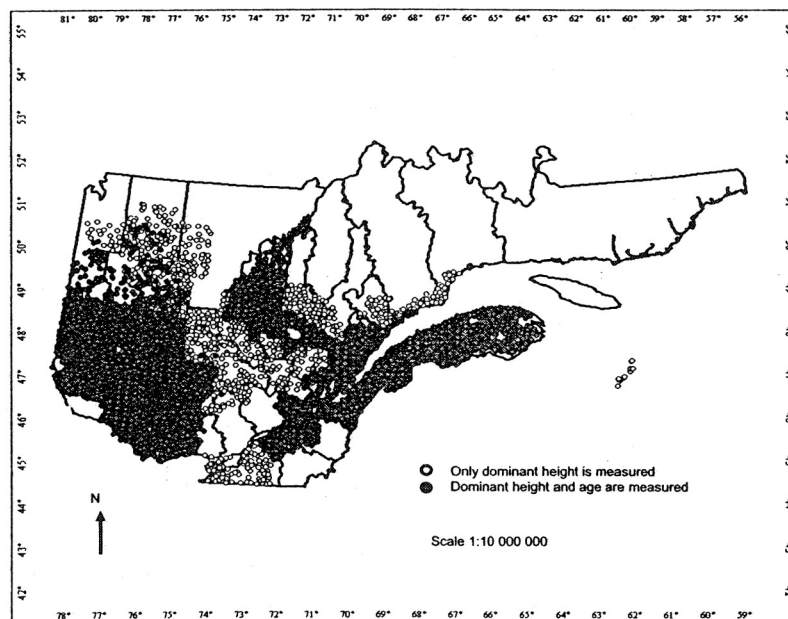


Figure 50.1. Spatial distribution of the temporary sample plots.

classes determined on site were also retained (DR), but the six initial classes were compressed into four classes by grouping classes 1 and 2 (dry) and classes 5 and 6 (wet). Climate-related variables were computed using the algorithms of BioSIM (Régnière and Bolstad, 1994; Régnière, 1996). Given the longitude, latitude, and elevation of a point, this model performs spatial interpolation from 30-year records of 120 permanent meteorological stations (Figure 50.2), as well as adjustments for elevation, slope and aspect, and maritime influences. Variables retained were degree-days above 5°C (DD), the sum of June, July, and August precipitation (PP), an aridity index (AI), and cumulative atmospheric vapor pressure deficit (VPD). All three temperature-related variables (DD, AI, and VPD) were computed from daily maximum and minimum temperatures. Finally, forest type (FT) was also included in the analysis as a class variable. In this first attempt at modeling site potential, we focused on three species, and plots were retained if they contained either sugar maple (*Acer saccharum* Marsh), balsam fir [*Abies balsamea* (L) Mill.], or black spruce [*Picea mariana* (Mill) BSP].

Analysis

Boundary-line analysis was used to determine the relationship between site potential and explanatory variables (Webb, 1972; Chambers et al., 1985). The

rationale for boundary-line analysis is that, in a scatter diagram of dominant tree height against an explanatory variable for all 46,000 plots, the upper limit of the cloud of points represents cases in which that particular variable actually limits growth (Jarvis, 1976). A function adjusted to this upper limit thus represents the relationship between this explanatory variable and dominant tree height.

Model fitting was performed on a subset of the 46,000 plots selected as follows. In each scatter diagram relating dominant height to one of the independent or explanatory variables, only the 5% uppermost points were retained for further analysis. The selected observations for each of the independent variables were combined into a final data set used for model fitting. All five explanatory variables were initially considered as fully independent so that their respective effect on the dependent variable would be multiplicative. When transformed logarithmically, the full model can be written as:

$$\begin{aligned} \text{LnH} = & b_0 + b_{\text{FT1}}\text{FT1} + b_{\text{FT2}}\text{FT2} + b_{\text{DR1}}\text{DR1} + \\ & b_{\text{DR2}}\text{DR2} + b_{\text{DR3}}\text{DR3} + b_{\text{DD}}\text{LnDD} + \\ & b_{\text{FT1,DD}}\text{FT1*LnDD} + b_{\text{FT2,DD}}\text{FT2*LnDD} + \\ & b_{\text{VPD}}\text{LnVPD} + b_{\text{PP}}\text{LnPP} + b_{\text{AI}}\text{LnAI} + \\ & b_{\text{SC}}\text{LnSC} + e_{\text{LnH}} \end{aligned} \quad (1)$$

where FT1 and FT2 are dummy variables which, in combination, represent the three possible species re-

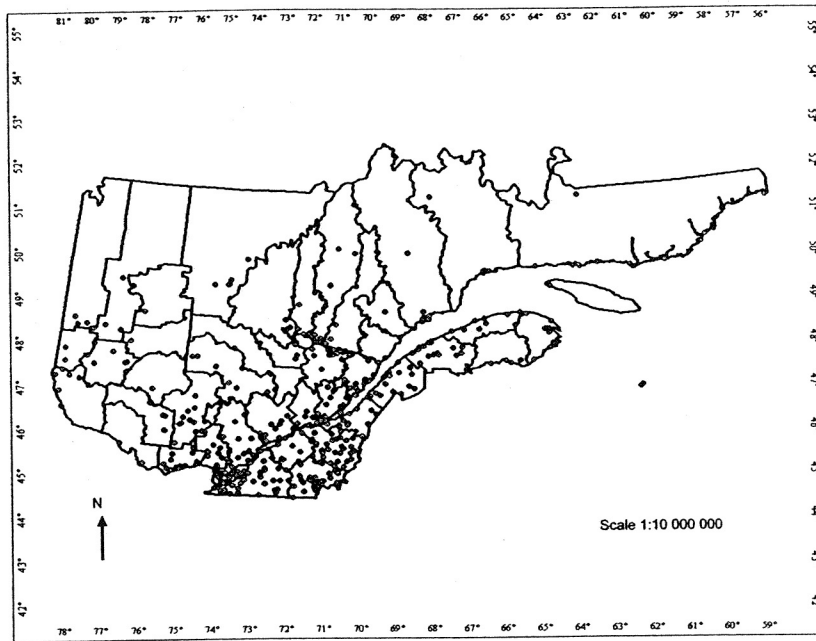


Figure 50.2. Spatial distribution of the long-term climatic stations used in the BIOSIM model.

tained, DR1 to DR3 are also dummy variables which, in combination, represent the four possible classes of drainage. All b 's are estimated parameters, and other variables are as described above. The parameters of Equation 1 were estimated by ordinary least-squares. When adjusted to the provincewide data set, this model was called the Provincial model. Descriptive statistics for the data used in fitting the Provincial model are given in Table 50.1.

In a second step, the same model was fitted to a much more geographically-constrained data set incorporating only temporary plots that were inside the boundary of a 3,000 km² pilot area. This pilot area is a long band of forest that stretches from the sugar maple stands just west of Quebec City, to the balsam fir stands of the *Réserve Faunique des Laurentides* about 130 km to the north. From north to south, this region is therefore composed essentially of three climatic domains: (1) balsam fir-white birch domain, ecological region 8f of Thibault (1985), with degree-day above 5°C of 890 to 1,000, (2) sugar maple-yellow birch domain, ecological region 3g with degree-day above 5°C of 1,220 to 1,550, and (3) sugar maple-American basswood domain, ecological region 2c with degree-day above 5°C of 1,660 to 1,780. Because black spruce is rare in the pilot region, only balsam fir and sugar maple were considered in model estimation. Descriptive statistics for the data used in fitting the Pilot Region model are given in Table 50.2.

Finally, the regional applicability of the Provincial model was tested by comparing predicted maximum tree heights with those obtained using the Pilot Region model.

RESULTS AND DISCUSSION

Ideally, all explanatory variables should have been independent. However, all four climatic variables proved to be highly correlated. Model fitting therefore required a few iterations to deal with these collinearities. After fitting the full Provincial model, parameters for the LnPP, LnAI, and LnSC variables were found to be nonsignificant. Removing these variables yielded a reduced model which was fitted to the provincial data set. In this reduced model, the parameter associated with the LnVPD variable also proved to be nonsignificant. This variable was therefore removed and a new reduced model was fitted to the data. Finally, the parameter associated with DR3 (drainage class 4) also turned out to be nonsignificant. However, DR3 was retained because the parameters associated with the other two drainage-related dummy variables (DR1 and DR2) were significant. The final Provincial model was therefore:

$$\text{LnH} = 0.966587 + 4.254747 \cdot \text{FT1} + 2.683395 \cdot \text{FT2} - 0.013622 \cdot \text{DR1} - 0.009983 \cdot \text{DR2} +$$

Table 50.1. Descriptive Statistics of the Data Used in the Adjustment of the Provincial Model.

Variable	Mean	Standard Deviation	Minimum	Maximum
Black spruce: 732 observations				
Maximum height (dm)	193.2	14.1	169.0	307.5
Degree-day (°C)	1208.5	189.1	654.9	1739.8
Deficit of vapor pressure (mbar)	1273.4	162.7	457.0	1609.4
Precipitation (mm)	308.0	25.9	244.9	435.0
Aridity index (no unit)	0.10	0.33	0.00	2.05
Sum of clay and silt percentage	41.4	22.9	8.0	93.0
Balsam fir: 874 observations				
Maximum height (dm)	188.7	14.2	166.3	255.0
Degree-day (°C)	1301.3	239.9	642.7	1816.3
Deficit of vapor pressure (mbar)	1253.2	214.2	438.4	1666.9
Precipitation (mm)	306.0	40.8	241.0	435.0
Aridity index (no unit)	0.14	0.41	0.00	2.70
Sum of clay and silt percentage	53.7	22.6	8.0	93.0
Sugar maple: 356 observations				
Maximum height (dm)	240.6	21.7	150.0	327.7
Degree-day (°C)	1474.8	167.4	760.4	1861.7
Deficit of vapor pressure (mbar)	1361.5	164.2	469.4	1671.7
Precipitation (mm)	297.9	39.5	241.0	429.7
Aridity index (no unit)	0.36	0.61	0.00	2.51
Sum of clay and silt percentage	56.5	20.8	8.0	93.0

Table 50.2. Descriptive Statistics of the Data Used in the Adjustment of the Pilot Region Model.

Variable	Mean	Standard Deviation	Minimum	Maximum
Balsam fir: 29 observations				
Maximum height (dm)	181.2	22.5	151.7	241.0
Degree-day (°C)	1027.1	198.8	816.2	1494.8
Deficit of vapor pressure (mbar)	1159.2	129.0	913.3	1528.8
Precipitation (mm)	406.4	37.5	285.4	429.7
Aridity index (no unit)	0.00	0.00	0.00	0.00
Sum of clay and silt percentage	47.1	22.0	18.0	80.0
Sugar maple: 7 observations				
Maximum height (dm)	227.0	24.2	174.0	245.0
Degree-day (°C)	1371.6	141.2	1109.1	1522.9
Deficit of vapor pressure (mbar)	1370.4	141.1	1204.6	1533.3
Precipitation (mm)	400.4	20.4	380.3	429.7
Aridity index (no unit)	0.00	0.00	0.00	0.00
Sum of clay and silt percentage	49.0	11.2	37.0	58.0

$$0.000936*DR3 + 0.624831*LnDD - \\ 0.615162*FT1*LnDD - 0.397782*FT2*LnDD (2)$$

The final model presented in Equation 2 was also fitted to the Pilot Region data set. Parameter values and

some underlying statistics for both models are presented in Table 50.3.

Equation 2 emphasizes the key role of degree-days in explaining maximum tree height, both as a main effect, and in interaction with tree species. This vari-

Table 50.3. Values and Statistics of the Parameters of the Provincial and the Pilot Region Models.

	Parameter Estimates	Standard Error	T Test Probability
Provincial model: 1356 observations; mean square error = 0.00447; adjusted R-square = 0.6698			
Intercept	0.966587	0.235075	0.0001
FT1	4.254747	0.277540	0.0001
FT2	2.683395	0.254913	0.0001
DR1	-0.013622	0.006100	0.0256
DR2	-0.009983	0.005039	0.0478
DR3	0.0000939	0.011533	0.9353
LnDD	0.624831	0.032384	0.0001
FT1*LnDD	-0.615162	0.038540	0.0001
FT2*LnDD	-0.397782	0.035254	0.0001
Pilot Region model: 36 observations; mean square error = 0.00968; adjusted R-square = 0.7313			
Intercept	-1.375271	2.701010	0.6139
FT1	11.525321	3.534985	0.0025
FT2	4.463306	2.788726	0.1187
DR1	-0.021194	0.054774	0.7012
DR2	0.006463	0.042860	0.8810
LnDD	0.940461	0.373445	0.0167
FT1*LnDD	-1.700434	0.496878	0.0016
FT2*LnDD	-0.635874	0.387268	0.1098

^a DR3 is absent in the pilot area.

able represents large-scale variability in tree height across the data set domain. Its interaction with species indicates that the height of each of the three species is influenced differently by differences in degree-days. The drainage effect is also important by locally modulating the effect of degree-days. These inferences drawn from the model confirm much of the ecophysiological work on the forest productivity (Pastor et al., 1984) in which effects of drainage and interactions between energy inputs (degree-days) and tree species are taken as basic premises. Vapor pressure deficit and aridity index were not significant because of their collinearity with degree-days. Precipitation was not significant simply because it is not a limiting factor to height growth in Eastern Canada. The sum of clay and silt percentages was not significant, indicating that textural contribution to soil fertility is not a major factor in explaining height growth.

Results of the comparison of predictions made with the Provincial model for the sites in the Pilot Region with maximum tree heights predicted by the Pilot Region model are shown in Figure 50.3. Fit around the 1:1 line was good for both balsam fir and sugar maple, indicating that provincewide relationships derived us-

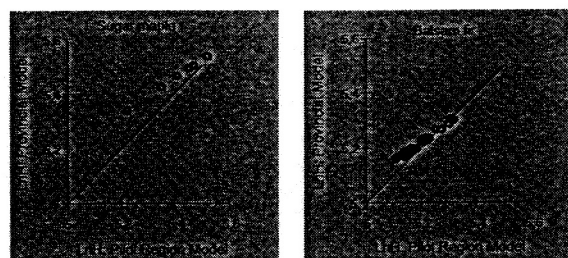


Figure 50.3. Maximum heights predicted by the Provincial model against maximum heights predicted by the Pilot Region model for sugar maple and balsam fir.

ing this method produce valid local estimates. The small bias for sugar maple possibly stems from the fact that drainage classes are less sampled than for balsam fir in the available data.

The procedure presented above was our first attempt at the derivation of a site productivity model based on biophysical variables. Its derivation revealed flaws that were not apparent at the outset, and convinced us to carry on using a different approach. In the next itera-

tion of this procedure, the dependent variable, maximum height, will be replaced by the classical logistic function relating dominant height and age. This change will enable us to use all plots in our analysis, and not the upper 5% as is the case in the present analysis. For each species, the relationship between dominant height H and age A can be described by the following function:

$$H = c_1 \exp(c_2/(1 - c_3)A) + e_H \quad (3)$$

Where c_1 is the maximum height achievable by that species, and c_2 and c_3 are adjusted coefficients. Unpublished work on that relationship has shown that c_2 is related primarily to broad ecological regions, whereas c_3 is related to local factors such as drainage. Consequently, these two parameters will be related to our biophysical variables in the following manner:

$$c_2 = c_{20} + c_{DD}DD + c_{VPD}VPD + c_{PP}PP + c_{AI}AI + c_{SC}SC \quad (4)$$

and

$$c_3 = c_{30} + c_{DR1}DR1 + c_{DR2}DR2 + c_{DR3}DR3 \quad (5)$$

The other development is to improve representation of the drainage class. Drainage is an important factor because it controls dominant height at the local scale. However, the use of the interpreted drainage class binds us to mapped values of drainage classes derived from the subjective interpretation of aerial photographs. Ideally, drainage should be derived from fixed terrain attributes, possibly in interaction with climatic variables such as the aridity index. Work is currently under way to derive such a potential drainage index.

CONCLUSION

By using data from the Quebec forest inventory, we quantified the significant effects of degree-days and drainage on maximum height reached by balsam fir, sugar maple and black spruce. After being fitted to all of the Quebec forest stands in our database, the maximum height prediction model was applied without large bias to a restricted Pilot Region. With boundary-line analysis, only 5% of the available data could be used. It is possible to improve site potential predic-

tions by incorporating in our analysis the functional relationship between dominant height and tree age, a relationship better known as the site index. This would enable the use of all the available data. Ongoing development of the procedure should therefore yield a site index model based on biophysical variables. With further refinements, we hope to replace drainage class by a quantitative drainage index derived from topographical and climate information. Finally, an accurate estimate of model error is a prerequisite for its eventual use in forest inventory or management. This problem will be addressed by quantifying both errors linked to site-specific predictions, and errors linked to spatial interpolation of underlying variables.

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REFERENCES

- Chambers, J.L., T.M. Hinckley, G.S. Cox, and R.G. Aslin. Boundary-Line Analysis and Models of Leaf Conductance for Four Oak-Hickory Forest Species, *For. Sci.*, 31(2), pp. 437-450, 1985.
- Jarvis, P.G. The Interpretation of the Variations in Leaf Water Potential and Stomatal Conductance Found in Canopies in the Field, *Philos. Trans. R. Soc. London*, Ser. B, 273, pp. 593-610, 1976.
- Pastor, J., J.D. Aber, and J.M. Melillo. Biomass Prediction Using Generalized Allometric Regressions for Some Northeastern Tree Species. *For. Ecol. Manage.*, 7, pp. 265-274, 1984.
- Régnière, J. A Generalized Approach to Landscape-Wide Seasonal Forecasting with Temperature-Driven Simulation Models, *Environ. Entomol.*, 25, pp. 869-881, 1996.
- Régnière, J. and P. Bolstad. Statistical Simulation of Daily Air Temperature Patterns in Eastern North America to Forecast Seasonal Events in Insect Pest Management, *Environ. Entomol.*, 23, pp. 1368-1380, 1994.
- Thibault, M. Les Régions Écologiques du Québec Méridional, *Ministère de l'Énergie et des Ressources*, Québec, 1 map, 1985.
- Webb, R.A. Use of Boundary Line in the Analysis of Biological Data, *J. Hortic. Sci.*, 97, pp. 309-319, 1972.