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An updated version of the Lake States variant of STEMS is evaluated and compared with the previous version. The new version is slightly more accurate and precise. The strengths and weaknesses of this tree growth projection system are also identified.

KEY WORDS: Validation, testing, growth model, prediction errors, model performance.

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AN EVALUATION OF LAKE STATES STEM S85

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In 1975, research was begun at the North Central Forest Experiment Station to develop a system to project tree growth in the Lake States region. This tree growth projection system (USDA Forest Service 1979), was later modified and renamed STEMS, Stand and Tree Evaluation and Modeling System (Belcher *et al*. 1982). In 1985 an updated version called STEMS85 was released.

A new model should replace a previous model only if judged better. When comparing alternative models, it is unlikely that one model will perform better for all stand conditions and forest types. The model chosen will depend on many aspects of model performance (the amount of bias and variability in the predictions, the relative importance of prediction errors, reasonable behavior when extrapolating to rare events) as well as nonperformance attributes (Buchman and Shifley 1983, Brand and Holdaway 1983).

STEMS' performance has been previously examined in detail (Holdaway and Brand 1983). The new version, STEMS85, is identical to STEMS in all but two aspects: (1) a diameter adjustment has been added to the growth component, and (2) the mortality model has been modified. The diameter adjustment[1] (Holdaway 1985) was added to correct diameter prediction errors. The mortality model in STEMS85 is a variation of the STEMS mortality model that includes an adaptation to more realistically predict survival rates for small trees and large, slow-growing trees (Buchman *et al*. 1983, Buchman 1983). Consequently, the new mortality function, although producing similar midrange results, has greater ability to forecast biologically reasonable behavior for trees at these two extremes.

This paper (1) compares the performance of STEMS85 with STEMS, (2) analyzes the performance of the STEMS85 tree growth projection system for a wide range of forest types, species, stand densities, and site qualities, and (3) identifies the strengths and weaknesses of STEMS85. Whenever possible, comparisons are made to the previous STEMS model. We evaluate the accuracy and precision of predictions of three key variables—d.b.h. (DBH), number of trees per acre (NT), and stand basal area (BA). DBH evaluates primarily the growth component of the model, NT evaluates primarily the mortality component, and BA evaluates the combination of these two components[2]. The results are presented in a simple format that can be interpreted without specialized statistical knowledge.

PROCEDURES

Data Base

The validation data base, not used in model development, consisted of remeasured inventory plots from the five locations listed below:

1. Cloquet Experimental Forest, Minnesota (Data courtesy of Alan Ek, College of Forestry, University of Minnesota)
2. Chequamegon National Forest, Wisconsin
3. Nicolet National Forest, Wisconsin
4. Hiawatha National Forest, Michigan
5. Manistee National Forest, Michigan.

The Cloquet plots were all 1/7 acre each with tree diameters greater than 4.9 inches recorded. The National Forest plots were 10-point clusters of variable radius plots (37.5 factor prism) for trees greater than 4.9 inches in diameter and a 0.01 acre sample for trees 1.0 to 4.9 inches in diameter. Nearly 12,700 trees were measured. The average initial stand age

[1] *STEMS85 does not use the white spruce diameter growth adjustment coefficients described in Holdaway (1985). Additional testing revealed that the white spruce adjustment coefficients produced inaccurate growth estimates.*

[2] *The growth and mortality components are intimately related—changing one changes the other. DBH errors are influenced by the accuracy of the mortality component. Likewise, NT errors are influenced by the accuracy of the growth component.*

was 46 years, with a maximum of 196 years; the average initial diameter was 8.2 inches; and the average time between measurements was 13 years.

Plot data included site index, stand age, measurement dates, and a list of trees. Data for each tree in the list included species code, tree factor (number of trees per acre represented by the measured tree), crown ratio code, and diameter and status code (alive, dead, or cut) for each measurement.

Basic Projection Data

The basic analysis involved calculating the error (i.e., predicted minus observed value) for each variable (DBH, NT, and BA). In general, the longer the prediction interval, the less accurate the prediction will be (Goodall 1972). Consequently, if the time intervals used vary greatly, it may be difficult to make any justifiable conclusions. To avoid these problems, we standardized the errors to 10 years using the equation:

$$10 \times \frac{\text{(Predicted attribute} - \text{observed attribute)}}{\text{Number of years in measurement interval}} \, .$$

With this equation, overprediction errors are positive values and underprediction errors are negative values.

TEST RESULTS AND DISCUSSION

Overview

The STEMS85 model consistently predicted slower growth than the STEMS model on all five areas which was generally an improvement (table 1). The STEMS85 model gave more accurate mortality predictions, as measured by NT errors, on 3 of the 5 locations. BA estimates were better on three of the locations and worse on one. For all locations combined, there was an overall improvement in diameter growth estimation of 0.05 inches in 10 years (0.05 inches closer to zero) and in basal area estimation of 2.6 square feet in 10 years, but a slightly worse estimation of mortality. As measured by the standard deviation, STEMS85 is slightly more precise than STEMS for all three key variables—DBH, NT, and BA.

The slight underestimation of diameter growth has an advantage. Purely random error in the estimation of diameter induces a small but systematic error in the derived value of nonlinear functions (Mandel 1964) such as tree basal area. When expanded to a per-acre basis, these biases may cause observable overestimation of stand basal area. Comparing DBH and BA errors from this and the previous evaluation (Holdaway and Brand 1983) confirms this—on the average, an underestimation of DBH of 0.08 inches in 10 years produces zero error in basal area estimation, whereas an overestimation of DBH of 0.08 inches produces an overestimation of basal area of about 2 square feet in 10 years. Thus, a slight underestimation of diameter is preferable to a similar overprediction when accurate estimation of both diameter and basal area is important.

The following detailed analysis of various aspects of STEMS85's performance, with occasional comparison to STEMS, will instill both confidence and caution in its application.

DBH Errors (Growth Component)

For all areas combined there are no species with a mean DBH error greater than ±0.30 inches in 10 years when using STEMS85 (table 2), as contrasted with 5 species with the STEMS model. Mean DBH errors in 10 years for 4 of the 5 problem species have been greatly improved with the STEMS85 model:

Errors in DBH estimates for the 5 species with the worst STEMS performance

Species	STEMS	STEMS85
	Inches per 10 years	
White spruce	0.32	0.19
Northern white-cedar	.37	−.05
Basswood	.38	.11
White ash	.35	−.04
Northern pin oak	.76	.14

Five of the first 6 conifers (table 2) have some of the largest negative errors. Many of these trees came from the Cloquet Experimental Forest in northern Minnesota, where the largest underestimation of growth is found. Black spruce is the only species with consistently low values on all areas. Diameter growth for all species combined shows a small but consistent underprediction on 4 of the 5 areas. Diameter growth on the Manistee National Forest in lower Michigan is overestimated.

NT Errors (Mortality Component)

Information on the mortality component is provided by the NT errors (table 3). Overestimating the number of live trees on a stand indicates that the mortality function is not "killing" enough trees (mortality underestimated). Because predicted mortality is sensitive to predicted diameter growth, small errors in diameter growth estimates can result in noticeable errors in mortality estimates.

The four National Forests have variable radius plots with small trees (1 to 5 inches) measured on a

Table 1.--Summary of the mean and standard deviation of the errors in 10 years for STEMS and STEMS85 (The errors are evaluated for tree d.b.h. (DBH), number of trees per acre (NT), and stand basal area per acre (BA). Errors are computed as predicted attribute minus observed attribute.)

	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85
Mean												
DBH (inches)	0.11	-0.06	0.06	-0.12	0.13	-0.03	0.09	-0.09	0.09	-0.06	0.28	0.15
NT (trees/acre)	2	6	6	0	-16	21	-18	1	5	1	2	12
BA (sq.ft./acre)	3.5	.9	4.2	-1.1	4.7	2.3	.8	-.8	2.2	-1.1	5.0	7.1
Standard deviation												
DBH (inches)	.63	.60	.54	.53	.63	.60	.69	.65	.67	.64	.69	.63
NT (trees/acre)	78	65	20	20	108	85	104	73	100	100	66	60
BA (sq.ft./acre)	13.4	12.1	9.4	9.8	13.3	11.9	12.4	11.5	14.2	12.9	19.0	14.1
Number of plots	822	822	292	292	123	123	145	145	114	114	148	148
Number of trees	11,182	12,696	4,572	5,267	1 ,587	1,753	1,775	1,992	1,720	1,897	1 ,528	1,787

Table 2.--Mean d.b.h. errors (inches) by Lake States species in 10 years using the STEMS85 model (The number of trees appears in parentheses. Positive values are overpredictions.)

Species	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	-0.11	(1,813)	-0.19	(1,334)	-0.12	(66)	-0.18	(52)	0.16	(182)	0.17	(179)
Red pine	-.16	(1,374)	-.18	(879)	-.28	(64)	-.13	(69)	-.34	(135)	.08	(227)
White pine	-.04	(310)	-.20	(139)	.05	(36)	-.16	(36)	.09	(74)	.52	(25)
White spruce	.19	(171)	-.11	(64)	1.16	(14)	.37	(54)	.09	(39)	-	
Balsam fir	-.19	(693)	-.25	(326)	-.17	(150)	-.09	(125)	-.15	(89)	.15	(3)
Black spruce	-.29	(769)	-.29	(614)	-.26	(29)	-.19	(42)	-.36	(82)	-.19	(2)
Tamarack	.07	(334)	.12	(278)	-.17	(27)	-.27	(21)	-.05	(7)	.78	(1)
N. white-cedar	-.05	(916)	-.12	(333)	-.03	(107)	-.01	(191)	-.02	(232)	.16	(53)
Hemlock	.11	(306)	-		.27	(50)	-.05	(122)	.19	(119)	.25	(15)
Black ash	.02	(189)	-.03	(51)	.16	(51)	.00	(35)	.03	(8)	-.09	(44)
Red maple	-.12	(798)	-.24	(68)	-.03	(191)	-.09	(64)	-.18	(258)	-.09	(217)
Elm	-.22	(194)	-		-.16	(48)	-.33	(126)	.08	(8)	.52	(12)
Yellow birch	-.09	(270)	.71	(2)	-.08	(92)	-.03	(78)	-.17	(83)	-.08	(15)
Basswood	.11	(274)	-		.01	(86)	.07	(150)	-.22	(5)	.62	(33)
Sugar maple	.01	(878)	-		.08	(293)	-.09	(354)	-.05	(164)	.34	(67)
White ash	-.04	(61)	-		-.19	(18)	-.43	(12)	-		.20	(31)
White oak	.21	(255)	-		-		-		-		.21	(255)
N. red oak	.01	(258)	-.51	(3)	.08	(119)	-.19	(25)	-.23	(24)	.06	(87)
N. pin oak	.14	(286)	-		.40	(4)	-		-		.13	(282)
Bigtooth aspen	.10	(227)	.45	(36)	-.11	(64)	-.14	(30)	-.05	(37)	.32	(60)
Quaking aspen	.08	(933)	.10	(388)	-.15	(134)	.04	(237)	.23	(118)	.25	(56)
Paper birch	-.03	(1,102)	.02	(752)	-.19	(101)	-.32	(123)	.05	(96)	.01	(30)
All[1]	-.06	(12,696)	-.12	(5,267)	-.03	(1,753)	-.08	(1,992)	-.06	(1,897)	.15	(1,787)

[1]Includes all species on the property

Table 3.--Mean number of trees errors (trees/acre) by Lake States species in 10 years using the STEMS85 model (The number of plots appears in parentheses. Positive values are overpredictions.)

Forest type	All	Cloquet	Chequamegon	Nicolet	Hiawatha	Manistee
Jack pine	7 (127)	-4 (79)	16 (7)	42 (6)	42 (20)	-2 (15)
Red pine	4 (85)	-1 (49)	22 (6)	-6 (4)	-11 (11)	26 (15)
White pine	-1 (13)	19 (6)	-6 (2)	-41 (2)	-12 (3)	-
White spruce	-13 (10)	5 (4)	-	-27 (4)	-45 (1)	-
Balsam fir	30 (51)	13 (23)	32 (14)	7 (8)	124 (6)	-
Black spruce	-16 (40)	-19 (29)	- 25 (2)	27 (3)	-22 (6)	-
Tamarack	-11 (23)	-3 (19)	- 46 (4)	-54 (2)	-	-
N. White-cedar	-10 (47)	11 (14)	-4 (2)	-25 (9)	-36 (14)	68 (2)
Hemlock	-24 (7)	-	-	-14 (4)	-38 (3)	-
Lowland hardwoods	35 (30)	13 (3)	80 (5)	48 (2)	-43 (1)	29 (19)
N. hardwoods	13 (135)	-	31 (40)	10 (49)	-16 (28)	27 (18)
White oak	21 (15)	-	-	-	-	21 (15)
N. red oak	7 (15)	-	5 (4)	-109 (1)	-62 (2)	40 (8)
Oak-pine	-19 (10)	-	-	-	-39 (1)	-17 (9)
Oak-hickory	-9 (35)	-	- 82 (1)	-	-	-7 (34)
Aspen	5 (121)	11 (30)	14 (23)	-2 (42)	1 (14)	3 (12)
Paper birch	5 (58)	3 (36)	16 (8)	-10 (9)	45 (4)	-3 (1)
All	6 (822)	0 (292)	21 (123)	1 (145)	1 (114)	12 (148)

Table 4.--Mean basal area errors (sq.ft./acre) by Lake States species in 10 years using the STEMS85 model (The number of plots appears in parentheses. Positive values are overpredictions.)

Forest type	All	Cloquet	Chequamegon	Nicolet	Hiawatha	Manistee
Jack pine	-2.5 (127)	-5.9 (79)	1.5 (7)	2.6 (6)	4.0 (20)	2.1 (15)
Red pine	-2.5 (85)	-3.6 (49)	2.8 (6)	-4.7 (4)	-9.1 (11)	4.2 (15)
White pine	-2.4 (13)	3.9 (6)	-2.7 (2)	-14.3 (2)	-6.6 (3)	-
White spruce	-3.1 (10)	5.9 (4)	-2.4 (1)	3.6 (4)	-4.4 (1)	-
Balsam fir	5.3 (51)	5.9 (23)	1.1 (14)	2.9 (8)	16.6 (6)	-
Black spruce	-4.3 (40)	-6.4 (29)	-2.5 (2)	11.3 (3)	-2.9 (6)	-
Tamarack	.0 (23)	1.7 (19)	-6.6 (2)	-10.2 (2)	-	-
N. White-cedar	-.7 (47)	1.7 (14)	.6 (8)	-4.0 (9)	-4.8 (14)	19.9 (20)
Hemlock	-12.5 (7)	-	-	-11.8 (4)	-13.4 (3)	-
Lowland hdwds.	16.4 (30)	4.4 (3)	18.2 (5)	3.1 (2)	-11.7 (1)	20.7 (19)
N. hardwoods	1.6 (135)	-	2.8 (40)	-1.2 (49)	-3.1 (28)	14.0 (18)
White oak	3.3 (15)	-	-	-	-	3.3 (15)
N. red oak	.6 (15)	-	-.7 (4)	-8.8 (1)	-8.7 (2)	4.7 (8)
Oak-pine	1.4 (10)	-	-	-	-21.3 (1)	3.9 (9)
Oak-hickory	.7 (35)	-	6.8 (1)	-	-	.5 (34)
Aspen	4.0 (121)	7.0 (30)	2.0 (23)	1.4 (42)	3.1 (14)	10.8 (12)
Paper birch	.7 (58)	1.0 (36)	1.1 (8)	-5.4 (9)	9.3 (4)	7.8 (1)
All	.9 (822)	-1.1 (292)	2.3 (123)	-.8 (145)	-1.1 (114)	7.1 (148)

0.01-acre fixed radius plot. Each tree measured on this fixed radius plot represents 100 trees per acre. If one of these small trees dies, the observed number of live trees per acre decreases by 100. This is the main reason why the errors were so much larger for these four locations than they were for either the calibration data or Cloquet. If the mortality function is accurate, these deviations should average out over all areas.

With STEMS85, only one forest type, lowland hardwoods, is in error by more than 30 trees in 10 years, as compared to five forest types with the STEMS model. The serious problem with some of the oak species in STEMS has apparently been corrected in STEMS85. Eight of the individual tracts were in error by more than 50 trees per acre with STEMS85, compared with 16 with STEMS.

BA Error (Overall Model)

The BA errors provide information on the combined growth and mortality predictions. For all the tracts, STEMS had four forest types with BA errors greater than ±9 square feet per acre in 10 years. With STEMS85, only two, hemlock (−12.5) and lowland hardwoods (16.4), have large BA errors (table 4).

Error Patterns

Errors in the three key variables—DBH, NT, and BA—graphed over various initial conditions help to highlight conditions where large errors occur (figs. 1 and 2). For example, large DBH errors occurred in STEMS when the initial basal area was low (third graph from the top in fig. 1). Many of the large errors occur where there are few observations. Errors in these classes are of concern only when projections are to be made for stands under these conditions. Because so much more variability exists in classes with few observations, caution needs to be exercised when emphasizing these trends.

Diameter error patterns for the two models are similar, but errors with STEMS85 were generally smaller. The STEMS85 overall reduction in predicted growth improves the error patterns, especially in terms of initial DBH and relative DBH. (Relative DBH for a tree is the ratio of its diameter to the average tree diameter for the stand.)

The STEMS model showed a marked overgrowth of overstory trees (as measured by relative DBH). The trend was bothersome because even a small overgrowth will be magnified with long projections. This problem has been corrected with STEMS85.

No strong trends emerge from the error patterns for the mortality component (fig. 2a). However, NT

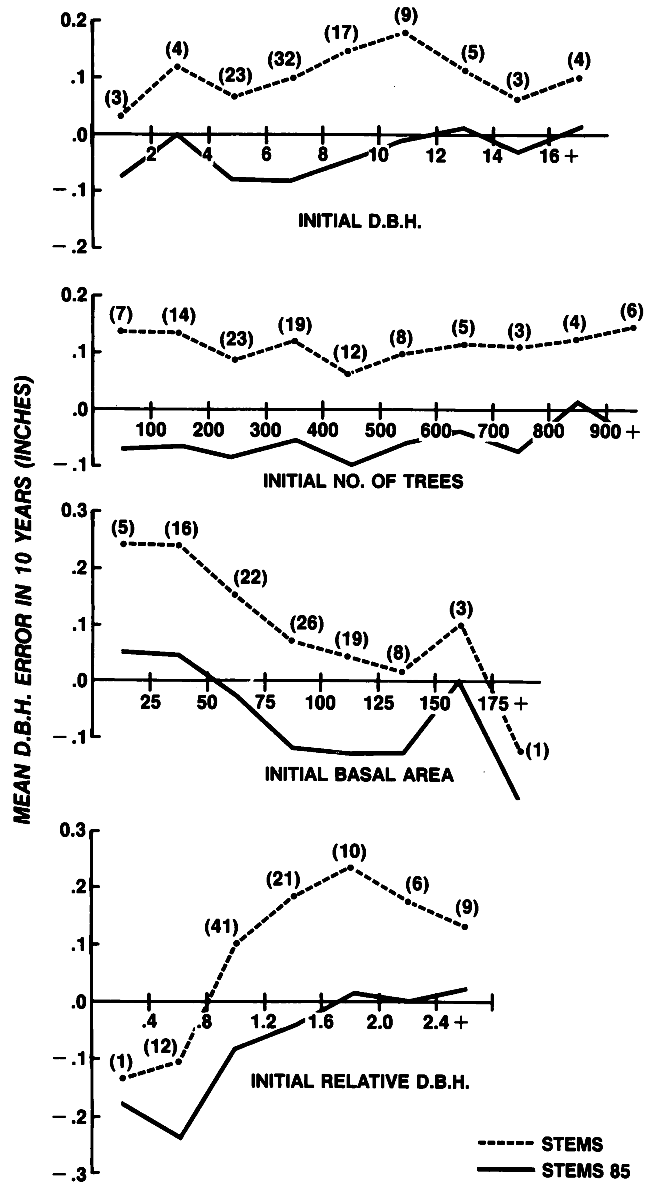

Figure 1.—*The mean DBH error in 10 years plotted against selected initial tree and stand conditions for STEMS and STEMS85. The percent of the observations in each class for both models is given in parentheses.*

variability increased for stands with low average DBH and many trees per acre. Both results are logical in that a greater number of trees will magnify NT errors. Also, NT was sharply underpredicted at high initial basal areas (1 percent of the observations).

Finally, the mean BA error (fig. 2b), a measure of overall model performance, decreases slightly as the initial basal area increases. Several examples investigated by Holdaway and Brand (1983) showed that a 10 percent error in DBH produces roughly a 20 percent error in BA, whereas a 10 percent error in

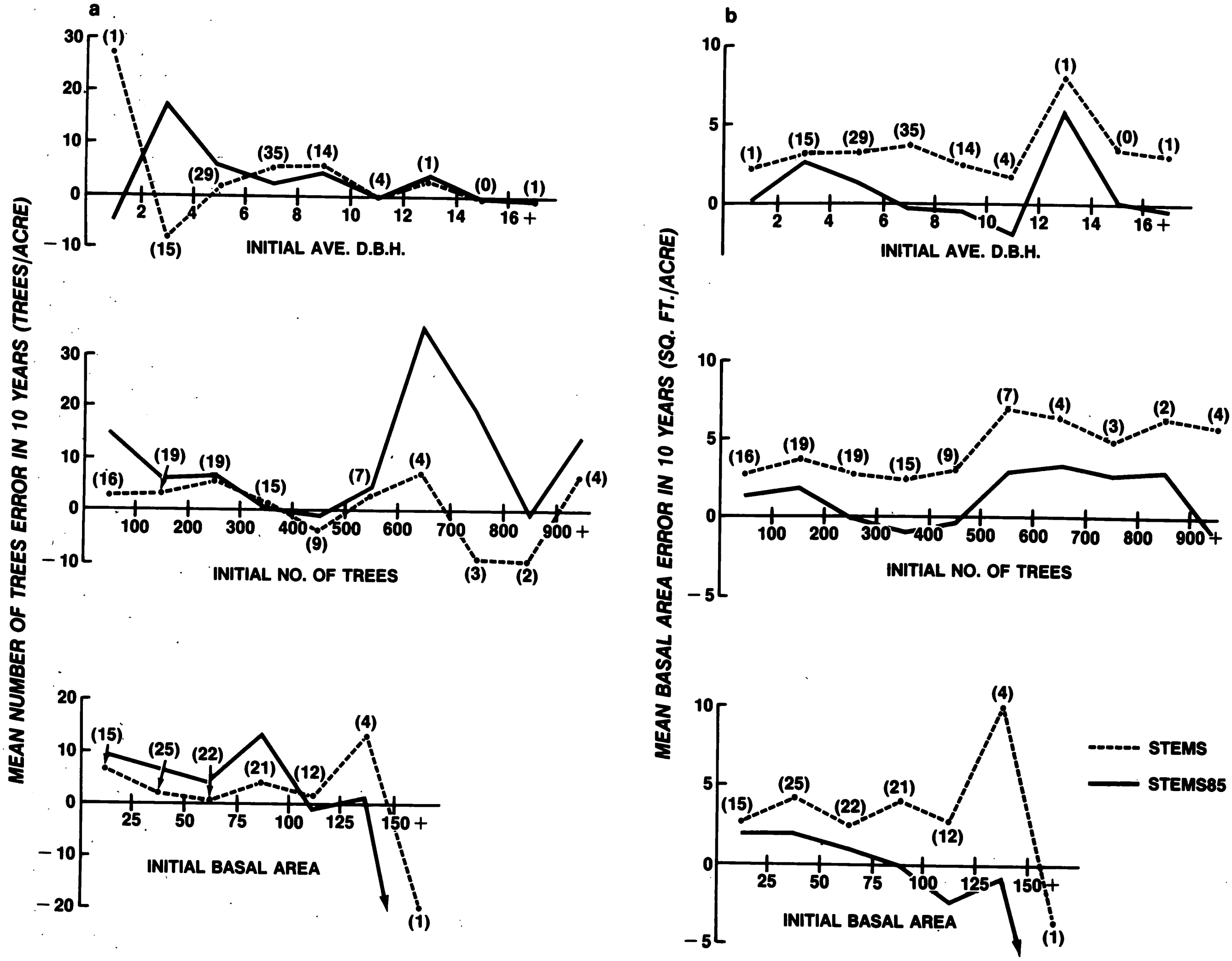

Figure 2.—*The (a) mean number of trees errors and (b) the mean basal area errors in 10 years plotted against selected initial stand conditions for STEMS and STEMS85. The percent of the plots in each class for both models is given in parenthesis.*

NT produced only a 10 percent error in BA. Thus, with these data, accuracy in predicting diameter growth is twice as important as accuracy in predicting mortality. In evaluating the data, the BA trend evident in the growth component is still present in the overall model.

DBH Error By Diameter Class

The growth component can be further analyzed by evaluating diameter errors for initial diameter classes (table 5). For all species combined, the STEMS85 model underestimated growth of trees between 4 and 8 inches; but for 8 inches and larger it reduced a problem with overprediction in STEMS.

The number of entries with a mean DBH error greater than ±0.30 inches in 10 years was reduced from 60 using STEMS to 27 using STEMS85. White spruce overpredictions with STEMS have been slightly improved. All other problem species with STEMS (northern white-cedar, basswood, northern pin oak, and bigtooth aspen) have been greatly improved with STEMS85 as measured by the errors in the DBH classes. No other species show large errors.

Species Mortality Rates

Mortality can be evaluated as a tree attribute in addition to evaluation as a stand attribute. We calculated the observed and predicted annual mortality rates for each species based on the number of trees that survive through an observation interval and the length of that interval (table 6).

The results for the two models show roughly the same overall accuracy and distribution of the errors (predicted - observed mortality rates) by species. Estimates for balsam fir and elm, which can be affected by insect or disease outbreaks, have now been improved in STEMS85. Although the problem with elm

Table 5.-- Mean d.b.h. errors (inches) in 10 years by species and diameter class for all validation data sources

Species	No. of trees[1]	Diameter class (inches)								All classes	Mean d.b.h. growth in 10 years
		0-3+	4-5+	6-7+	8-9+	10-11+	12-13+	14-15+	16+		
Jack pine	1,813	-0.04	-0.07	-0.13	-0.11	-0.12	-0.14	-0.24	-0.71	-0.11	0.97
Red pine	1,374	-.21	.01	-.12	-.42	-.48	-.28	-.20	-.02	-.16	1.72
White pine	310	-.73	-.31	-.37	-.14	.19	.48	.00	.07	-.04	1.82
White spruce	171	.40	-.02	.03	.37	.45	.43	.45	.34	.19	1.84
Balsam fir	693	.03	-.21	-.23	-.17	-.27	-.24	-.24	-	-.19	1.03
Black spruce	769	-.13	-.29	-.31	-.29	-.04	-	-2.20	-	-.29	.63
Tamarack	334	.24	.08	.04	.03	.34	.00	.65	-	.07	.68
N. white-cedar	916	-.09	-.12	-.07	.02	.06	.14	-.13	-.31	-.05	.76
Hemlock	306	.17	.00	.16	.07	.23	-.07	.10	.18	.11	.91
Black ash	189	-.08	-.03	.01	.07	.23	.05	-.22	-.18	.02	.66
Red maple	798	.13	-.15	-.17	-.11	-.19	-.17	-.45	-.08	-.12	1.20
Elm	194	-.18	-.17	-.26	-.03	-.23	-.58	-.01	-.43	-.22	1.32
Yellow birch	270	-.06	-.02	-.08	-.30	.09	.03	-.20	-.06	-.09	.92
Basswood	274	-.13	.37	.12	.03	.00	.05	.11	.33	.11	1.23
Sugar maple	878	.03	-.04	-.04	.01	.17	.08	.11	-.09	.01	1.13
White oak	255	.14	.24	.17	.24	.17	.19	.16	.43	.21	.89
N. red oak	258	-.05	.15	.02	-.08	.00	-.25	-.17	.25	.01	1.35
N. pin oak	286	-.36	-.03	-.15	.18	.28	.34	.41	.14	.14	1.12
Bigtooth aspen	227	-.06	.21	.19	.14	.02	-.23	-.29	-.15	.10	1.58
Quaking aspen	933	-.22	-.03	.16	.15	.13	-.03	.02	-.18	.08	1.41
Paper birch	1,102	-.20	-.12	-.05	.06	.05	.30	.27	-.15	-.03	1.16
All[2]	12,696	-.03	-.08	-.08	-.05	-.01	.01	-.03	.01	-.06	1.15
Percent trees in diameter class		7	23	32	17	9	5	3	4	100	

[1]Species with fewer than 100 observations have been omitted

[2]Includes species with fewer than 100 observations

has been lessened, the same general trends are evident. The predicted and observed elm mortality rates are close for all sources except the Manistee National Forest in lower Michigan. There, the observed mortality rate was 13 percent as compared to a predicted rate of just over 2 percent. As shown in Holdaway and Brand (1983), this is likely due to Dutch elm disease spreading into lower Michigan before entering Wisconsin and upper Michigan.

Precision

The DBH errors for STEMS85 are less skewed than for STEMS (fig. 3). There is little difference between the two models for the distribution of NT errors in 10 years, except that the distribution was slightly more peaked.

The graph of the distribution of BA errors in 10 years is similar in shape to that shown in figure 3, and so has not been presented. Again, the basal area errors are less skewed.

For 10 year projections with STEMS85, 75 percent of the trees had predicted diameters within 0.5 inches of the true value, 92 percent of the plots had predicted NT within 100 trees per acre, and

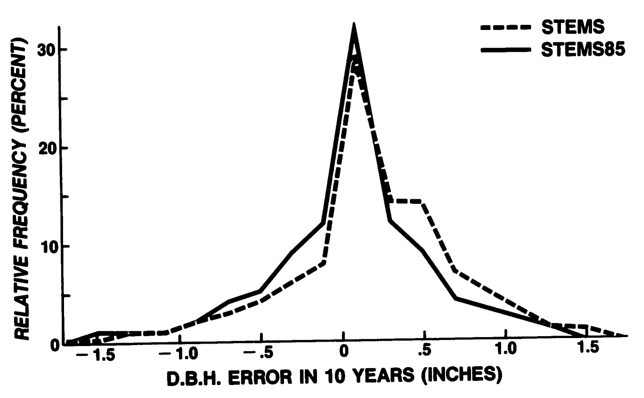

Figure 3.—*A comparison of the frequency distributions of the 10-year errors for STEMS and STEMS85 in predicting tree DBH for all validation sources.*

Table 6.--Predicted and observed annual tree mortality rates by Lake States species for all validation properties using STEMS85

Species	No. of trees	Annual tree mortality rate	
		Predicted	Observed
		Percent	
Jack pine	2,336	1.6	1.8
Red pine	1,397	.1	.3
White pine	363	.1	1.7
White spruce	187	1.0	.6
Balsam fir	1,092	1.1	2.0
Black spruce	1,024	2.7	1.4
Tamarack	370	1.3	.7
N. white-cedar	987	.4	.8
Hemlock	323	.5	.6
Black ash	254	1.5	2.0
Red maple	852	1.8	1.4
Elm	293	3.0	4.1
Yellow birch	321	1.1	2.0
Basswood	303	2.0	1.2
Sugar maple	946	1.3	1.7
White ash	65	1.7	2.2
White oak	274	.1	1.9
N. red oak	273	4.2	1.5
N. pin oak	312	5.1	2.6
Bigtooth aspen	270	2.3	1.6
Quaking aspen	1,468	1.9	3.3
Paper birch	1,191	.4	.9
All[1]	15,240	1.4	1.6

[1]Includes all species on the property

72 percent of the plots had BA values predicted to within 10 square feet. All three values are 4 percent higher than for STEMS.

Long-term Projections

Projections become less accurate as the projection interval increases. The original prediction system was calibrated with remeasurement data spanning 10 to 30 years. Thus, we feel that caution should be exercised in applying this growth projection beyond 30 years. Although constraints were built into the model that prevent grossly unrealistic behavior, the model may exceed or fall short of reasonable basal areas per acre on long-term projections. We recommend that long-term projections be compared critically with expectations based on professional judgment.

SUMMARY

We evaluated two growth models—the STEMS model and the current STEMS85 model—and found the two models to be fairly similar. However, the STEMS85 model was slightly more accurate and precise.

The important findings and observations from the tests on STEMS85, including the major areas of weakness, are:

1. On the five tracts studied the STEMS85 model undergrows trees on the average by 0.06 inches in 10 years. On 75 percent of these trees, it predicted the diameter to within 0.5 inches of the observed diameter after 10 years growth. Likewise, the model overestimated stand basal area on the average by 0.9 square feet per acre after 10 years growth; on 72 percent of these plots, it predicted the basal area to within 10 square feet per acre of the true value.
2. STEMS85 had far fewer species or forest types showing large errors for all three key variables. The major problem areas involved predicting mortality and stand basal area for lowland hardwoods.
3. In an evaluation of the error patterns for the two models, the STEMS85 model predicted slower DBH growth, which was generally an improvement. The main exception was extreme understory trees, representing 13 percent of the trees.
4. Tree diameter errors given by species and initial diameter classes show that the problem of overpredicting growth for trees larger than 8 inches has been corrected, but growth for trees from 4 to 8 inches is slightly underpredicted with STEMS85. Again, the number of DBH classes for each species with large positive or negative errors has been halved.

5. The problem of underpredicting mortality on balsam fir and elm has been improved with STEMS85.
6. STEMS85 predicts slower diameter growth for most trees, resulting in a slight underestimation of growth. Because of the positive bias in estimating stand basal area, this underestimation of growth is preferable to an equivalent overprediction.
7. Throughout the evaluation the number of and magnitude of the large prediction errors using STEMS85 were consistently reduced by 50 to 80 percent. The extent of this improvement is somewhat surprising, considering the slight increase in precision, along with the decrease in skewedness demonstrated in the precision analysis. Evidently, the model is sensitive to even slight improvements in precision.
8. Although the STEMS85 mortality predictions were not much improved, that model is known to have desirable biological characteristics that ensure reasonable estimates for large trees (Buchman *et al*. 1983).

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