AN EVALUATION OF THREE GROWTH AND YIELD SIMULATORS FOR EVEN-AGED HARDWOOD FORESTS OF THE MID-APPALACHIAN REGION

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Abstract.—Data from even-aged hardwood stands in four ecoregions across the mid-Appalachian region were used to test projection accuracy for three available growth and yield software systems: SILVAH, the Forest Vegetation Simulator, and the Stand Damage Model. Average root mean squared error (RMSE) ranged from 20 to 140 percent of actual trees per acre while RMSE ranged from 2 to 65 percent of actual basal area per acre (BAAC), depending on thinning category and dataset. Overall, SILVAH produced the smallest average error across all datasets and thinning categories, although significant improvement in projection accuracy is deemed feasible.

INTRODUCTION

In the late 1960s Schlaegel (unpublished) developed cubic foot and basal area growth and yield models for even-aged yellow-poplar (*Liriodendron tulipifera* L.) stands in West Virginia. These models were based on the concept of the mathematical compatibility of growth and yield as developed by Clutter (1963). Perkey (1985) published an adaptation of Martin E. Dale's FORTRAN GROAK program in MBASIC. Perkey's (1985) whole stand model predicted future basal area per acre (BAAC), trees per acre (TPA), quadratic mean diameter, percent stocking, cubic foot yield, and board foot yields at some future age. The equations were based on a thinning study in even-aged white oak and black oak stands in Iowa, Missouri, southern Ohio, and southeastern Kentucky (Dale 1972). Although whole stand models can provide quantitative information on future estimates of TPA, BAAC, and volume per acre at the stand level, the need for tree-level information within those stands is obvious when such characteristics as product quality and value are being considered.

During this period, development of growth and yield systems in the southern United States took the diameter distribution approach to disaggregating stand-level data through the use of the Weibull distribution function, as developed by Bailey and Dell (1973). The approach first employed in the Central Appalachian region followed a distance-independent individual tree growth and yield system. Hilt (1985) developed such a system (OAKSIM) for even-aged upland oak stands in southern Ohio and southeastern Kentucky. This growth and yield system was based on a thinning study in white, black, and scarlet oak stands typical of this region and the computer program OAKSIM was developed in FORTRAN for use on mainframe computers. Although this system was incorporated in the NED SIPS (Stand Inventory Processor and Simulator) program, the DOS platform was not consistently stable and so no further analysis of this system was attempted. Yandle and others (1987) developed whole stand growth models for even-aged hardwood stands based on remeasurement data collected in east central Ohio and north central West Virginia. The system provides basal area and volume

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projection models that are based on current stand parameters of percent basal area of shade-intolerant species, percent basal area of shade-tolerant species, merchantable basal area, site index, number of merchantable trees, stand age, quadratic mean diameter of tolerant species, and the square of current mean diameter. Although these models were based on a limited dataset, fairly accurate estimates were reported.

During this same period, The Woodsman's Ideal Growth Projection System (TWIGS) was developed starting with the Lake States version (LS TWIGS) in 1982, followed by the release of the Central States version (CS TWIGS) in 1987 and the Northeast version (NE TWIGS) in 1989 (Hilt and Teck 1989). The NE TWIGS computer software was a distance-independent individual tree growth and yield system written in FORTRAN for the DOS operating system having the same functional structure as the LS and CS TWIGS versions. Individual tree models were fitted to data collected on U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis plots from the 14 northeastern states, including West Virginia. Numerous organizations modified this system to represent more localized conditions. This system later became the basis for the northeast variant of the U.S. Forest Service Forest Vegetation Simulator (FVS), which was initially developed in 1991 and released in 1993 (Bush 1995).

In 1992, the SILVAH software system was released (Marquis and Ernst 1992). This software system is more of an expert system designed to manage hardwood forests of the Allegheny Plateau region. As part of this expert system, SILVAH includes a stand growth simulator. Unlike the individual tree models discussed thus far, this system employs a modified stand table projection algorithm. Although this system includes a diameter growth algorithm for oak species from OAKSIM, the overall growth projection and mortality systems are significantly different from the original OAKSIM program. The last system to enter the hardwood growth and yield platform was the Stand Damage Model (SDM), which was released in 1995. This system is a distance-independent tree-growth simulator based on gap modeling theory (Colbert and Racin 1995, Colbert and Sheehan 1995, Racin and Colbert 2004).

Within the past 5 years, Brooks and Wiant (2004, 2006) have developed stand-level cubic and board foot volume prediction models for northern West Virginia based on stand basal area and average dominant height. In addition, a basal area projection model for this same area was published by Brooks and others (2008). This algebraic difference equation model predicts future basal area based on initial basal area and changes in trees per acre and stand age. This model was originally applied to a slash pine growth and yield system in the Southeast (Pienaar and Shiver 1986).

The purpose of this report is to review those growth and yield systems specific to hardwood stands in the mid-Appalachian region, to identify and review those systems available in computer program format, and to test existing systems on actual remeasured plot data from this region.

METHODS

The Central Appalachian mountain region is made up of several ecoregions with distinctly different soils, length of growing season, annual precipitation, elevation, and species distributions and thus growth rates. Height-diameter and volume relationships have been shown to be different among these regions (Brooks and Wiant 2007, 2008).

The datasets selected for study represented long-term remeasurement data from the unglaciated Allegheny Plateau (Allegheny National Forest Data), the Western Allegheny Plateau and Mountains (OAKSIM Data), the Southern Appalachian Ridge and Valley (MeadWestvaco Data), and Eastern Allegheny Plateau and Mountains (WVU Hatch Data) (Fig. 1). These even-aged datasets were selected because they were available, had a thinning component, and provided an opportunity to evaluate growth and yield among the different ecoregions. Only plot data that spanned three measurement periods were included in this analysis. For thinned treatments, only growth following initial thinning but prior to a second thinning was included. Since these and other datasets evaluated for this study did not include height measurements at each of the remeasurement periods, differences in volume were not evaluated. Analysis was based on TPA and BAAC. These datasets included trees greater than or equal to the 1-inch diameter class.

The four long-term datasets provided 125 permanent plots and 1,401 actual remeasurement periods. Since at least some of the data were based on a 5-year remeasurement cycle, this analysis is based on 5-year projection intervals from 5 to 30 years. A maximum of 100 growth projection comparisons resulted. Plot-level summary statistics for each dataset are described in Table 1.

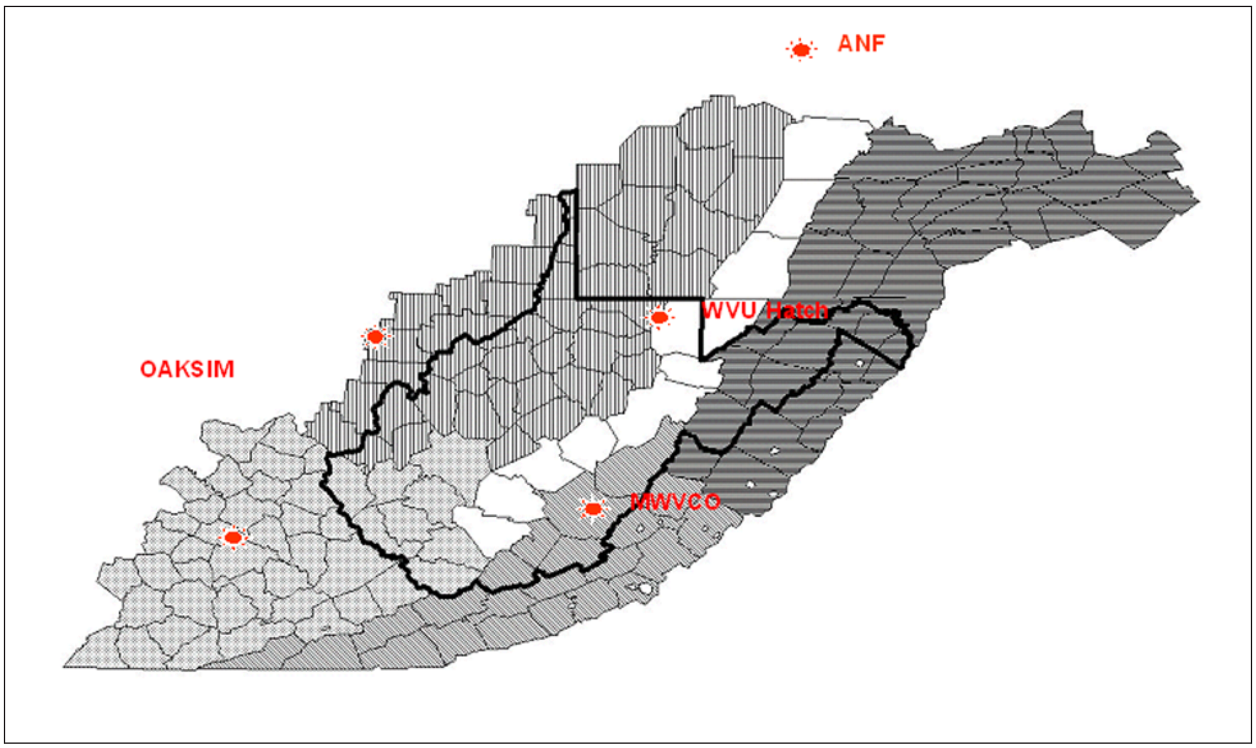

Figure 1.—Location of sample datasets by ecoregion.

Table 1.—Plot-level summary statistics for trees per acre and basal area per acre by dataset.

	Min TPA	Max TPA	Min BAAC (ft^2/ac)	Max BAAC (ft^2/ac)	Initial Stand Age (yrs)	No. Sample Plots
ANF	92	997	45.2	181	53 - 54	35
OAKSIM	50	798	15.1	116.5	20 - 93	53
MWVCO	200	2,218	10.3	75.6	10 - 16	20
WVU Hatch	374	1,026	60.2	115.3	20 - 24	17

Tree data files for each plot were summarized for BAAC and TPA in each remeasurement period. For thinned stands, the plot-level summary was based on post-thinning conditions and continued until the remeasurement period prior to the second thinning. Initial tree lists for each plot were entered into each growth simulator and projected for 30 years or for the longest remeasurement period available for that particular plot, in 5-year intervals. In some instances, actual remeasurement periods did not fall exactly in 5-year intervals and in these situations a linear interpolation was used between adjacent measurement intervals. For each growth projection interval the average error (bias) and root mean squared error (RMSE) for TPA and BAAC were calculated based on observed measured data and the model prediction. These simple sample statistics were used for their ease of interpretation. Average error (bias) was used in situations where predictions either continuously over- or underestimated the stand parameters, as well as in cases where both situations occurred during the growth projection period. In these situations, the algebraic sign of the bias may change during the projection period. The RMSE provides an estimate of average error unaffected by changes in the algebraic sign of the estimation. As mentioned previously, no attempt to compare volume estimates was made due to the general lack of height data to obtain actual volume estimates. Summary statistics were generated by the growth and yield systems separately for each dataset and thus ecoregion. In all cases, only the original tree list was used in computer simulations with no simulated ingrowth.

The three available growth and yield computer systems that were selected for testing were: SILVAH (version 4.04, DOS), FVS (Northeast variant, Windows version 6.21, release 07.05.06) and the SDM (version 2.0, DOS). All simulators were tested based on an "out-of-the-box" condition using all default settings, with the exception of the Northeast Variant of FVS, where the most appropriate national forest location was employed. To evaluate model projection error, RMSE was plotted as the percent of actual TPA and actual BAAC. Model projection length was limited to the range of the actual measurement periods in each dataset. Averages for thinned (T) and unthinned (NT) plots (stands) were plotted separately and presented separately by dataset and thus ecoregion.

RESULTS

PROJECTION ACCURACY

Evaluation of the performance is solely the subjective evaluation by the authors, but it is based on preliminary whole stand model development in these same regions.

Allegheny National Forest (ANF) Data

The ANF data were projected with each simulator for three 5-year growth intervals. SILVAH and FVS overestimated TPA, while the SDM underestimated TPA for these stands. In general, average TPA prediction error increased with increasing projection length, a commonly found scenario for growth and yield systems. Thinned plots exhibited smaller average prediction error than their unthinned counterparts.

Average TPA error (RMSE) at the end of the 15-year projection period ranged from 20 to 30 percent of actual stand density. The smallest error was associated with thinned stands when projected using the SILVAH simulator.

SILVAH and FVS underestimated BAAC for the thinned stands and overestimated BAAC for unthinned stands. The SDM underestimated BAAC for both thinning categories; the largest errors were associated with the unthinned stands. For BAAC, the SDM exhibited average prediction errors above 25 percent of actual

BAAC within a 5-year projection period and exceeded 35 percent by the end of the 15-year projection. Both SILVAH and FVS performed well with prediction errors less than 15 percent of the actual BAAC over the range of projection years; their performance was slightly better performance for unthinned stands.

OAKSIM Data

The OAKSIM data were projected using each simulator for six 5-year growth intervals. SILVAH, FVS, and SDM all overestimated TPA. In general, average bias for thinned stands exceeded that of unthinned stands, although these differences were small for the SDM. Average TPA error (RMSE) at the end of the 30-year projection period ranged from 60 to more than 140 percent of actual stand density; the smallest errors were associated with the SILVAH and SDM (unthinned stand only) simulators. Initial differences between thinning category were not apparent, but the unthinned stands appear to have smaller prediction errors than their thinned counterparts.

SILVAH and SDM underestimated BAAC for thinned and unthinned stands with the unthinned stands having a slightly larger average error, although the magnitude of these differences was small, especially for SDM. For the FVS simulator, BAAC was overestimated for both thinned and unthinned stands, but these differences were small. Both the SDM and FVS simulators exhibited average prediction errors above 25 percent of actual BAAC by the end of the 30-year projection period. SILVAH performed well with prediction errors less than 15 percent of actual BAAC across the entire 30-year projection period for both thinned and unthinned stands; the thinned stands performed slightly better than the unthinned stands.

MeadWestvaco Data (MWVCO)

The MeadWestvaco data were projected with each simulator for two 5-year growth intervals. All three simulators overestimated TPA. RMSE projection errors for TPA were generally lower for the thinned stands than for their unthinned counterparts. Maximum error was associated with the FVS simulator, which overestimated TPA in excess of 140 percent of actual TPA in the 10-year projection period.

All simulators underestimated BAAC with the unthinned stands having smaller average errors than their thinned counterparts. The smallest errors were associated with the SILVAH simulator for unthinned stands and the largest errors were associated with unthinned stands projected with the FVS simulator.

WVU Hatch Data

The WVU Hatch data were projected with each simulator for six 5-year growth intervals. SILVAH and FVS overestimated TPA while SDM underestimated TPA for these stands. One exception to this pattern was for thinned stands using the SILVAH simulator, where initial error (average bias) was positive and then turned negative from projection age 20 through 30. Generally, thinned plots exhibited smaller average prediction errors than their unthinned counterparts. SILVAH underestimated BAAC for unthinned stands and initially overestimated then underestimated BAAC for thinned stands. The magnitude of these differences was small. For the FVS simulator, BAAC was underestimated for both thinned and unthinned stands; the unthinned stands exhibited a slightly larger average error. The SDM underestimated BAAC for both thinning categories, with the largest errors associated with the unthinned stands. Average TPA error (RMSE) at the end of the 30-year projection period ranged from 20 to 140 percent of actual stand density; the smallest error was associated with SILVAH and the SDM simulators. Although some initial differences were apparent, little practical difference exists between thinning categories at the end of the projection period. SDM (unthinned stands only) and FVS simulators exhibited average prediction errors above 12 percent of actual BAAC within the 5-year projection period and exceeded 25 percent by the end of the 30-year projection. Both SILVAH and the SDM (thinned stands only) performed well, with prediction errors less than 15 percent across the entire 30-year projection period.

PROJECTION ACCURACY BY ECOREGION

To evaluate model projection accuracy by ecoregion, RMSE as a percent of actual TPA and BAAC were plotted for both thinning categories for all datasets, separately by simulator. Evaluation of the performance is solely the subjective evaluation by the authors, but it is based on preliminary whole stand model development in these same regions.

SILVAH

In terms of RMSE for TPA, SILVAH performed better for the ANF and WVU Hatch datasets (Fig. 2). For the OAKSIM dataset, average projection error was nearly twice that for the WVU Hatch dataset when projected for 30 years. The largest error was associated with the unthinned stands for the younger MWVCO dataset, but this result may be more a function of stand age than of ecoregion. For BAAC, all projections were considered good with few visible differences by ecoregion, except for the thinned MWVCO stands (Fig. 3).

FVS

In terms of RMSE for TPA, FVS performed poorly for all datasets except the thinned stands from the MWVCO and ANF datasets (Fig. 4). In terms of average RMSE for BAAC, FVS performed poorly for all datasets except those from the ANF dataset (Fig. 5). Again, the larger error associated with the MWVCO dataset may be more a function of stand age.

SDM

In terms of RMSE for TPA, the SDM performed best for both thinned and unthinned stands for the WVU Hatch dataset (Fig. 6). The poorest long-term projections were associated with the stands from the OAKSIM dataset. In terms of average RMSE for BAAC, the SDM performed poorly for the OAKSIM, ANF, and MWVCO datasets (Fig. 7). The best predictions were associated with the WVU Hatch data, perhaps because baseline models were fit to data from the same area.

CONCLUSIONS

Datasets from four ecoregions across the mid-Appalachian region were used to test projection accuracy for three available growth and yield software systems, SILVAH, FVS, and the SDM. Average prediction error (RMSE) generally ranged from 20 to 140 percent of actual TPA, depending on thinning category and dataset. Average prediction error (RMSE) ranged from 2 to 65 percent of actual BAAC, depending on thinning category and dataset. Preliminary investigation by Brooks and Wiant (2004, 2006), using very simple model forms, indicate that whole stand estimates of volume within ±10 to 15 percent of actual stand volume seem feasible in these Appalachian hardwood stands. It is recognized that these volume prediction errors were based on the same dataset as model fitting, thus reducing prediction variability. However, whole stand estimates in excess of 20 percent of actual stand values seem unacceptably high and a reduction in prediction error appears attainable for this region. Using a more complex basal area projection model, Brooks and others (2008) were able to provide basal area predictions within 10 percent of actual stand basal area for undisturbed

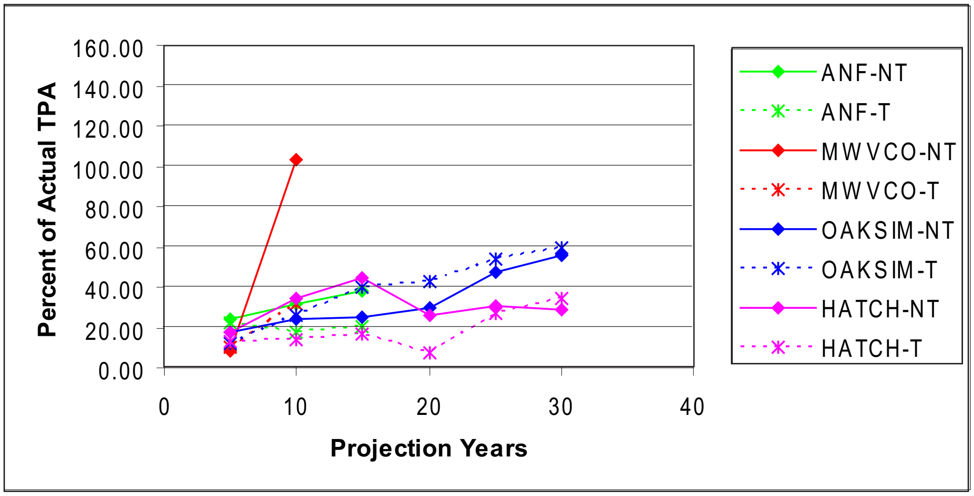

Figure 2.—SILVAH RMSE as a percent of actual TPA by projection year for all datasets.

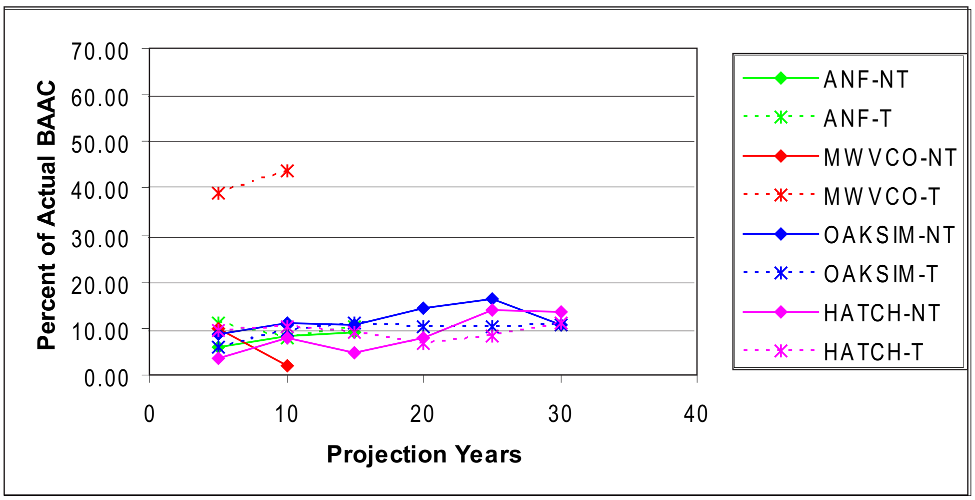

Figure 3.—SILVAH RMSE as a percent of actual BAAC by projection year for all datasets.

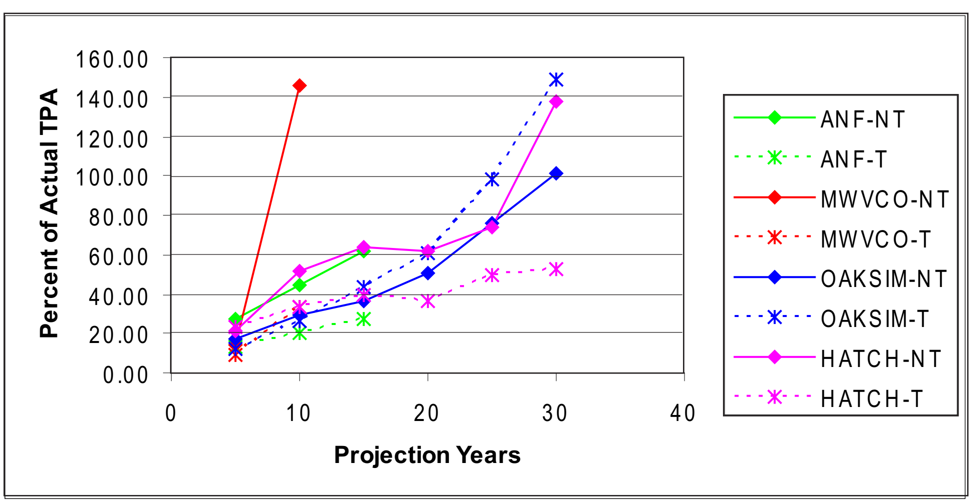

Figure 4.—FVS RMSE as a percent of actual TPA by projection year for all datasets.

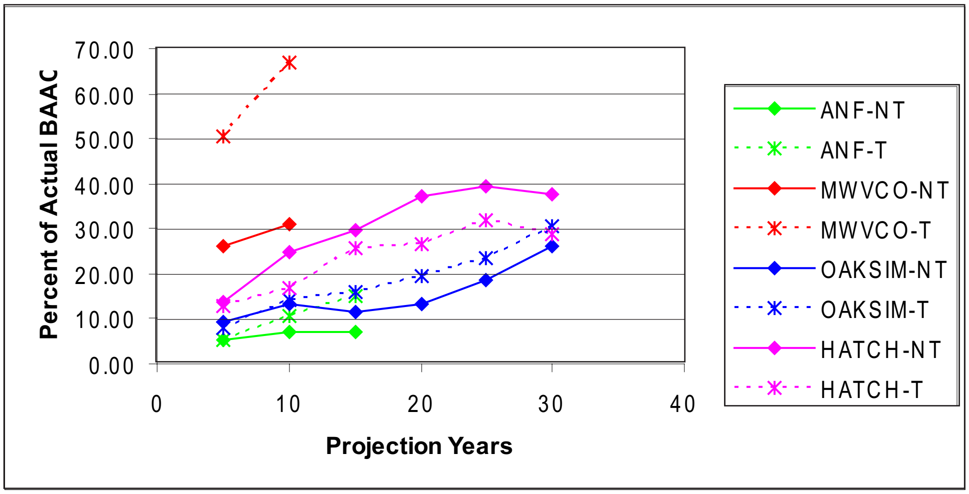

Figure 5.—FVS RMSE as a percent of actual BAAC by projection year for all datasets.

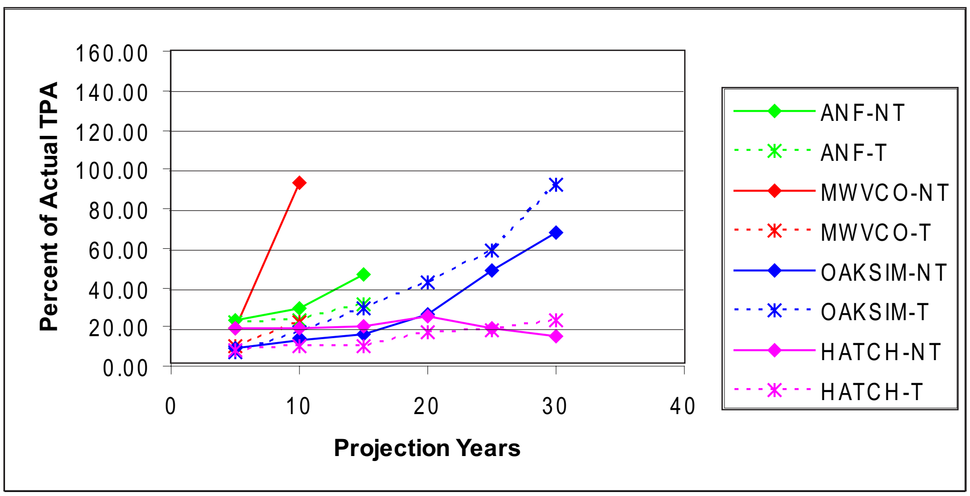

Figure 6.—SDM RMSE as a percent of actual TPA by projection year for all datasets.

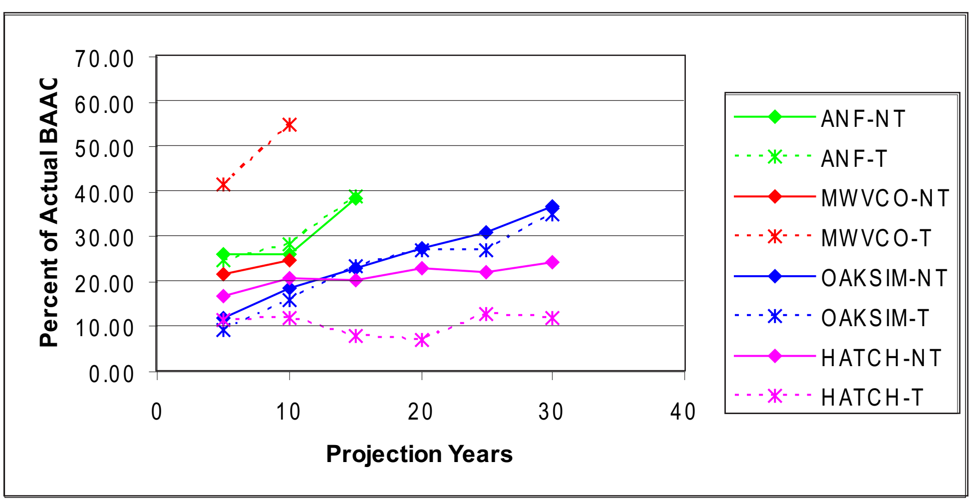

Figure 7.—SDM RMSE as a percent of actual BAAC by projection year for all datasets.

even-aged stands from this region. In addition, the authors believe that the increasing prediction error associated with increasing projection length can be controlled, though not eliminated. Overall, SILVAH produced the smallest average error across all datasets and thinning categories, although significant improvement in projection accuracy is deemed feasible. All results are based on remeasurement data from even-aged stands and should not be extrapolated to selectively harvested conditions. In terms of total basal area prediction, Schuler and others (1993) recommended SILVAH and NE-TWIGS for Allegheny hardwoods and oak-hickory stands in their earlier evaluation of hardwood growth and yield systems. The poorer performance of FVS in this project may indicate that changes to model structure or parameters of the original NE-TWIGS system negatively influenced projection accuracy in these datasets.

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