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Adjusting STEMS Growth Model for Wisconsin Forests

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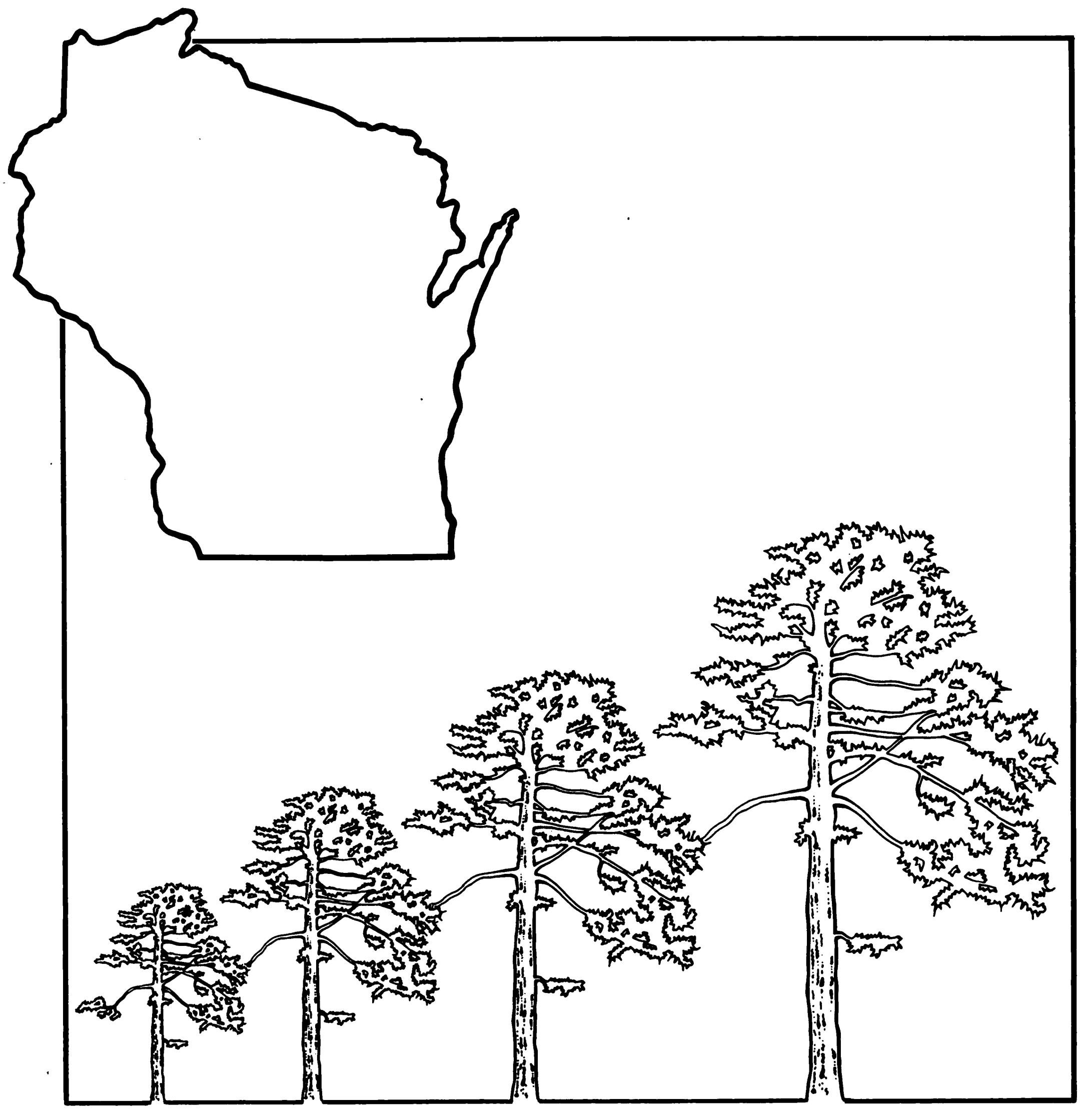

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ADJUSTING STEMS GROWTH MODEL FOR WISCONSIN FORESTS

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Forest growth projection systems for estimating individual tree growth, developed from data collected over a large geographic region, furnish broad-scale regional estimates (Wykoff *et al.* 1982, USDA Forest Service 1979). These regional systems may not provide satisfactory subregional projections as demonstrated by Smith (1983) in Michigan; they do not directly account for macro-climatic variations and macro-soil differences. However, with appropriate adjustment, the benefits of the growth, mortality, and regeneration models established from large data sets can be retained for application on specific sites.

Various approaches have been proposed to adjust regional growth models for local use. Gertner (1984) applied a sequential Bayesian procedure to adjust the model's parameters. Stage (1981) proposed a logarithmic transformation to adjust basal area growth rate using past growth information. On the other hand, Smith (1983), used a more elementary ratio of the means adjustment by species for each of three size classes. This approach was used to adjust an earlier Lake States STEMS version (Hahn *et al.* 1979) for use in northern Michigan.

This paper presents a simple method for adjusting the tree diameter growth estimates of STEMS, the Stand and Tree Evaluation and Modeling System of the North Central Station (Belcher *et al.* 1982). We give coefficients for adjusting the Lake States STEMS to the forests of northern and central Wisconsin.

BACKGROUND

A comprehensive growth projection system, STEMS, has been developed for the Lake States (Belcher *et al.* 1982). This regional growth model has many strengths; some result from the size and breadth of the data base used. The STEMS data base included 1,501 plots containing multiple measurements on 92,649 trees. Data came from cutting experiments, demonstration woodlots, industrial continuous inventory systems, and personal records of forest growth from across the Lake States. These data included a wide range of forest types, varying species composition, sites, stand structures and densities for even- and uneven-aged stands (Christensen *et al.* 1979).

STEMS uses species-specific, individual-tree-based growth and mortality models formulated on principles of biological growth. The growth model treats the forest community as a cluster of interacting, dynamic trees. The processes involved were observed over a broad range of forest conditions. The large size of the data base permitted the development of complex interacting model forms. The flexibility of the resulting models facilitates their use in a variety of region-wide inventory and silvicultural analyses.

Special features and constraints are included in the model forms to produce biologically reasonable behavior for certain rarely encountered extremes. Hahn and Leary (1979) constrained tree diameter growth to be less than or equal to a biologically realistic potential growth. Silvicultural literature was consulted to determine reasonable upper d.b.h. limits for each species. Also, a maximum stand basal area limit was included in the competition modifier (Holdaway 1984) to restrict stand density to biologically realistic values.

In spite of the broad data base and biologically formulated models, applications and testing (Holdaway and Brand 1983) revealed small systematic errors for some species and conditions. There are several potential causes for this. The tree growth model coefficients were developed mainly from research plots. Such plots usually are chosen for their good location and minimum natural damage. They are usually carefully managed, resulting in a more uniform stand than would be found on general forest land. When these models are used to project stands that have not been maintained under the same optimal conditions growth is usually overpredicted (Bruce 1977).

Also, the available sources for the calibration data were mostly young established stands—approximately 90 percent of the trees were from 3 to 7 inches for softwoods and 5 to 11 inches for hardwoods. Thus the growth models were extrapolated beyond the limits of the calibration data in order to accurately constrain growth estimates at the upper diameters. Extrapolation problems also existed at the lower limits of the calibration data for many of the species. Fourteen species had very few observations below 4 inches. As a result, the growth function was developed from data representing anywhere from 25 to 60 percent of the full range of diameter for each species—although the mid diameters were well represented.

A time element is also involved. The forest is a dynamic system undergoing continual change. The model development data is aging—most initial measurements were taken between 1945 and 1960, with final remeasurements made in 1975 and 1976. Has the general forest condition changed recently and if so, what factors are contributing to the change? The major factors possibly affecting the forest condition are changes in the macroclimate, insect and disease outbreaks, and forest decline due to acid deposition.

Climate is never static. Precipitation and temperature, which affect growth, fluctuate both yearly and also over longer time periods. The average annual northern hemispheric air temperature has been slowly dropping since 1940. This cooling followed a 60-year warming of the northern hemisphere. Climatic records of the past show that coolings last at least 40 years (Bryson 1974). Kalnicky (1974) indicated that the temperature across Wisconsin has followed the same cooling trends. These climatic fluctuations over decades have biological ramifications affecting the length of growing seasons, precipitation distribution, species distribution, tree growth, and pathogen activity (Layser 1980, Moran and Morgan 1976). Consequently, even modest temperature changes between the calibration period and future periods could have an effect on the accuracy of tree growth projections.

Three species in the Lake States—balsam fir, black spruce, and elm—have been subjected to insect or disease outbreaks. None of the damaging agents involved were present at high levels on the calibration locations during the measurement interval. Since then, these insect and disease infestations have spread into much of the area (Holdaway and Brand 1983), often reducing growth. To model current growth for these species, more recently collected data must be incorporated into the original model.

Forest decline due to acid deposition is a recent conjecture. The Lake States region has only moderate levels of acid deposition, increasing in magnitude along a gradient from northern Minnesota to southern Michigan. What would be the effect of such a condition on forest growth projections? Much of the calibration data for the STEMS model was collected during a period that was relatively unaffected by acid deposition, and thus the basic model coefficients would estimate a "normal" growth condition. However, in recent years, acid deposition has been increasing. If slight decreases in growth were occurring as a result of acid deposition, the "normal" STEMS model would be expected to overgrow trees on more recent validations.

Thus, problems originating from the use of experimental plots, possible long-term cooling of the climate, and/or possible forest decline due to acid deposition, would all result in overestimation of diameter growth on the general forest plots used in more recent studies. These results have been confirmed by the validation of STEMS (Holdaway and Brand 1983) where diameter growth was consistently overpredicted on all properties by an average of 0.11 inches in 10 years. Limitations in the original data base could result in underestimation or overestimation of diameter growth for certain diameter sizes. One route to achieving up-to-date resource information consists of adjusting the growth model to reflect the ongoing changes inherent in a dynamic system. This paper presents a simple method to adjust STEMS for these combined factors.

WISCONSIN APPLICATION

Wisconsin is partitioned into five geographically homogeneous survey units—the Northeast, Northwest, Central, Southeast, and Southwest Units (fig. 1). The Northern and Central Units—heavily glaciated leaving gravel hills, sandy plains, bare rock outcrops, extensive swamps and many lakes and streams—are largely forested. Roughly 70 percent of the two northern survey units and 39 percent of the Central Unit are in commercial[1] forest land (Spencer and Thorne 1972). This area is characterized by high annual precipitation, received predominantly during the summer and increasing as one moves northward (Rauscher 1984).

Remeasurement forest inventory plots from these three northern units were used to develop the methods described in this report. The two southern units were excluded since they are chiefly agricultural and were distinctly different from the north and central in climate. Subregional adjustments of regional growth models should be restricted to small regions of essentially uniform climate and similar broad physiographic features.

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[1]*Commercial forest land is land capable of growing industrial wood and not reserved from timber harvesting.*

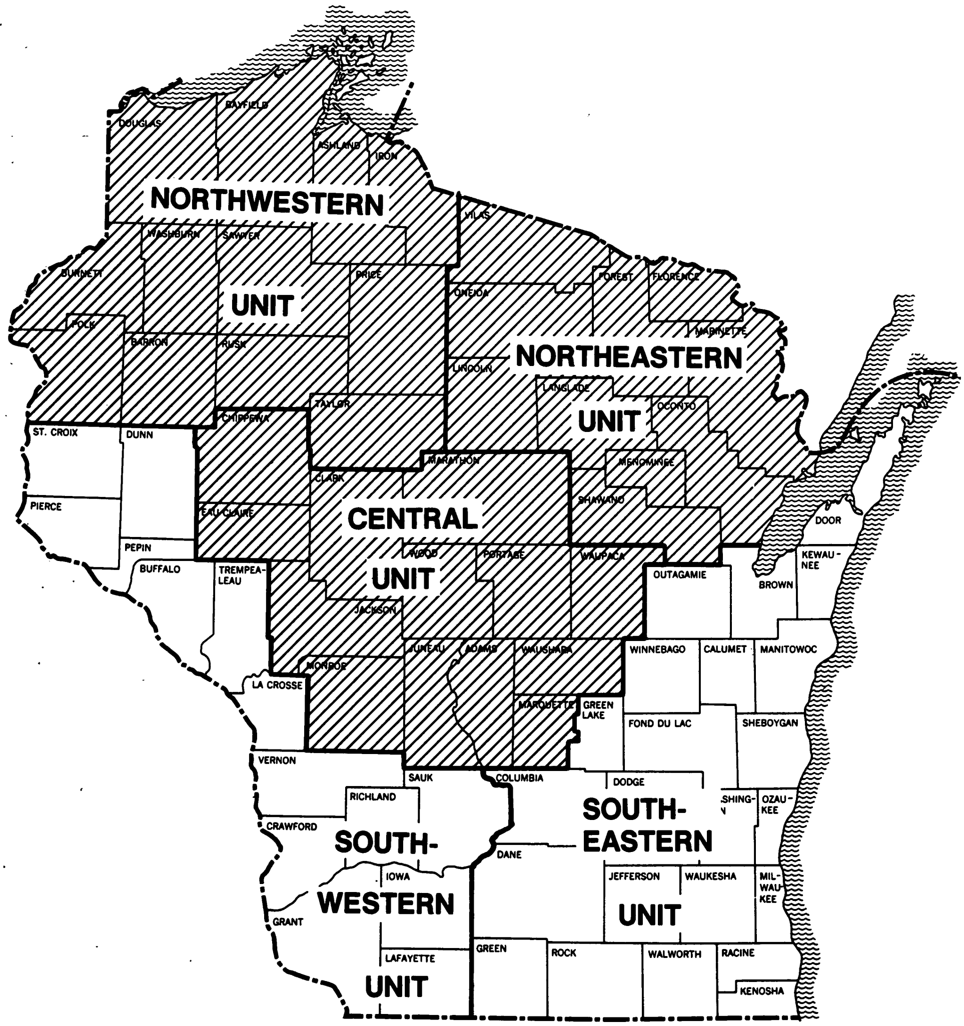

Figure 1.—*Location of Wisconsin Survey Units—data from the three shaded units were used to adjust the Wisconsin forests.*

METHODS

Data Base

Permanent plots from the 1966-1969 survey of non-National Forest land and the 1974-1976 survey of the Chequamegon and Nicolet National Forests were remeasured in 1983. The permanent plots, systematically distributed across each Unit, were variable-radius plots established at 10 points uniformly spaced over an acre. At each point, trees 5.0 inches d.b.h. and larger were sampled with a 37.5 factor prism. At the first three points tree saplings (d.b.h. 1.0 to 4.9 inches) were recorded for fixed area subplots. Only forest survey data for the Northeast, Northwest, and Central Survey Units, including the National Forests within these units, were used (fig. 1).

In 1968, forests in Wisconsin were generally young and rebuilding with the predominance of stands originating around 1920 (Spencer and Thorne 1972). Eighty-three percent of the stands were less than 70 years old. Despite the general youth of the forests, there were small areas of overmature stands within most forest types. Consequently, the data base contained ample moderate sized trees with fewer large trees. Trees under 5 inches were well represented because of the three fixed radius subplots taken on each plot. Approximately 90 percent of all trees were between 1 and 14 inches—a considerable increase in the d.b.h. range noted earlier for the calibration data base, especially for the softwoods.

Stand history obtained during the second measurement was used to identify all plots disturbed within the past 15 years. Disturbed plots, 32 percent of the original plots, were removed; 1,177 plots were retained for the analysis (table 1). Initially, every fourth plot was reserved for validation.

Table 1.—*Number of nondisturbed remeasured plots on commercial forest land in Wisconsin used in the analysis*

Survey Unit	Non-National Forest lands	National Forest lands	All
Northeast	308	113[1]	421
Northwest	407	88[2]	495
Central	261	0	261
All	976	201	1,177

[1]Nicolet National Forest.
[2]Chequamegon National Forest.

Analysis

STEMS[2] was used to grow the trees from the time of the earlier survey to 1983. Tree species, midpoint observed d.b.h.[3], and annual predicted and observed growth were used for developing the adjustment function. From this information, species-specific mean annual growth errors and ratios of predicted over observed growth, grouped by 2-inch diameter classes up to 30 inches, were graphed by d.b.h. class and survey unit. The graphs indicated distinct curvilinear error patterns related to tree d.b.h.

The merits of multiplicative and additive adjustment models were compared using a second-order polynomial equation. Each model was examined for long-term projections under a wide selection of stand characteristics. The additive model was more realistic in overall projections of stand characteristics. On the average, it accounted for 3 percent more variability than did the multiplicative model, using ratio-of-means estimates. In addition, the multiplicative model does not have the flexibility of the additive model to increase or alter growth for large diameter trees, a major disadvantage.

The additive diameter adjustment (ADJ) for the annual growth of a tree,

$$ADJ = a_1 \cdot DBH + a_2 \cdot DBH^2 + a_3 \ , \qquad (1)$$

yields a new d.b.h. estimate, $DBH_{NEW} = DBH + ADJ$. DBH and DBH^2 were retained in equation (1), i.e. a_1 and/or a_2 not zero, only if their contribution to the prediction was significant at the 0.05 level. A large, negative diameter adjustment, which could produce negative growth, is prevented by restricting growth after the adjustment to nonnegative values.

[2]*The mortality model used is the original model described in Buchman (1979).*

[3]*Using the midpoint d.b.h. removed the effect of varying interval lengths in the data.*

Preliminary results showed that the mean 10-year d.b.h. error was reduced from 0.17 inches before adjustment to 0.03 inches after adjustment on the validation plots. The final model coefficients were based on the 1,177 combined calibration-validation plots to strengthen coefficient estimation for species and diameter classes having few observations.

RESULTS

Coefficients for the diameter adjustment function were calculated for 25 species groups (table 2). The model showed close agreement between predicted and observed d.b.h.: maximum differences over various initial conditions were seldom greater than 0.10 inches in 10 years. With the growth adjustment, the average 10-year diameter prediction error based on 17,646 trees decreased from 0.16 inches to 0.02 inches; the standard deviation of the prediction error decreased, going from 0.70 inches to 0.65 inches.

Previous validation results for unadjusted STEMS (Holdaway and Brand 1983) on two National Forests in Wisconsin and two in Michigan, plus an experimental forest in Minnesota, revealed overprediction of growth for the middle diameter classes. The diameter adjustment corrected much of this problem (fig. 2).

A related area of concern, also revealed during the previous STEMS validation, was the overprediction of growth for overstory trees, i.e. trees with an initial relative d.b.h. (relative d.b.h. = d.b.h./average d.b.h.) greater than 1 (Holdaway and Brand 1983). The diameter adjustment reduces this overprediction by about 75 percent (fig. 3). The reduction of the average error and the damping of these two error patterns provide a general measure of confidence in the adjusted model.

Diameter (DBH) errors measure how well the growth component functions; number of trees (NT) errors how well the mortality component functions and its response to the growth function; and basal area (BA) errors, a combination of the two, measures

Table 2.—*Annual diameter adjustment function*[1] *coefficients for 25 species groups in North and Central Wisconsin*

Species group	Trees	Coefficients			Annual d.b.h. adjustment		
		a_1	a_2	a_3	1	10	20
	Number				*Inches*		
Jack pine	664	−0.0174	0.00065	0.069	0.052	−0.040	−0.019
Red pine	390	.0000	−.00017	.018	.018	.001	−.050
White pine	538	−.0043	.00011	.029	.025	.003	−.013
White spruce	227	−.0225	.00067	.050	.028	−.108	−.131
Balsam fir	771	−.0112	.00040	.030	.019	−.042	−.034
Black spruce	316	−.0248	.00162	.037	.014	−.049	−.049
Tamarack	342	−.0093	.00042	.048	.039	−.003	.030
N. white-cedar	813	−.0050	.00000	−.004	−.009	−.054	−.104
Hemlock	452	−.0043	.00022	.039	.035	.018	.041
Black ash	605	−.0115	.00032	.051	.040	−.032	−.051
Silver maple	48	.0109	.00000	−.106	−.095	.003	.112
Red maple	1,792	.0008	.00004	−.017	−.016	−.005	.015
Elm	344	−.0102	.00023	.028	.018	−.050	−.084
Yellow birch	453	−.0021	.00010	.001	−.001	−.010	−.001
Basswood	813	.0000	.00007	−.037	−.037	−.030	−.009
Sugar maple	2,251	.0014	.00002	−.024	−.023	−.008	.012
White ash	148	−.0113	.00066	−.002	−.013	−.048	.037
White oak	480	−.0079	.00039	.048	.040	.008	.046
Select red oak	1,158	.0015	−.00003	−.026	−.025	−.014	−.008
Other red oak	697	.0026	.00000	−.088	−.085	−.062	−.036
Bigtooth aspen	588	.0124	−.00022	−.079	−.067	.023	.080
Quaking aspen	2,168	−.0132	.00079	.031	.019	−.022	.084
Paper birch	1,242	−.0066	.00038	.011	.005	−.017	.032
Other hardwoods	219	.0085	−.00026	−.088	−.080	−.030	−.022
Noncommercial	175	−.0046	.00000	−.070	−.075	−.116	−.116
Total	17,694						

[1]General model is $ADJ = a_1 \cdot DBH + a_2 \cdot DBH^2 + a_3$. The adjustment is added to the annual diameter growth, such that growth ≥ 0.

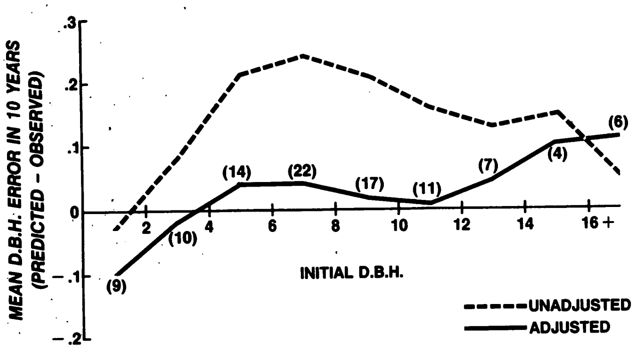

Figure 2.—*Mean 10-year d.b.h. errors plotted against initial d.b.h. for all trees. The percent of the observations in each class is given in parenthesis.*

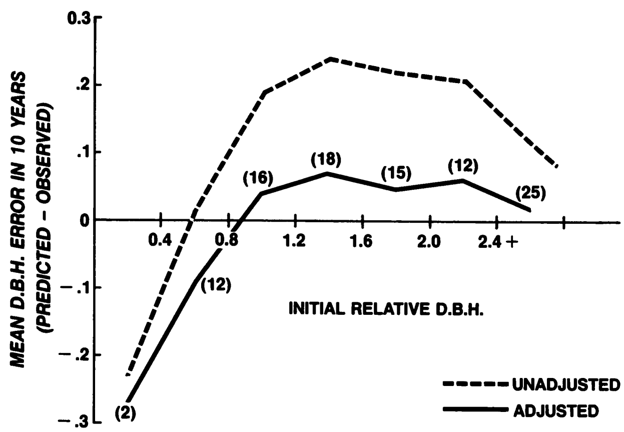

Figure 3.—*Mean 10-year d.b.h. errors plotted against initial relative d.b.h. for all trees. The percent of the observations in each class is given in parenthesis.*

how well the model functions as a whole. Thus, an evaluation of the DBH errors and NT errors separately, plus the BA errors, helps understand how the system is operating.

Error patterns and interactions for DBH errors after adjustment are shown for basal area by diameter classes (table 3). Although the overall DBH error is low, some potential problem areas are evident. The model appears to have a systematic bias with regard to basal area. It overpredicts for low basal area stands and underpredicts for high basal area stands. The worst overprediction is for the 3 percent of all trees that are found in the very low basal area plots. In the low basal area stands there appears to be a bias with respect to tree size, with overpredictions of DBH increasing with tree size.

Analysis of NT error patterns by basal area and average stand diameter classes (table 4) shows the number of small trees (trees <4 d.b.h.) is overestimated when stand basal area is less than 75 square feet and greatly underestimated for the more dense stands. There is a sharp decreasing trend in estimating NT for the youngest stands (average d.b.h. <4 inches). However, because very young stands have a large number of trees, mortality errors are magnified when expanded to a per acre basis. This trend is most marked for the young stands with higher basal area (75 square feet or more). These plots account for 19 percent of all plots in this study.

Finally, performance of the adjusted growth model in combination with the mortality model, as measured by the mean BA error (table 5), shows slight overestimation uniformly spread over the BA—DBH classes. The separate trends in DBH and NT were muted when the components were combined. Obviously, even large errors in the number of very small trees have very little influence on estimating stand basal area.

In summary, the major problem areas are:

1. The adjusted STEMS Model overgrows the larger trees (DBH ≥ 4 inches) on understocked plots (below 25 square feet/acre), representing one percent of the trees.
2. The model severely overestimates NT (or underestimates mortality) on very young stands (average d.b.h. <4 inches), especially for BA >75 square feet/acre. Translated into trees, this means that the system may be off by 60 to 80 trees on young stands composed of over 1,000 trees per acre. The conditions under which this kind of error occurs are found on 19 percent of the plots and, presumably, roughly 19 percent of the land area.

DISCUSSION AND CONCLUSIONS

The design of STEMS provides coverage for a wide variety of conditions encountered in the Lake States, and the coefficients of the model are based on data throughout the region. Evidence suggests that the performance of the model on a subregion of the Lake States could be improved by developing adjustment coefficients that more accurately reflect local growing conditions.

Table 3.—*Mean d.b.h. errors in 10 years by basal area and diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of trees appear in parenthesis. Positive values are overpredictions*

Stand basal area (ft²/ac)	Tree diameter (inches at breast height) 0.0–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
			Inches		
0–24	0.11 (208)	0.24 (151)	0.25 (62)	0.56 (49)	0.22 (470)
25–74	–.08 (1,350)	.12 (1,996)	.21 (1,233)	.26 (636)	.11 (5,215)
75–124	–.07 (1,271)	.02 (2,936)	–.01 (2,383)	.08 (1,527)	.01 (8,117)
125+	–.06 (574)	–.06 (1,323)	–.16 (1,186)	–.10 (761)	–.10 (3,844)
All classes	–.06 (3,403)	.04 (6,406)	.01 (4,864)	.08 (2,973)	.02 (17,646)

Table 4.—*Mean number of trees error in 10 years by stand basal area and average diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of plots appears in parenthesis. Positive values are overpredictions*

Stand basal area (ft^2/ac)	Average stand diameter (inches as breast height)				
	0.–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
	Trees/acre				
0–24	17 (86)	2 (36)	−1 (6)	1 (8)	11 (136)
25–74	16 (301)	9 (184)	0 (21)	8 (4)	13 (510)
75–124	−40 (169)	2 (216)	−2 (17)	4 (4)	−15 (406)
125+	−93 (52)	0 (67)	−1 (5)	−3 (1)	−39 (125)
All classes	−9 (608)	4 (503)	−1 (49)	3 (17)	−3 (1,177)

I have demonstrated a simple method to recalibrate a regional tree growth model for use in a subregion of similar climate and geography—namely the commercial forests of northern and central Wisconsin.

Tree growth models for estimating the biological behavior of and constraints on tree growth are nonlinear and often very complex in how the various submodels interact. Even a simple change in how one aspect of the model functions can have complex

Table 5.—*Mean stand basal area error in 10 years by basal area and average diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of plots appears in parenthesis. Positive values are overpredictions*

Stand basal area (ft^2/ac)	Average stand diameter (inches at breast height)				
	0.0–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
	Sq ft/ac				
0–24	4 (86)	1 (36)	2 (6)	3 (8)	3 (136)
25–74	3 (301)	4 (184)	3 (21)	11 (4)	4 (510)
75–124	1 (169)	3 (216)	0 (17)	11 (4)	2 (406)
125+	−3 (52)	−1 (67)	−2 (5)	2 (1)	−2 (125)
All classes	2 (608)	3 (503)	1 (49)	7 (17)	2 (1,177)

effects elsewhere in the model. When changes are made, all aspects of the model performance must be evaluated. Since mortality is modeled as a function of d.b.h., mortality will also be "adjusted" due to the adjustment of d.b.h. in the growth model.

The analysis of the diameter adjustment revealed a few conditions where the adjusted model performed poorly, especially in underestimating mortality on young, well-stocked stands. Because of the small diameter of the trees involved, this problem does not affect the basal area error. The analysis shows the model adjustment will improve model performance for the vast majority of forest conditions.

Extrapolation of these adjustment functions very far beyond the limits of the available data may be unwise. Since only 2 percent of the trees in the calibration were above 20 inches, I recommend using the 20-inch adjustment for all trees above 20 inches. For black spruce and the noncommercial species, the adjustment becomes too large beyond the data range. For these two species the value at 10 inches should be used for all trees greater than 10 inches.

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Adjusting STEMS growth model for Wisconsin forests. Res. Pap. NC-267. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 8 p.

Describes a simple procedure for adjusting growth in the STEMS regional tree growth model to compensate for subregional differences. Coefficients are reported to adjust Lake States STEMS to the forests of Northern and Central Wisconsin—an area of essentially uniform climate and similar broad physiographic features. Errors are presented for various combinations of stand and tree variables.

KEY WORDS: Lake States species, modeling, subregion, forest growth, projection system.