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ADJUSTING THE STEMS REGIONAL FOREST GROWTH MODEL TO IMPROVE LOCAL PREDICTIONS

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ABSTRACT.—A simple procedure using double sampling is described for adjusting growth in the STEMS regional forest growth model to compensate for subregional variations. Predictive accuracy of the STEMS model (a distance-independent, individual tree growth model for Lake States forests) was improved by using this procedure.

KEY WORDS: Growth model, double sampling, ratio estimators.

In recent years much effort has been expended to create mathematical models capable of accurately predicting the dynamic processes of forest growth (Fries 1974). Several of these models have been fitted to data from wide geographic areas and broad ranges of site and stand conditions (Arney 1974, Ek and Monserud 1974, Stage 1973, USDA Forest Service 1979).

Frequently, it is desirable to "extend" a model slightly beyond the geographic area for which it was calibrated or to use it intensively within a small portion of the stated range. However, the model may perform poorly for these applications.

When a regional growth model is calibrated using permanent growth plot remeasurement data, the resulting coefficients generally reflect the average of the natural forces operating in that geographic area during the period between remeasurements. Thus, predictions may deviate when the growth model is applied intensively to a subregion within or slightly beyond the geographic range of the model, hence making the regional coefficients inappropriate.

To compensate for such variations, it is seldom practical to recalibrate the entire model. Indeed, all that may be needed is to "fine tune" or "self-calibrate" the existing regional model to improve performance in the subregion or extended area (Stage 1973). This paper describes a simple way to adjust the STEMS regional growth model to compensate for subregional variation.

STEMS is a distance-independent, individual tree growth model currently calibrated for two major geographic areas: the Pacific Northwest and the Lake States (Belcher *et al.* 1981, Shifley 1981, USDA Forest Service 1979, Ek *et al.* 1980, Hahn *et al.* 1979, Smith and Raile 1979, Lundgren and Essex 1979). The Lake States model was calibrated with remeasurement data from approximately 1,500 permanent plots containing 93,000 trees in Minnesota, Wisconsin, and Michigan (Christensen *et al.* 1979). Subsequent validation tests revealed that as one progresses south and east in the Lake States, the predictive power of the Lake States STEMS model diminishes (Leary *et al.* 1979). At the time the model was developed, calibration data were not available from the Upper Peninsula of Michigan and only conifer plantation data were available from the Lower Peninsula. Thus, in effect, applications in Michigan are "extensions" of the current STEMS model.

During the course of a recent field survey in the Upper Peninsula of Michigan, 415 permanent inventory plots that had been previously measured in 1965 were remeasured in 1979. The 8,000 trees on these plots provided the data to calculate growth adjustment factors to improve the predictions of STEMS in this subregion.

METHODS TO ESTIMATE ADJUSTMENTS

Measurements made in 1965 on the 415 permanent plots formed the basis for a 14-year projection by the STEMS model. The projected tree data were then compared with the data from the 1979 remeasurement to produce a file of initial and final observed d.b.h. and final predicted d.b.h. The file of predicted and observed values was then divided into diameter classes by species group. A correction factor was derived for each species group and diameter class where the data indicated measurable deviation from the growth of the model. This method is an application of double sampling with ratio of means estimators (Cochran 1977).

The diameter increment adjustment, applied to the annual predicted diameter increment, was derived from the following function:

$$GR_{ij} = \frac{\bar{y}_{ij}}{\bar{x}_{ij}}$$

where: GR = annual adjustment factor for diameter increment,

i = *ith* species group,

j = *jth* d.b.h. class,

$\bar{y}$ = mean difference of initial and final observed diameters, and

$\bar{x}$ = mean difference of initial observed and final predicted diameters.

Following the derivation of the adjustment factors for growth, a totally independent data set of 9,000 trees from 419 permanent remeasurement plots in the Upper Peninsula of Michigan was used to test the "tuned" STEMS model. The plots were initially measured in 1964 and 1965 and remeasured in 1975.

Validation tests of the adjusted and unadjusted STEMS model were made by comparing prediction errors of the two models for stand basal area and numbers of trees by forest type, and diameter increment by species. Mean annual prediction error and standard deviation were used as measures of bias and precision of the estimates, respectively.

RESULTS AND DISCUSSION

The annual adjustment rates for diameter increment reflect the magnitude of the subregional deviation from the regionally calibrated model by species group and diameter class (table 1). For all forest types, annual basal area prediction error after adjustments decreased nearly five-fold, from an overprediction of 0.60 square feet per acre per year to an overprediction of 0.13 square feet per acre per year (table 2). All forest types except northern white-cedar, oak, and lowland hardwoods improved in precision or bias, and 8 of the 14 types simultaneously reduced bias and increased precision.

Overall, d.b.h. prediction error for the adjusted STEMS model improved 94 percent, from an annual error of 0.033 inches to (-)0.002 inches (table 3). Adjustments by species produced a simultaneous decrease in bias and increase in precision for 16 of the 23 species included in the validation data. Thus, the adjustments to the model reduced bias and increased precision of basal area and d.b.h. predictions, while only modestly changing predictions for number of trees. An overall change in bias was expected, because the adjustments were essentially linear. However, we assumed that the changes in precision were primarily the effect of modified species interactions resulting from the adjustments or the separate ratios by d.b.h. class.

Table 1.—*STEMS annual growth increment adjustment factors for the Upper Midwest Peninsula of Michigan.*

		Annual diameter increment adjustment factor		
		DBH class		
Species group	**Trees**	**1.0-4.9**	**5.0-14.9**	**15.0-24.9**[1]
	Number			
Jack pine	116	0.8926	0.8107	1.0000
Red pine	62	1.1430	.8954	.6489
White pine	88	1.0000	1.5620	1.6745
White spruce	97	.7386	.6905	1.0000
Balsam fir	429	.8313	.8314	1.0000
Black spruce	159	.7082	.7307	1.0000
Tamarack	51	1.2785	1.8116	1.0000
N. white-cedar	608	.7167	.6372	.5917
Hemlock	243	1.1327	1.1702	.8357
Black ash	260	1.7230	1.3585	1.0000
Red maple	749	.8486	.7797	.7772
Elm	97	.9675	.6521	.4938
Yellow birch	321	1.5898	.9637	.9617
Basswood	134	.5418	.6648	.4966
Sugar maple	1,537	.6622	.6975	.8297
Red oak	38	1.0000	.8188	.8100
Bigtooth aspen	81	1.0000	.7760	1.0000
Quaking aspen	440	1.9135	.7408	.6747
Paper birch	245	1.3005	.7190	1.4168
Other hardwoods	184	.9632	.5771	1.0000
Noncommercial	65	.4646	.2228	1.0000

[1] Data insufficient to compute adjustments for trees greater than 25 inches DBH.

Table 2.—*Average annual prediction errors for basal area and number of trees by forest type for the STEMS model (unadjusted and adjusted) in the Upper Peninsula of Michigan*

		Annual basal area prediction error				**Annual number of trees prediction error**			
		Unadjusted		**Adjusted**		**Unadjusted**		**Adjusted**	
Forest Type	**Plots**	**Mean**	**s**	**Mean**	**s**	**Mean**	**s**	**Mean**	**s**
	Number	-------- *Feet²/acre/year* ----------				------ *Number of trees/acre/year* -------			
Jack pine	25	0.74	1.13	0.48	0.96	4.75	9.72	4.47	9.31
Red pine	16	.44	1.09	− .71	.91	−1.51	6.88	− .80	4.93
White pine	9	.96	.82	.13	.68	.18	.48	.18	.72
Hemlock	8	.18	1.03	− .12	1.09	−1.41	3.73	1.18	3.82
Balsam fir	22	1.18	1.97	.67	1.84	4.15	8.26	4.16	8.24
Black spruce	27	.49	.61	.22	.55	1.43	4.57	1.66	4.43
Tamarack	30	.76	1.06	.20	.92	− .70	11.77	−1.26	6.68
N. white – cedar	4	− .07	.26	− .25	.33	− .35	.42	− .14	.16
White spruce	6	.97	1.24	− .07	1.08	− .18	1.45	− .59	1.47
Oak	5	.12	.64	− .23	.56	1.67	5.47	1.70	5.43
Lowland hardwoods	5	.10	.60	− .37	.80	− .07	.78	−2.40	4.53
Northern hardwoods	85	.50	1.00	.01	.98	1.00	5.54	.97	5.92
Aspen	162	.65	.79	.15	.77	.36	2.19	.36	2.14
Birch	15	1.16	.67	.53	.77	− .39	2.64	.34	4.55
All species	419	0.60	1.02	0.13	0.95	0.80	5.69	0.82	5.09

Residual analysis regressing periodic d.b.h. prediction errors of the adjusted and unadjusted STEMS models with initial basal area (X_1), initial average stand diameter (X_2), initial site index (X_3), initial tree crown ratio (X_4), and initial tree d.b.h.(X_5) was performed using the following test model:

residuals =

$$B_0 + B_1 X_1 + B_2 X_2 + B_3 + B_4 X_4 + B_5 X_5 + e. \quad (1)$$

Most of the variables and their cross products were significant for both the adjusted and unadjusted STEMS models, but the variability explained in each case was minimal (0.04 vs. 0.08 percent according to R^2 values for the adjusted and unadjusted models, respectively). This seems to indicate that a variable or relation not currently considered in the STEMS model may play a significant role in describing the growth process.

Further residual analysis at the tree level indicated that for 10-year periodic diameter increments of 1.5 inches or less, the adjusted model was 81 percent more accurate in explaining prediction error variability (R^2 values of 0.31 and 0.56 for the unadjusted and adjusted models, respectively) and also had a smaller prediction error.

Although STEMS was designed as an individual-tree projection system, predictions of plot characteristics such as basal area and number of trees are also important. Predicted changes in number of trees were 22 percent more accurate with the adjusted model than the unadjusted model (R^2 values of 0.46 vs 0.56 for the unadjusted and adjusted models respectively). And predicted basal area was 4 percent more accurate with the adjusted model (R^2 values of 0.57 and 0.59, respectively).

Overall, the analysis indicates that the adjusted STEMS model is a better prediction tool for Michigan.

CONCLUSION

The value of the adjustment process lies in adjusting species when evidence is sufficient to do so. Species for which subregional data are insufficient to determine measurable deviation or for which no significant deviation exists would rely on the regional model calibration to fill in the gaps, thus providing the user with a more powerful "local" model. This process should be of particular interest to STEMS users who own or manage large forest holdings in concentrated areas and have some basic remeasurement information available.

The success of model adjustment ultimately hinges on availability of sufficient quantities of recent remeasurement data for calibrating and validating the selected procedure. Note that even though 8,000 trees

Table 3.—*Average annual prediction errors for growth increment by species for the STEMS model (unadjusted and adjusted) in the Upper Peninsula of Michigan*

		Growth increment annual prediction error			
		Unadjusted		Adjusted	
Species	**Observations**	**Mean**	**s**	**Mean**	**s**
	Number	*Inches*			
Jack pine	205	0.036	0.060	0.009	0.060
Red pine	157	−.018	.070	−.044	.066
White pine	149	.105	.103	−.001	.094
White spruce	247	.131	.109	.042	.097
Balsam fir	631	.010	.065	−.012	.063
Black spruce	462	.010	.047	−.009	.045
Tamarack	44	−.008	.051	.071	.066
N. white-cedar	555	.028	.046	−.011	.045
Hemlock	188	.019	.066	.028	.064
Black ash	44	.035	.056	.080	.079
Red maple	568	.025	.064	−.003	.059
Elm	61	.029	.105	−.041	.093
Yellow birch	247	.008	.064	.007	.062
Basswood	108	−.001	.075	−.042	.070
Sugar maple	438	.020	.066	−.023	.062
White ash	6	−.006	.089	.006	.091
Red oak	98	.001	.067	−.032	.085
Bigtooth aspen	137	.039	.071	−.004	.063
Quaking aspen	1,019	.058	.074	.003	.069
Paper birch	555	.033	.050	−.001	.049
Other hardwoods	129	.034	.075	.037	.073
Noncommercial	24	.082	.032	−.020	.023
All species	6,012	.033	.074	−.002	.067

were available to calculate factors in the method presented, 32 percent (37 of 132) of the correction factor cells had insufficient data to determine an adjustment (cells containing an adjustment factor of 1.0000 in table 1). This does not include the d.b.h. classes for trees more than 25 inches in diameter that had no cells with sufficient data to calculate a correction factor. An alternative solution would be to derive a single adjustment factor for each species rather than for each species and diameter class. This would reduce the amount of calibration data needed.

It is important to realize that information not available during the original calibration may be added during the adjustment process. Valuable time need not be spent recalibrating the entire model. The calibration data, however, should be representative of the size and vigor of the species to which the adjustment will be applied.

The predictive ability of the STEMS growth model in the Upper Peninsula of Michigan was significantly improved using simple correction factors derived from a recent set of remeasurement data. These adjustment factors transformed the STEMS regional growth model into a more powerful local growth model.

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