ESTIMATION OF TOTAL HEIGHT, GROWTH, AND MORTALITY OF FOREST TREES IN MISSOURI

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Master of Science

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

ESTIMATION OF TOTAL HEIGHT, GROWTH, AND MORTALITY OF FOREST TREES IN MISSOURI

Presented by James R. Lootens

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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For more than 50 years the managers of the Pioneer Forest have been measuring forest change in detail using a system of continuous forest inventory (CFI) plots. Those data have served purposes far beyond those envisioned when the plots were established in 1952, including serving as the basis for much of the research presented in this thesis. I thank Leo Drey, the L-A-D Foundation, Clint Trammel, and Terry Cunningham for making these data available.

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ABSTRACT

A model for predicting total tree height as a function of tree diameter was calibrated for twelve tree species common to the Missouri Ozarks. Model coefficients were derived from nearly 10,000 observed trees. The calibrated model did a good job predicting the mean height-diameter trend for each species (pseudo-R^2 values ranged from 0.56 to 0.88), but for a given tree diameter observed tree heights were highly variable. We also present a technique for incorporating the observed variation in tree heights in the predicted values.

In addition, an evaluation of the Central States variant of the Forest Vegetation Simulator (CS-FVS) was performed using forest inventory data from a managed, uneven-aged forest in the Missouri Ozark Highlands. CS-FVS is a distance-independent, single-tree growth model. Simulations were run for ten and forty year time periods and evaluated projections of diameter growth, number of trees per acre, and basal area per acre. The model was evaluated with and without providing diameter increment calibration information. CS-FVS performed reasonably well in predicting diameter growth, as compared to other evaluations of similar models. The model consistently overpredicted the number of trees per acre and basal area for all simulations. Simulations indicate that the model underpredicts mortality, especially for black and scarlet oak. CS-FVS performed best in ten-year simulations when diameter increment information was provided. Forty-year simulations showed similar results to the ten-year results, but with larger mean errors, and smaller improvements with the inclusion of diameter increment information.

INTRODUCTION

Sound forest management requires the manager to consider the past, present, and future of a forest stand. The present stand can be characterized through forest inventory; the future stand conditions Sampling techniques can be used to examine the individual tree, expand these measurements to the acre level, or an even larger scale. However some measurements are difficult and time consuming to collect, such as total tree height, or difficult to predict without the use of quantitative tools.

Simulation models can predict the growth of a single tree (Holdaway and Brand 1983, Miner et al 1988) or simulate growth at a much larger scale (Solomon et al 1995). Presently, in the state of Missouri, the forest growth model most commonly used by federal and state agencies is some form of Central States TWIGS (CS-TWIGS). CS-TWIGS is based on the mainframe program STEMS (Holdaway and Brand 1983), developed by the North Central Forest Experiment Station of the USDA Forest Service (Miner et al 1988).

STEMS and CS-TWIGS have been previously tested outside of Missouri and shown to provide reliable results for many tree and stand conditions (Holdaway and Brand 1983, Miner et al. 1988, Kowalski and Gertner 1989). Additionally, sub-regional examinations have shown satisfactory performance from the model over short time frames (Kowalski and Gertner 1989). In addition to growth and yield projections, economic models have been developed for use with the TWIGS framework (Blinn et al. 1988).

The USDA Forest Service has adopted a standard growth and yield system, the Forest Vegetation Simulator (FVS). This single-tree, distance-independent framework is based on the Prognosis model developed for the Inland Empire of Idaho and Montana (Stage 1973). During the 1980's and 90's, the Forest Service began the task of standardizing growth and yield models across the nation by creating "geographic variants" of FVS. CS-TWIGS 3.0 was placed into the FVS framework and became the Central States Variant of FVS (CS-FVS).

CS-TWIGS does not utilize tree heights in any of its underlying functions. FVS not only has a height growth model, but also requires height values for the estimation of volume (Dixon 2003). This fact necessitated the use of a system of height "dubbing" equations. The current version of the Central States Variant of FVS uses height equations developed for the Lake States by Ek and others (1984). One of the goals of this project was to develop height-estimation equations for the state of Missouri, specifically the Ozark Highlands. While height-diameter equations have recently been developed for bottomland species in the central hardwood region (Colbert et al. 2004), no such models exist for upland species. Chapter 2 of this document addresses this information need.

Produced in tandem with Central States TWIGS, Lake States TWIGS (Miner et al. 1988) has been tested (Guertin and Ramm 1996) and shown to provide reliable estimates of tree, stand growth, and survival. Canavan and Ramm (2000) evaluated the Lakes States variant of FVS (LS-FVS) as a continuation of the work done by Guertin and Ramm (1996). The 2000 study evaluated LS-FVS and determined the simulation length and the inclusion of dbh growth in tree input data improved prediction accuracy.

Chapter 3 evaluates CS-FVS in a similar manner. Continuous Forest Inventory (CFI) data from a large, privately owned forest in the Missouri Ozark Highlands (McNab and Avers 1994) was used to evaluate CS-FVS. Simulations evaluated lengths of 10 years and 40 years, and varying levels of tree-specific information. The model was evaluated by comparing observed and predicted dbh growth, mortality per acre, and basal area per acre.

HEIGHT-DIAMETER EQUATIONS FOR TWELVE UPLAND SPECIES IN THE MISSOURI OZARK HIGHLANDS

Introduction

Total tree heights are costly and difficult to accurately obtain. However, they provide a great deal of information about tree volume, site productivity, and stand size structure. In the absence of observed tree heights, total tree heights can be estimated by the use of a height-diameter equation. These equations predict a tree's total height based on its diameter at breast height (4.5 feet above ground), and in many situations, they provide a valuable alternative to measuring the heights in the field. Several such models exist for different species and geographic regions e.g., (Monserud 1975, Ek et al. 1984, Larsen and Hann 1987), (Parresol 1992, Flewelling and de Jong 1994, Colbert et al. 2002). This paper presents equations for predicting total tree height for twelve species in the southeastern Missouri Ozarks.

Methods

Data used in model development came from the Missouri Ozark Forest Ecosystem Project (MOFEP) (Brookshire and Shifley 1997, Shifley and Brookshire 2000) and the Missouri Ecological Classification System Project (MOECS) (Becker 1999, Grabner 2002). Study sites were located in Missouri counties of Shannon, Reynolds, and Carter, in the Ozark Highlands Section of the Eastern Broadleaf Forest (Continental) Province (McNab and Avers 1994). Trees included in the database were from all crown classes and spanned a wide-range of diameters (0.1 to 36.0 inches). Individual trees with signs of damage or broken tops were removed from the data set. In all cases, diameters at breast height were measured with a diameter tape or caliper to the nearest 0.1-inch. Heights were measured to the nearest foot with a telescoping height pole or a clinometer.

After preliminary examination of height-diameter models by Monserud (1975), Ek et al. (1984), Larsen and Hann (1987), Parresol (1992), and Flewelling and de Jong (1994) we settled on Monserud's (1975) model:

$$H = 4.5 + \exp(b_0 + b_1 D^{b_2}) \qquad (1)$$

where H is total tree height in feet, 4.5 corresponds to breast height (ft), D is diameter at breast height (in.), and the b_i are regression coefficients. The flexible model form is easy to fit and has worked effectively for species in the Midwest and elsewhere (e.g. Larsen and Hann 1987, Colbert et al. 2002). This equation enforces the constraint that as D approaches zero, H approaches 4.5 feet, given b_1 and b_2 are negative.

We fit separate equations for species with at least 75 observations (Table 2A). We also fit composite equations for upland oaks and hickories. Blackjack oak, chinkapin oak and bitternut hickory were included in their respective pooled groups, but did not have sufficient numbers for individual models.

We used nonlinear regression to fit models for all species and species groups. We evaluated model fit using the residual standard error, graphics, and a pseudo-coefficient of multiple determination for the nonlinear regression (Kvålseth 1985). The pseudo coefficient of multiple determination is analogous to the R^2 in linear regression, and is computed:

$$R^2 = 1 - \frac{\sum (Y_j - \hat{Y}_j)^2}{\sum (Y_j - \overline{Y})^2} \qquad (2)$$

Where $\hat{Y}_j$ = model estimate for the *j*th estimate, $\overline{Y}$ = sample mean, and Y_j = *j*th observation.

Results and Discussion

Equation 1 did a good job of defining the height-diameter relationship for the Ozark species. Pseudo R^2 values ranged from 0.56 to 0.92 (Table 2B). The fitted equations closely followed the trends in the data (Figures 2A-2K) and residual analyses revealed no patterns indicating a need for remedial measures.

Oaks were the most abundant species in the dataset, however they also had the largest residual standard errors (RSE) and the lowest pseudo R^2. White oak had a slightly lower RSE and a higher pseudo R^2 than the other two individual oak species, scarlet and black oak. Less accurate prediction in these species may be related to the wide-variety of sites on which these species exist. Better fit statistics for white oak may be related to white oak being more of a site generalist – being able to thrive on a wide variety of sites. The pooled oak group, including all of the above mentioned oaks, as well as chinkapin and blackjack oak, had a higher RSE and lower pseudo R^2 than white and scarlet oak species, but it may provide a useful tool for determining height for aggregated groups of oaks.

Table 2A. Summary of dbh and height statistics for each species group.

		dbh (in.)				ht (ft)			
Species Group	*N*	Mean	SD	Min	Max	Mean	SD	Min	Max
Flowering dogwood	647	1.3	1.13	0.1	6.1	12	6.36	5	43
Shortleaf pine	990	11.2	3.72	4.0	28.9	66	14.25	21	113
Red maple	186	0.9	0.99	0.1	6.0	12	9.23	5	61
Hickory	279	4.0	3.67	0.1	25.6	29	20.38	5	91
Pignut hickory	91	3.3	2.88	0.1	16.1	26	16.40	5	76
Black hickory	88	3.7	4.20	0.1	25.6	25	16.95	5	65
Mockernut hickory	81	3.1	2.74	0.1	14.7	23	16.50	5	80
Bitternut hickory[a]	19	8.7	2.06	5.8	13.1	65	6.93	57	78
Upland Oak (Composite)	7,758	10.2	4.42	0.1	35.8	64	17.51	5	128
White oak	2,881	8.6	4.31	0.1	35.8	56	17.50	5	109
Scarlet oak	2,516	11.0	4.19	0.1	33.0	70	16.32	5	116
Black oak	2,288	11.5	4.18	0.1	27.7	68	14.21	5	114
Blackjack oak[a]	28	9.2	2.79	5.3	15.7	43	8.93	26	62
Chinkapin oak[a]	45	6.9	1.86	4.6	12.0	44	12.38	21	67

[a]Too few observations for a separate species-specific equation. Use composite equation.

Table 2B. Coefficients for the fitted Equation (1) to predict height (ft) from diameter at breast height (in.) for each species group. *RSE* is the residual standard error (ft) and the R^2 is a puedo-R^2 as described in the text.

Species or group	*N*	b_0	b_1	b_2	*RSE*	R^2
Flowering dogwood	647	2.9876	-1.0111	-1.2462	3.2	0.75
Shortleaf pine	990	4.6189	-5.9256	-1.0645	8.9	0.62
Red maple	186	8.0535	-5.9141	-0.2000[a]	3.2	0.88
Pignut hickory	91	4.3756	-3.0539	-0.8358	6.2	0.86
Black hickory	88	4.2136	-2.8050	-0.8743	4.8	0.92
Mockernut hickory	81	4.5333	-3.2153	-0.7138	6.6	0.84
Hickory	279	4.5456	-3.3358	-0.7915	7.1	0.88
White oak	2,881	4.5024	-5.0009	-1.0845	8.1	0.75
Scarlet oak	2,516	4.5004	-9.1643	-1.4756	8.9	0.66
Black oak	2,288	4.3702	-13.0002	-1.8022	9.4	0.56
Upland Oak	7,758	4.5409	-6.7095	-1.2405	9.5	0.70

[a] b_2 was constrained at -0.2 for red maple as equation (1) failed to converge.

Fit statistics for the hickories are much better than the oak species. However, with many fewer observations than the oaks, caution should be taken when comparing the fits of these two species groups. Pseudo R^2 values for the hickories are all relatively high, over 0.84 for each hickory species and for the aggregate hickory group, including all listed hickories and bitternut .

Fit statistics for shortleaf pine, the only conifer in the group, were similar to the oak species listed, with a RSE of 8.9 ft and a pseudo R^2 of 0.62. Flowering dogwood had the smallest RSE, 3.2 ft. However, this is due to the fact that dogwood also has the smallest range of diameters and heights. Flowering dogwood does not typically reach the canopy in mature Missouri Ozark forests. The nonlinear regression of red maple failed to converge for equation (1) because coefficient b_1 and b_2 were highly correlated. When b_2 was constrained to -0.2 for red maple, the remaining parameters were readily obtained, and the resulting model had a pseudo R^2 of 0.88 and RSE of 3.2 ft. For all species, the fitted model coefficients are similar in sign and magnitude to those developed for other species and geographical regions (Larsen and Hann 1987, Colbert et al. 2002).

Although the model does a good job of predicting the mean height-diameter trend for each species, tree heights for a given diameter were highly variable in the data. For example, white oak trees with diameters of approximately 20-inches ranged from about 50 to 90 feet in height. The model, which predicts the mean tree height (e.g., 80 ft for a 20-inch white oak), tends to obscure this variability. In situations where it is desirable to retain the variation in estimated heights, a random component based on the root mean square error can be added to the model estimate so estimates vary within the 95 percent confidence bounds:

$$H \pm 1.96(RSE) \tag{3}$$

It is generally advisable to apply these equations only over the range of the observed diameters (Table 2A). With the exception of red maple, all species approach reasonable maximum tree heights for diameters greater than 30 inches. At large diameters the oak tree heights level out at 80 to 95 feet, the hickories reach 75 to 90 feet, shortleaf pine reaches nearly 100 feet, and dogwood tops out at 24 feet. The equation for red maple is based only on trees less than 6 inches in diameter, and when extrapolated to larger diameters modeled red maple heights are unreasonably large (Figures 2A-2K). Although in other mesic and hydric ecosystems red maples can reach much larger diameters and heights, in these upland Ozark ecosystems red maples typically remain small trees that are restricted in size by droughty conditions.

Conclusions

The height-diameter equations presented here can be used to obtain height estimates for trees for which height was not measured. The equations produced estimates that are consistent with biological expectations for each species group and well constrained for trees with very small and very large diameters. The fitted model is suitable for application within the range of the fitted data for each species and it produces reasonable estimates when extrapolated to various diameters. The model is relatively easy to apply to a wide variety of inventory, modeling, projection, silvicultural and wildlife settings. With as little information as tree species and dbh – heights can be estimated to provide additional information to practitioners on tree volume and stand characteristics such as vertical structure.

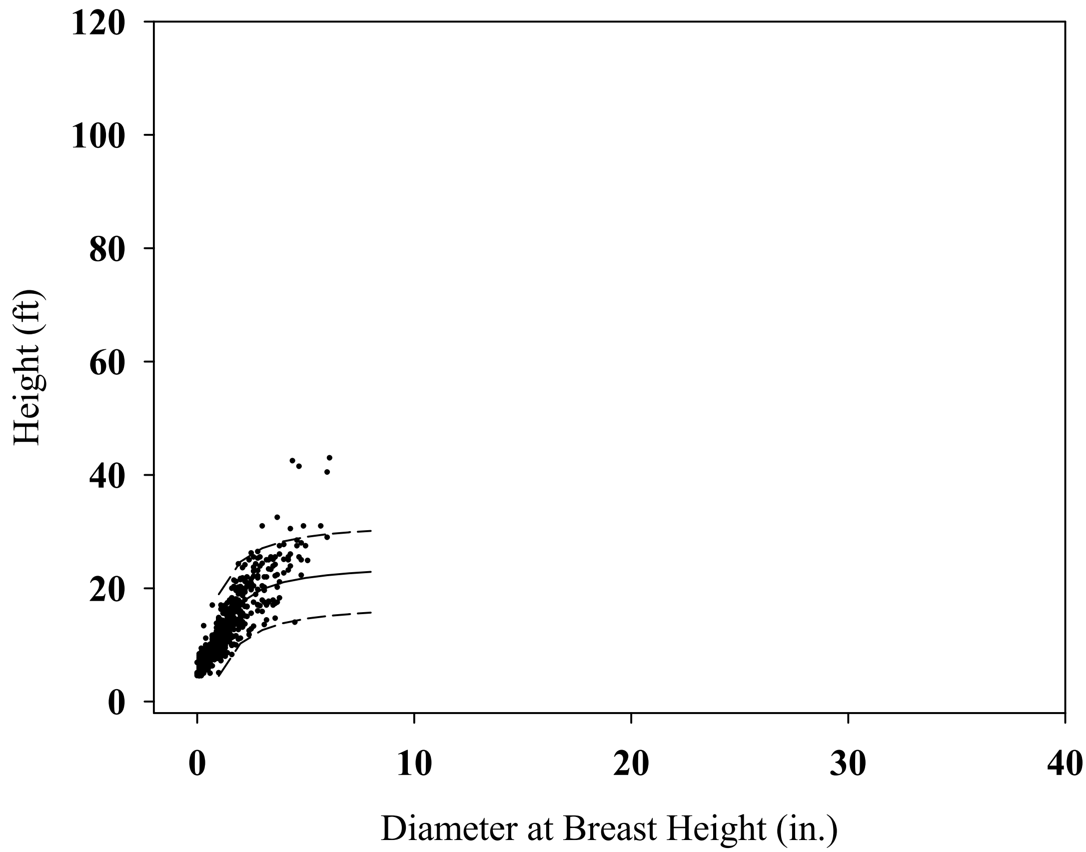

Figure 2A. Height-diameter curves for flowering dogwood (*Cornus florida* L.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

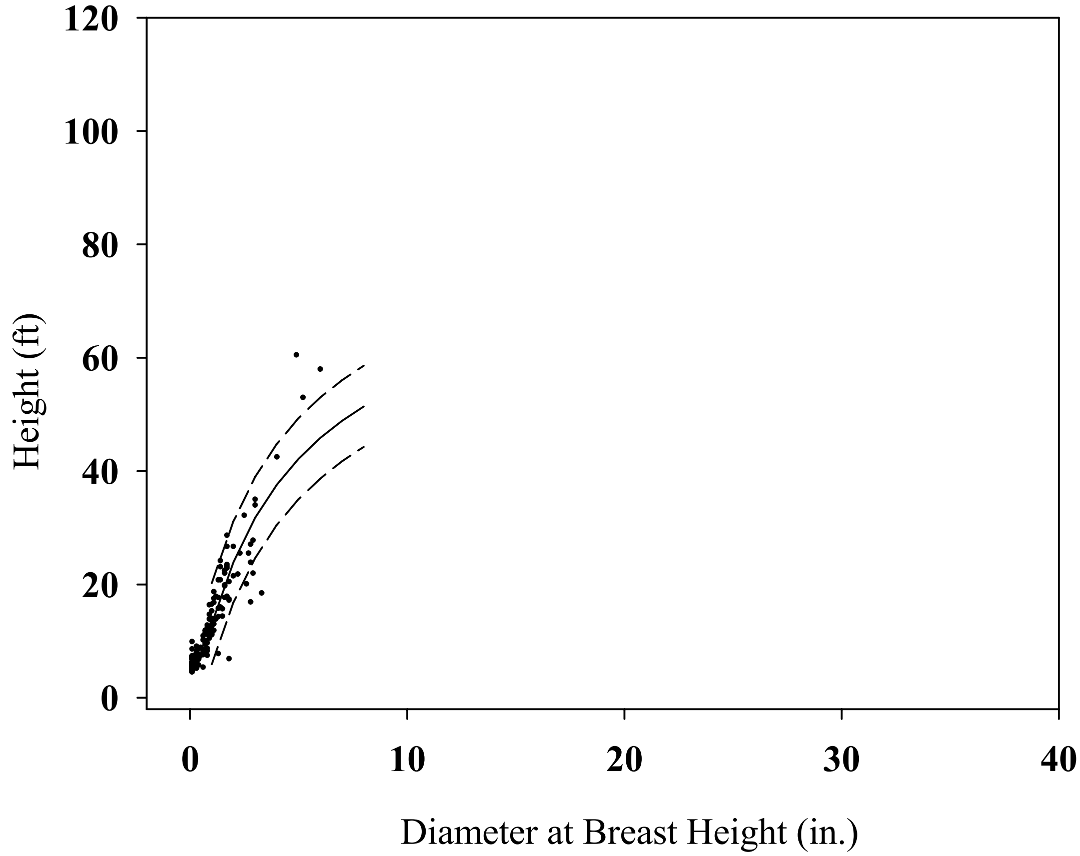

Figure 2B. Height-diameter curves for red maple (*Acer rubrum* L.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

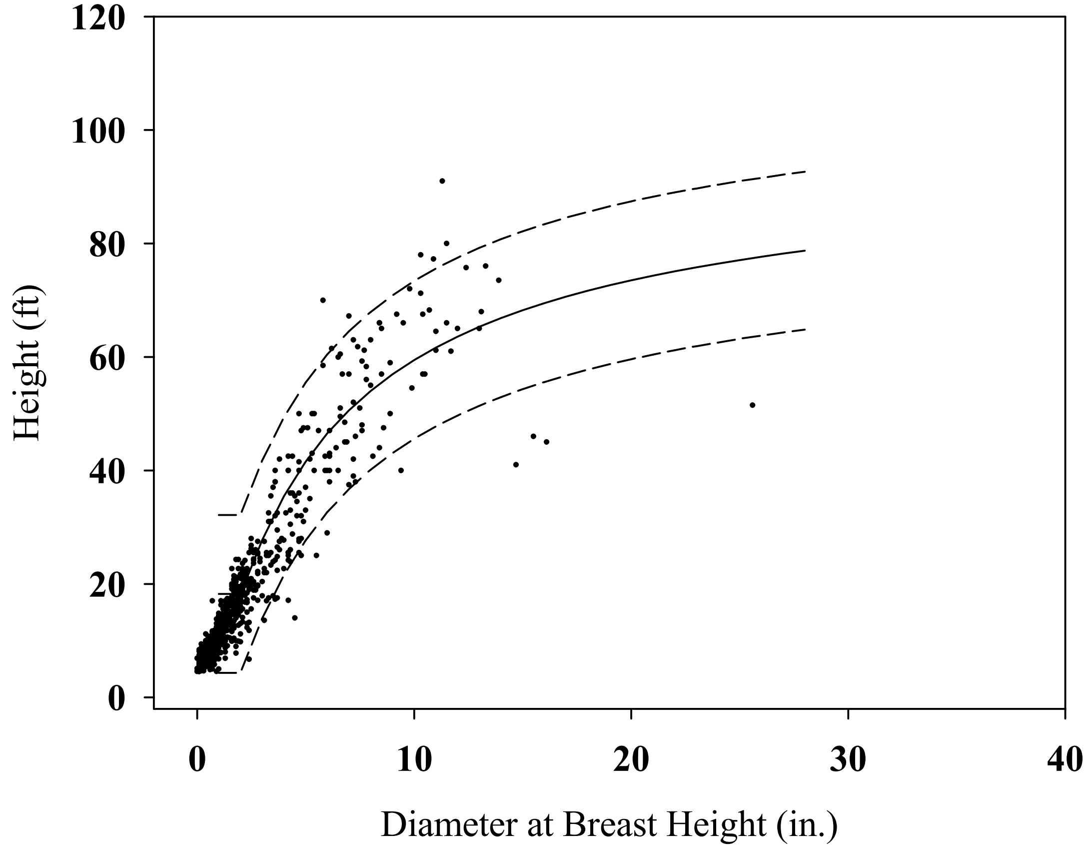

Figure 2C. Height-diameter curves for hickory (composite) (*Carya spp.)*. The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

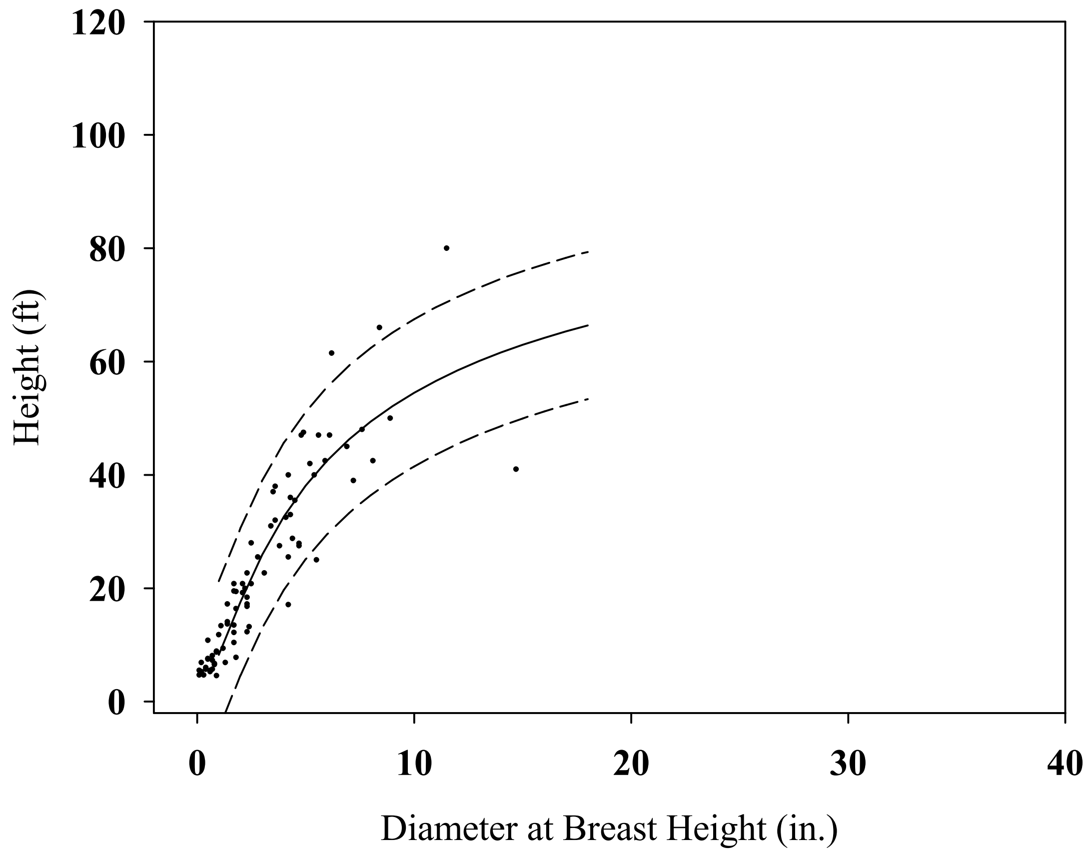

Figure 2D. Height-diameter curves for mockernut hickory (*Carya tomentosa* Nutt.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

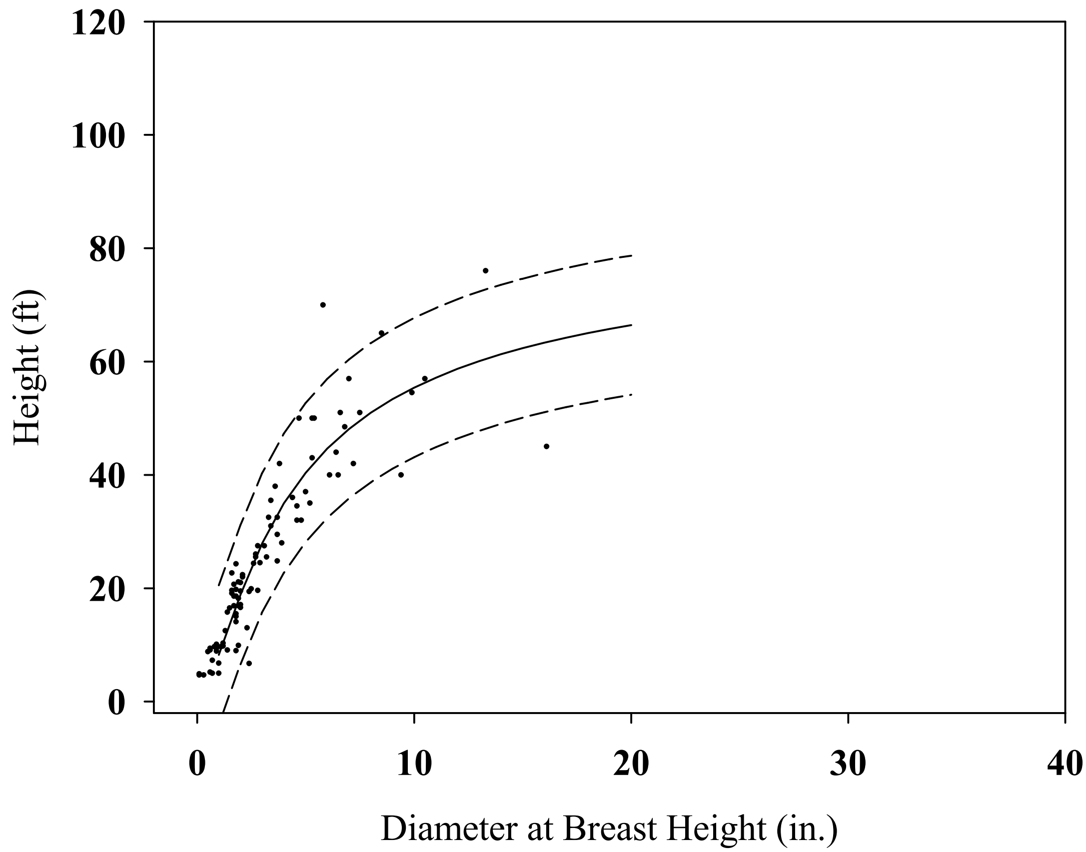

Figure 2E. Height-diameter curves for pignut hickory (*Carya glabra* (Mill.) Sweet). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

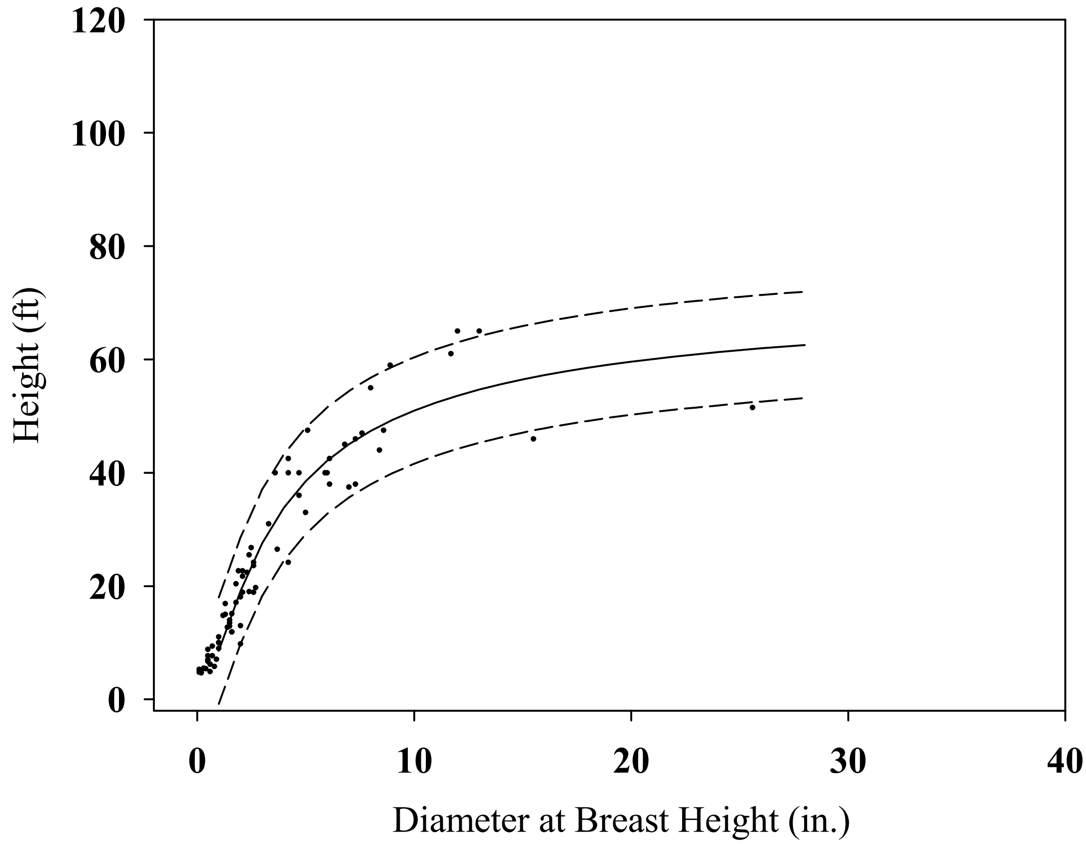

Figure 2F. Height-diameter curves for black hickory (*Carya texana* Buckl.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

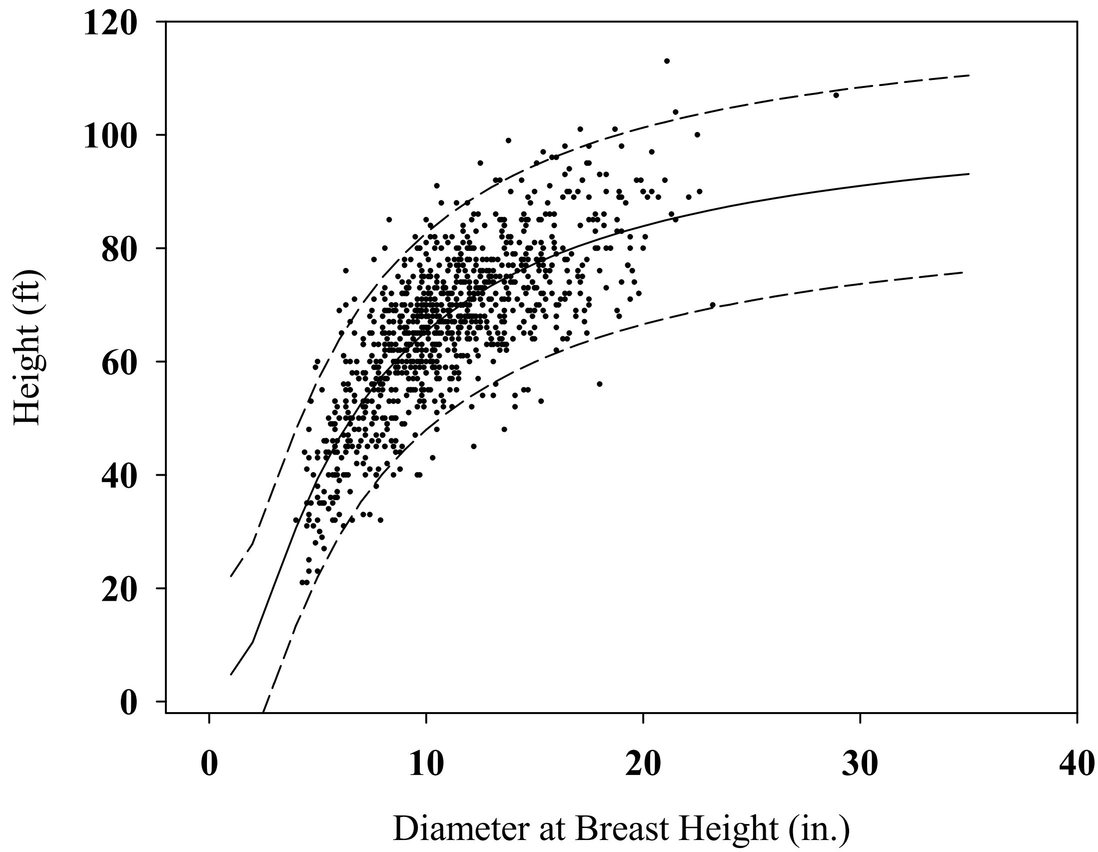

Figure 2G. Height-diameter curves for shortleaf pine (*Pinus echinata* Mill). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

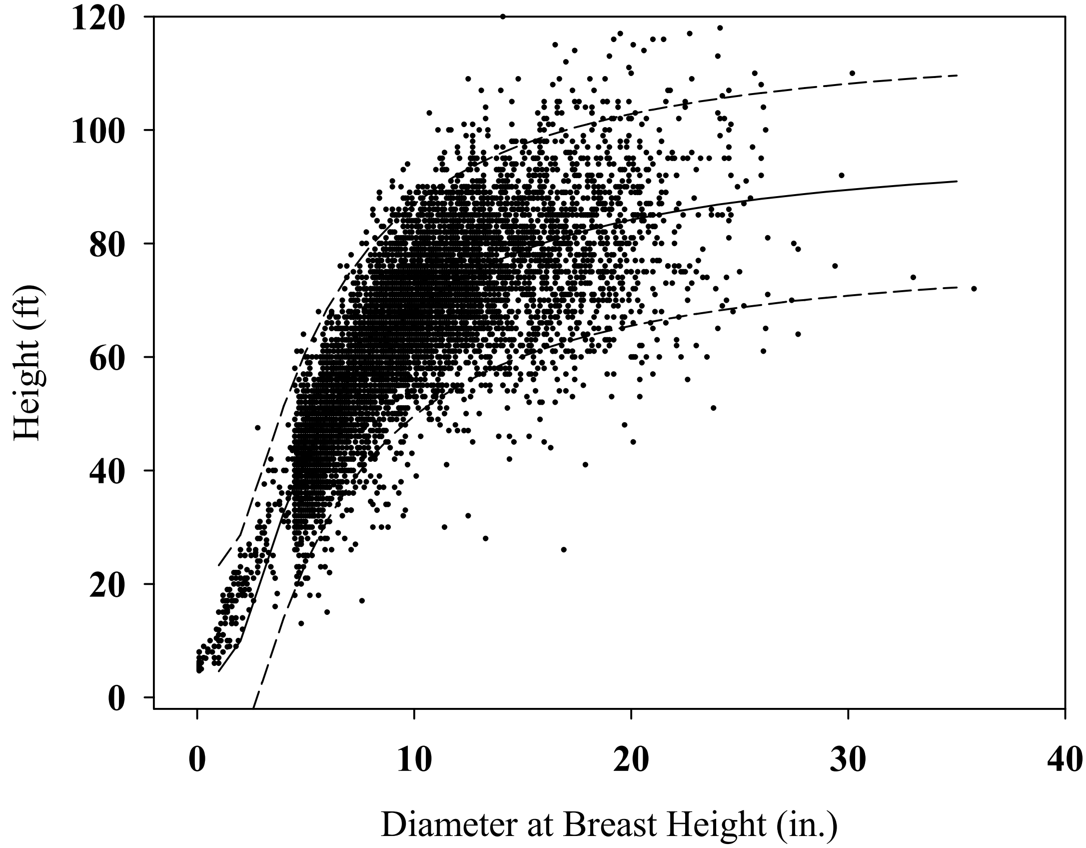

Figure 2H. Height-diameter curves for upland oaks (*Quercus spp.)*. The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

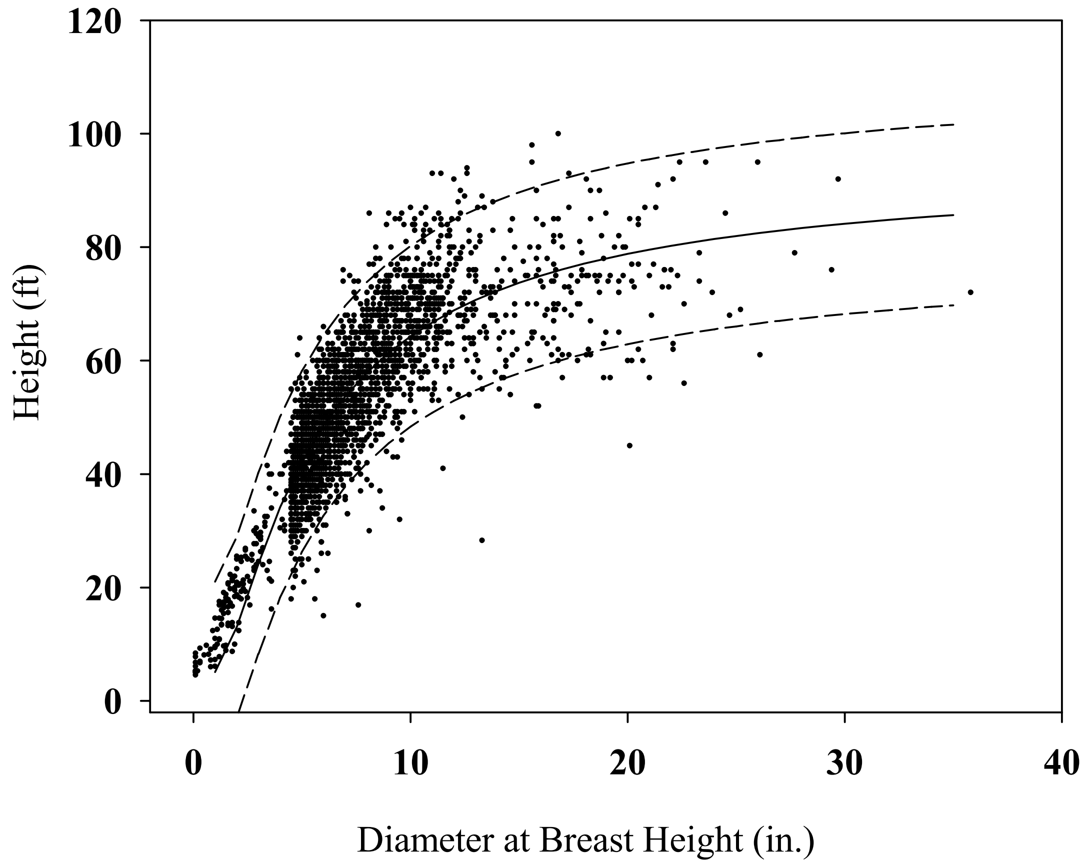

Figure 2I. Height-diameter curves for white oak (*Quercus alba* L.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

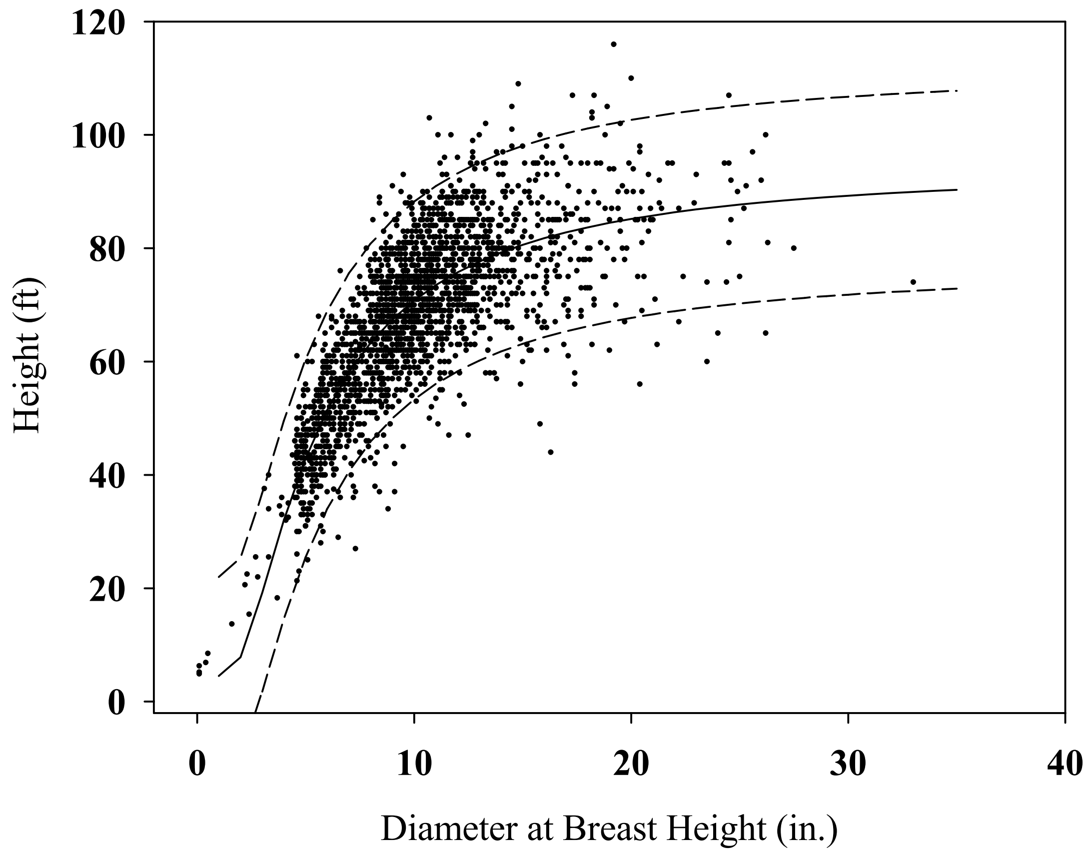

Figure 2J. Height-diameter curves for scarlet oak (*Quercus coccinea* Muenchh.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

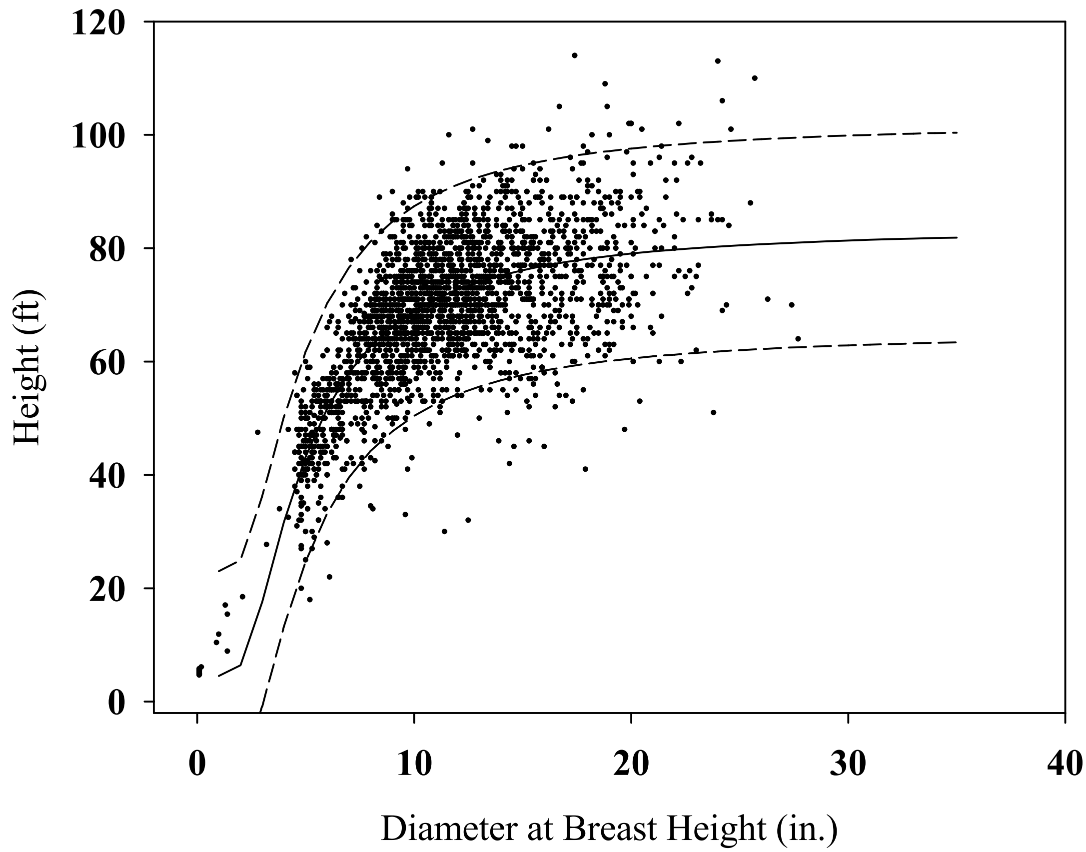

Figure 2K. Height-diameter curves for black oak (*Quercus velutina* Lam.). The prediction equations (solid lines) and the 95% confidence limits (dashed lines) are plotted over the observed data.

AN EVALUATION OF THE GROWTH AND MORTALITY FUNCTIONS IN THE CENTRAL STATES VARIANT OF FVS: THE FOREST VEGETATION SIMULATOR

Introduction

Forest managers must consider both the short-term and the long-term effects of management activities. For stand-level management they rely on stand history, current stand conditions, and quantitative tools such as growth and yield models that forecast future stand conditions. The accuracy and precision of these models must be appropriate for their intended use. Ideally, the models will perform well for the current and future species mix and the array of site conditions presented on the forest landscape.

In the state of Missouri, the forest growth model most commonly used by federal and state agencies is some form of Central States TWIGS (CS-TWIGS) (Miner et al. 1988). CS-TWIGS is based on the mainframe program STEMS (Holdaway and Brand 1983), developed by the North Central Forest Experiment Station of the USDA Forest Service. Descriptions of the component models and their species-specific coefficients are found in Shifley (1986) and Miner et al. (1988).

The Forest Service has adopted a standard growth and yield system, the Forest Vegetation Simulator (FVS) to implement individual-tree, distance independent models, including the variants of TWIGS. The FVS growth and yield model application framework was derived from the Prognosis model developed for the Inland Empire of Idaho and Montana (Stage 1973, Wykoff et al. 1982). During the 1980's and 90's, the Forest Service began the task of standardizing growth and yield models across the nation by creating "geographic variants" of FVS. CS-TWIGS 3.0 was placed into the FVS framework and became the Central States Variant of FVS (CS-FVS). FVS has a wide range of tools and reporting options that greatly simplify the implementation of individual-tree-based growth models. (Crookston 1997, Vandendriesche 2002)

Evaluation of a growth and yield models encompasses three broad areas: the application environment, the biological and ecological relationships embedded in the component models (i.e. the "bio-logic"), and the statistical accuracy and precision (Buchman and Shifley, 1982). The FVS software has evolved over decades and provides a versatile application environment (Dixon 2004). The biological relationships embedded in the STEMS/TWIGS models are well documented and have endured for roughly 20 years (USDA Forest Service 1979, Holdaway and Brand 1983). Greater availability of remeasured plot data and newer statistical techniques could be used to revise or embellish the basic growth and mortality models—particularly with regard to site quality and ecological land types. Nevertheless the general ecological relationships embedded in the models are sound. This study focuses on a statistical analysis of the accuracy and precision of model estimates when compared to short- and long-term observations of tree and stand change.

A few prior studies have evaluated the predictions of the CS-TWIGS models. Kowalski and Gertner (1989) determined that CS-TWIG produces acceptable results for Illinois forests. Wang (1997) evaluated CS-TWIGS using a smaller sub-sample of the data set used in this study. He determined that for a relatively short period (15 years), CS-TWIGS was "generally adequate."

The current study evaluates the accuracy and precision of the CS-TWIGS model estimates relative to observed of tree and stand change over time. This study differs from previous investigations of the performance of CS-TWIGS or CS-FVS in its (1) focus on the heavily forested Ozark Highland region, (2) evaluation of change in a forest managed with uneven-aged silviculture, (3) comparisons of observed and predicted changes over periods up to 40-years in duration, and (4) test of the gains from the FVS self-calibration capabilities.

Data

Data used to evaluate CS-FVS comes from the Pioneer Forest, a privately owned, 156,000-acre forest located in the Missouri Ozark Highlands. (Loewenstein et al. 1995, Pioneer Forest 2004). A Continuous Forest Inventory (CFI) system was installed in 1952. The number of permanent, 0.2 acre CFI plots was doubled in 1957; one plot was installed for every 320 acres on the forest. The plots have been remeasured every five years, recording tree measurements and mortality for all trees five inches and larger. All ingrowth stems at the five-inch dbh threshold were recorded and given new permanent identification numbers. Due to land exchanges, some plots were relocated, or renumbered between the periods of 1952-1997.

By 1954, the Pioneer Forest was approximately 90,000 acres. As a stipulation of the sale, the previous owner, National Distillers was permitted to continue removing any 16-inch or larger white oaks from the property. This practice continued until the early

Table 3A. Species and species groups used in evaluation of all simulations.

Group[1]	Common Name	Scientific Name
White oak	White oak	*Quercus alba* L
Black oak	Black oak	*Quercus velutina* Lam.
Shortleaf pine	Shortleaf pine	*Pinus echinata* Mill
Hickory[2]	Shagbark hickory	*Carya ovata* (Mill.) K. Koch
	Mockernut hickory	*Carya tomentosa* Nutt.
	Bitternut hickory	*Carya Cordiformis* (Wangenh.) K. Koch
	Pignut hickory	*Carya glabra* (Mill.) Sweet
	Black hickory	*Carya texana* Buckl.
Scarlet oak	Scarlet oak	*Quercus coccinea* Muenchh.
Red oak	Northern red oak	*Quercus rubra* L.
	Southern red oak	*Quercus falcata* Michx.
Post oak	Post oak	*Quercus stellata* Wangenh.
Blackjack oak	Blackjack oak	*Quercus marilandica* Muenchh.
Chinkapin oak	Chinkapin oak	*Quercus meuhlenbergii* Engelm.
	Bur oak	*Quercus macrocarpa* Michx.
Tupelo	Blackgum	*Nyssa sylvatica* Masrh.
Elm	Winged Elm	*Ulmus alata* Michx.
	American Elm	*Ulmus americana* L.
	Slippery Elm	*Ulmus rubra* Muhl.
White & Green ash	White ash	*Fraxinus americana* L.
	Green ash	*Fraxinus pennsylvanica* March.

[1]Species groups from Miner et al 1988.
[2]Pioneer Forest inventory does not distinguish between hickory species, but supporting documentation indicates the species listed are present on the forest. All hickories were coded as “hickory spp.,” a member of the “other hickory” group. Model coefficients for all hickories are identical in CS-FVS.

1960's. Most of the Pioneer Forest has since been managed under single-tree-selection. More information on the management of the Pioneer Forest can be found in Loewenstein (1996) and Pioneer Forest (2004).

Methods

Simulations

Simulations were run for two different time periods, 10-years and 40-years. For 10-year simulations, plots and remeasurements deemed to be free of errors and measured consistently over the 10-year period were pooled. Plots and measurement years were randomly selected to comprise the validation set. A total of 244 plots were selected for the 10-year simulations. For the 40-year simulations, plots were evaluated for the presence of errors, and consistent measurement throughout the 40-year period from 1957-1997. A total of 145 plots were selected for the 40-year simulations. Land exchanges and movement of plots limited the number of plots available for this relatively long time period of 40 years.

For all simulations, actual harvest removals were tracked and reproduced during testing. The cycle length, or time between projections for all simulations is ten years. Ten year projections consisted of one cycle, and 40-year projections had four cycles. Trees that were actually cut on a CFI plot were simulated to be harvested at the beginning of the cycle. IPRSC (short-run prescription recommendation) (Dixon 2004) codes were assigned to all trees. These codes indicate a cycle for tree removal, if required. The THINPRSC keyword (Van Dyck 2005) was used to schedule removals.

CS-FVS contains only a “partial establishment model” to simulate regeneration (Dixon 2004). The only modeled form of natural regeneration is stump sprouting. By default, a proportion of stems harvested will sprout, given they are in a species group that is considered to sprout (Bush 1995). In order to be able to directly compare simulated results with observed tree- and plot-level statistics from the subsequent inventories, the NOAUTOES keyword was used to disable stump sprouting.

To create stochasticisity in model output, by default CS-FVS “triples” the tree records in a tree file every cycle, and distributes the corresponding expansion and mortality factors to the “tripled” records (Dixon 2004). Again, to permit tree- and plot-level comparisons with later inventories and to be able to model removal of the trees that were harvested, the NOTRIPLE keyword was used in all projections.

In addition to the two time periods used for simulations, two levels of information were used to evaluate the model. Initial simulations were conducted using dbh, species and tree status information. In subsequent simulations, periodic diameter increment (DG) values were supplied for each of the time periods (INCR) and used to modify projections based on observed tree growth rates. DG was entered as the dbh of a tree from the inventory performed ten years after the initialization time of the model. If DG is provided for five or more trees of a species, the model for that species will be calibrated (Dixon 2004). Additionally, for each time period, the model was run with no incremental calibration information (NoINCR). The number of plots that had sufficient numbers of trees for calibration by species is shown in Tables 3R and 3S for ten and forty years, respectively.

Models were run using the Suppose user interface (Crookston 1997), and CS-FVS version 6.21. Tree files were aggregated by total simulation length, amount of information used to evaluate the model, and initialization time. Tree- and stand-level attributes were output for every cycle.

Validation Statistics

The three tree- and stand-level characteristics used were diameter at breast height (dbh), trees per acre (TPA), and stand basal area (BA). These three values have been used in other evaluations of FVS-, TWIGS-, and STEMS-based models routinely (Holdaway and Brand 1983, Canavan and Ramm 2000, and Kowalski and Gertner 1989). Dbh predictions evaluate the large-tree growth and competition models of CS-FVS. TPA evaluates the mortality model – its effectiveness at modeling stand competition. Finally, basal area combines the growth and mortality output – to provide an overall evaluation of the model's performance.

Model errors were characterized by mean error. In order to express the mean error of the model characteristics in the same sign as the bias, the error form of predicted – observed, or ($\hat{y}_i - y_i$) was used, as opposed to ($y_i - \hat{y}_i$).

Trees that were present at both the time of initialization and at the end of all cycles, or surviving trees, were used to evaluate diameter growth prediction for individual trees. Trees were aggregated by species groups (Miner et al. 1988) and three-inch diameter class (5.0-7.9, 8.0 – 10.9, 11.0 – 13.9, and 14.0 and larger).

TPA and BA were evaluated at the plot level for surviving trees. TPA estimates for the "predicted" values were the summation of the model output TPA for a plot after ten or forty years. “Observed” TPA values were the count of surviving trees, multiplied times the trees per acre expansion factor of five. Basal area was calculated in a similar fashion, using the model output, or inventory values at the end of the simulation, multiplied by the appropriate expansion factor.

One-tailed t-tests ($\alpha = 0.5$) were conducted for dbh, BA, and TPA to determine if mean prediction errors were statistically smaller for INCR simulations, as opposed to NoINCR. As the sign of the mean errors may have been different (e.g. INCR simulations may have yielded an overprediction, while NoINCR an underprediction), the absolute value of the error was used. T-tests evaluated the following: H_0: $\mu\{|\text{NoINCR}| - |\text{INCR}|\} \leq 0$; H_A: $\mu\{|\text{NoINCR}| - |\text{INCR}|\} > 0$. Where NoINCR is mean prediction error for NoINCR and INCR is mean prediction error for INCR. Tests were conducted between INCR and NoINCR for both ten- and forty-year simulation lengths.

Results

Diameter Growth

Ten-Year Simulations

For ten-year simulations, twelve species groups (Miner et al. 1988) having 50 or more trees were selected for analysis. All trees, regardless of species group were pooled for the aggregated diameter class results. CS-FVS overpredicted diameter growth for a single, ten-year cycle for all species groups in the 5.0 – 7.9 inch diameter class. Overprediction was significantly different from zero ($\alpha = 0.05$) for all species groups, except hickory and chinkapin oak for the INCR simulations in the smallest diameter class

(Table 3B). For NoINCR simulations, all overpredictions were significantly different from zero (Table 3C). Figure 3A shows graphically the relationship between predicted and observed diameters for both INCR and NoINCR.

For the 8.0 – 11.9 inch diameter class, fewer species mean errors were significantly different from zero. While the INCR simulations had a mixture of over and underpredictions, five species groups' mean prediction errors were different from zero, NoINCR simulations were predominantly overpredictions and half of the species groups were significantly different from zero. In aggregate, the 8.0 – 11.9 inch diameter class for both INCR and NoINCR were signifigantly different than zero, with an underprediction for INCR, and overprediction for NoINCR.

For the two largest diameter classes, 11.0 - 13.9 inches and 14 inches and larger, the sign and magnitude of prediction errors were mixed, though the NoINCR simulation tended toward overprediction. Fewer species groups/diameter class combinations were significantly different from zero. This is likely due to the smaller number of observations in these categories. Standard deviation values for prediction errors are presented in Table A1-1 in Appendix A for ten-year INCR simulations, and Table A1-2 for ten-year NoINCR simulations. Figure 3B illustrates the mean diameter prediction errors for four species of interest: white oak, shortleaf pine, hickory, and black oak.

As was found with other TWIGS-based variants of FVS (Canavan and Ramm 2000), including diameter increment information, as in the INCR simulations, generally improves diameter growth prediction. For most species and diameter classes, mean prediction errors were smaller for the INCR simulations, when evaluated with a one-tail t-test ($\alpha = 0.05$) (Table 3D). Aggregating all diameter classes for individual species groups, mean prediction errors for INCR simulations were smaller for all groups except elm. INCR mean prediction errors were smaller for all trees when examining only diameter class, with P values ranging from < 0.0001 to 0.021.

Forty-Year Simulations

For forty-year simulations, eight species groups (Table 3A) having 25 or more trees were selected for analysis (Table 3E). Again, all trees, regardless of species group were pooled for the aggregate diameter class results. In the 5.0 – 7.9 inch diameter class, INCR generally overpredicted mean diameter by species, or mean errors were not significantly different from zero ($\alpha = 0.05$). One notable exception was white oak. White oak in the smallest diameter class showed an average underprediction of 0.49 inches, which was shown to be significantly different from zero. As shown in Figure 3C, the variation is observed and predicted diameters was greater for the 40-year than the 10 year simulations (Figure 3A). NoINCR simulations (Table 3F) resulted in a mean prediction error of -0.18, which was not significantly different from zero. Overall results for the 5.0 – 7.9 inch diameter class show that both simulations produce an overestimation of diameter, 0.26 and 0.55 inches for INCR and NoINCR respectively. Both values were different than zero.

In the 8.0 – 11.9 inch diameter class for INCR, only two species prediction errors were significantly different from zero: white oak, with an underprediction, and hickory was overpredicted. Hickory also showed a signifigant overprediction in NoINCR simulations. For all species groups in this diameter class, mean dbh errors were not different from zero for the INCR simulations. The NoINCR simulations had a significant overprediction of 0.42 inches for the 8.0 – 11.9 inch diameter class.

In the two largest diameter classes, none of the mean dbh errors were significantly different from zero for the INCR simulations, and only white oak overprediction was significant in both classes for NoINCR. When aggregating all species in the two largest diameter classes, only the NoINCR simulations yielded mean prediction errors that were significantly different than zero. Figure 3D presents the mean diameter increment errors for both levels of information for four species of interest.

Table 3G shows P-values for the one-sided t-test ($\alpha = 0.05$) of forty-year diameter predictions. Mean prediction errors were found to be statistically smaller for the three smallest diameter classes for all species for INCR, when aggregated, as well as the grand mean or all trees analyzed. INCR mean errors were also smaller for the following species groups: white oak, shortleaf pine, hickory, red oak, and chinkapin oak.

Trees Per Acre

Ten-Year Simulations

Results of the ten-year TPA analyses are shown in Tables 3H and 3I for INCR and NoINCR, respectively. Mean errors (bias) for all species groups were significantly different from zero. Values are based on plot-level bias, and are expressed in number of trees per acre. The smallest bias for both groups was white oak. Mean errors for INCR simulations were not significantly different from NoINCR simulations for any species groups, or the aggregated all species group. Mean errors for NoINCR were smaller or equal to INCR errors for all species groups but one – though none were significantly different. Figure 3E presents the observed number of trees per acre, and the predicted values for both INCR and NoINCR ten year simulations.

Fory-Year Simulations

Forty-year results for TPA were similar to the ten-year results, in that all species groups yielded overpredictions. White oak again had the smallest bias for both INCR and NoINRC.   All species groups' biases were significantly different from zero. Mean errors were smaller for all species groups in the NoINCR simulations. NoINCR mean errors were statistically smaller ($\alpha = 0.05$) for all species but shortleaf pine and red oak. One-tailed t-test P values ranged from 0.0032 – 0.2932, with the "all species" group having a P-value of 0.0103. The forty-year observed number of trees per acre, and the predicted values for both INCR and NoINCR simulations are shown in Figure 3F.

Basal Area

Ten-Year Simulations

Mean errors for all species groups with more than 75 plot observations are presented in Tables 3L and 3M for INCR and NoINCR, respectively. Basal area was overpredicted for all species groups in both simulations, and all biases were significantly different from zero ($\alpha = 0.05$). Figure 3G presents the observed basal area per acre, and the predicted values for both INCR and NoINCR ten year simulations. Table 3N presents P values for a one-sided t-test, evaluating the null hypothesis: H_0: $\mu\{|NoINCR| - |INCR|\}$

Table 3B. Mean dbh errors (inches) in 10 years by species and diameter class for INCR projections. Positive values are over predictions.

Species Group[1]	No. of Trees[1]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes	dbh Incr[3]
White Oak	822	0.16*	-0.15*	-0.03	0.01	0.01	1.3
Black Oak	760	0.18*	-0.06*	-0.15*	-0.16*	-0.02	1.6
Shortleaf Pine	655	0.26*	-0.04	0.03	-0.33*	0.07*	1.2
Hickory	536	0.13	0.09	0.04	-0.17	0.09*	0.8
Scarlet Oak	520	0.27*	-0.09*	-0.09	-0.09	0.01	1.7
Red Oak	287	0.30*	-0.03	-0.10	-0.16	0.00	1.7
Post Oak	217	0.11*	0.01	0.09*	-0.19	0.05	0.8
Blackjack Oak	85	0.22*	0.17*	0.05	-0.10	0.17*	1.6
Chinkapin Oak	59	0.11	0.08	0.45*	0.33*	0.17*	0.8
Tupelo	59	0.24*	0.09	0.25*	0.12	0.17*	0.5
Elm	55	0.53*	0.22	0.83*	0.53	0.48*	0.9
White & Green Ash	51	0.68*	0.58*	0.22	0.80	0.60*	0.7
All[2]	4256	0.23*	-0.03*	-0.03	-0.10*	0.06*	1.3
Percent trees in diameter class		37	38	17	9	100	

[1]Species with fewer than 50 observations have been omitted
[2]Include species with fewer than 50 observations
[3]Average ten year diameter increment for all trees in the species grou
*Mean error is different from zero ($\alpha = 0.05$)

Table 3C. Mean dbh errors (inches) in 10 years by species and diameter class for NoINCR projections. Positive values are over predictions.

Species Group	No. of Trees[1]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes	dbh Incr[3]
White Oak	822	0.20*	-0.17*	-0.01	0.07	0.02	1.3
Black Oak	760	0.30*	-0.04	-0.09	-0.04	0.05*	1.6
Shortleaf Pine	655	0.57*	0.12*	0.17*	-0.17	0.28*	1.2
Hickory	536	0.21*	0.15*	0.19*	-0.10	0.17*	0.8
Scarlet Oak	520	0.36*	0.07	0.03	0.01	0.14*	1.7
Red Oak	287	0.38*	0.02	0.04	-0.08	0.09*	1.7
Post Oak	217	0.17*	0.10*	0.15*	-0.15	0.12*	0.8
Blackjack Oak	85	0.26*	0.25*	0.20*	0.20	0.24*	1.6
Chinkapin Oak	59	0.17*	0.14	0.50*	0.31*	0.22*	0.8
Tupelo	59	0.24*	0.09	0.25*	0.12	0.17*	0.5
Elm	55	0.62*	0.29	0.81*	0.53	0.54*	0.9
White & Green Ash	51	0.87*	0.84*	0.22*	0.80*	0.78*	0.7
All[2]	4256	0.34*	0.04*	0.06*	-0.01	0.15*	1.3
Percent trees in diameter class		37	38	17	9	100	

[1]Species with fewer than 50 observations have been omitted
[2]Include species with fewer than 50 observations
[3]Average ten year diameter increment for all trees in the species grou
[*]Mean error is different from zero (α = 0.05)

Table 3D. P Values for one-sided t-test of ten-year diameter predictions ($\alpha = 0.05$). H_0: $\mu\{|NoINCR| - |INCR|\} \leq 0$; H_A: $\mu\{|NoINCR| - |INCR|\} > 0$. Where |NoINCR| is absolute value of the diameter prediction error for NoINCR and |INCR| is absolute value of the diameter prediction error for INCR. **Bold** values indicate a rejection of H_0.

Species Group	No. of Trees[1]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	822	**0.000**	**0.000**	0.290	**0.021**	**0.001**
Black Oak	760	**0.000**	**0.016**	**0.019**	0.240	**0.000**
Shortleaf Pine	655	**0.000**	**0.000**	0.176	0.790	**0.000**
Hickory	536	**0.000**	**0.008**	**0.022**	0.195	**0.000**
Scarlet Oak	520	**0.000**	**0.000**	**0.012**	0.089	**0.000**
Red Oak	287	**0.000**	**0.003**	**0.011**	0.202	**0.000**
Post Oak	217	**0.008**	**0.006**	**0.007**	**0.041**	**0.000**
Blackjack Oak	85	0.500	**0.004**	0.439	#	**0.017**
Chinkapin Oak	59	0.238	**0.020**	0.204	0.822	**0.020**
Tupelo	59	#	0.082	#	0.166	**0.042**
Elm	55	0.207	0.139	0.822	#	0.109
White & Green Ash	51	**0.004**	**0.040**	#	#	**0.001**
All[3]	4256	**0.000**	**0.000**	**0.000**	**0.021**	**0.000**
Percent trees in diameter class		37	38	17	9	100

[1]Species with fewer than 50 observations have been omitted
[2]Include species with fewer than 50 observations
[#]Fewer than five trees were present for this species in any plot where a tree of this species occurred in this diameter class. Therefore, simulation results were identical between simulation levels.

Table 3E. Mean dbh errors (inches) in 40 years by species and diameter class for INCR projections. Positive values are over predictions.

		Diameter Class (inches)					
Species Group	No. of Trees[1]	5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes	dbh Incr[3]
White Oak	230	-0.49*	-0.43*	0.51	0.84	-0.35*	5.3
Shortleaf Pine	223	0.62*	0.18	-0.02	--	0.50*	4.8
Hickory	205	0.45*	0.66*	-0.60	1.10	0.47*	3.2
Post Oak	114	-0.09	-0.33	0.04	0.90	-0.14	3.5
Black Oak	97	-0.09	-0.31	-0.20	-0.60	-0.16	6.4
Red Oak	82	0.35	-0.95	0.00	0.90	-0.06	6.7
Chinkapin Oak	26	0.21	-0.05	-0.13	2.60	0.17	3.0
Scarlet Oak	26	0.06	-0.60	-5.50	-2.70	-0.35	7.1
All[2]	1078	0.26*	0.03	0.22	0.68	0.20*	4.7
Percent trees in diameter class		67	25	6	1	100	

[1]Species with fewer than 25 observations have been omitted
[2]Include species with fewer than 25 observations
[3]Average forty year diameter increment for all trees in the species grou
*Mean error is different from zero ($\alpha = 0.05$)

Table 3F. Mean dbh errors (inches) in 40 years by species and diameter class for NoINCR projections. Positive values are over predictions.

Species Group	No. of Trees[1]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes	dbh Incr[3]
White Oak	230	-0.18	0.33	1.29*	1.24*	0.12	5.3
Shortleaf Pine	223	1.01*	0.28	0.23	--	0.82*	4.8
Hickory	205	0.63*	0.85*	-0.43	-0.30	0.65*	3.2
Post Oak	114	-0.04	0.03	1.09	1.30	0.06	3.5
Black Oak	97	-0.04	-0.17	-0.16	0.30	-0.08	6.4
Red Oak	82	0.76*	-0.20	-0.15	2.20	0.45	6.7
Chinkapin Oak	26	0.89*	0.35	0.28	2.60	0.70*	3.0
Scarlet Oak	26	0.72	0.53	-5.50	-2.70	0.32	7.1
All[2]	1078	0.55*	0.42*	0.66*	1.02*	0.53*	4.7
Percent trees in diameter class		67	25	6	1	100	

[1]Species with fewer than 25 observations have been omitted
[2]Include species with fewer than 25 observations
[3]Average forty year diameter increment for all trees in the species grou
*Mean error is different from zero (α = 0.05)

Table 3G. P Values for one-sided t-test of forty-year diameter predictions (α = 0.05). H_0: $\mu\{|NoINCR| - |INCR|\} \leq 0$; H_A: $\mu\{|NoINCR| - |INCR|\} > 0$. Where |NoINCR| is absolute value of the diameter prediction error for NoINCR and |INCR| is absolute value of the diameter prediction error for INCR. **Bold** values indicate a rejection of H_0

		Diameter Class (inches)				
Species Group	No. of Trees[1]	5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	230	**0.004**	0.188	**0.064**	0.248	**0.003**
Shortleaf Pine	223	**0.000**	**0.017**	0.292	#	**0.000**
Hickory	205	**0.004**	0.377	**0.023**	#	**0.002**
Post Oak	114	0.228	0.591	0.219	#	0.203
Black Oak	97	0.409	0.535	0.762	#	0.459
Red Oak	82	**0.006**	**0.032**	0.917	0.274	**0.002**
Chinkapin Oak	26	0.075	0.097	0.196	#	**0.019**
Scarlet Oak	26	0.540	0.313	#	#	0.396
All[2]	1078	**0.000**	**0.004**	**0.029**	0.210	**0.000**
Percent trees in diameter class		67	25	6	1	100

[1]Species with fewer than 25 observations have been omitted
[2]Include species with fewer than 25 observations

Table 3H. Ten-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated number of trees per acre by species for INCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs TPA[4]
White Oak	137	1.00*	3.16	0.53	6.19	22.6
Black Oak	180	3.51*	6.02	1.02	11.80	20.5
Shortleaf Pine	116	2.75*	5.47	1.15	10.73	29.3
Hickory	152	1.61*	3.55	0.65	6.97	18.5
Scarlet Oak	126	3.91*	7.16	1.39	14.03	22.0
Red Oak	91	1.55*	3.54	0.84	6.94	15.6
Post Oak	79	1.92*	3.48	0.89	6.82	12.8
All species[5]	244	10.73*	12.56	1.84	24.63	83.7

[1]Include species with fewer than 75 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed average number of trees per acre for plots where species group were observed at the end of all cycles
[5]Species with fewer than 75 plot observations have been omitted
[*]Mean error is different from zero ($\alpha = 0.05$)

Table 3I. Ten-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated number of trees per acre by species for NoINCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs TPA[4]
White Oak	137	0.99*	3.17	0.54	6.21	22.6
Black Oak	180	3.47*	5.94	1.01	11.65	20.5
Shortleaf Pine	116	2.75*	5.47	1.15	10.72	29.3
Hickory	152	1.68*	3.50	0.65	6.86	18.5
Scarlet Oak	126	3.86*	6.99	1.36	13.70	22.0
Red Oak	91	1.55*	3.54	0.84	6.94	15.6
Post Oak	79	1.92*	3.48	0.89	6.82	12.8
All species[5]	244	10.66*	12.44	1.82	24.39	83.7

[1]Include species with fewer than 75 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average number of trees per acre for plots where species group were observed at the end of all cycles
[5]Species with fewer than 75 plot observations have been omitted
[*]Mean error is different from zero ($\alpha = 0.05$)

Table 3J. Forty-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated number of trees per acre by species for INCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs TPA[4]
White Oak	91	4.51*	6.16	1.29	12.08	14.2
Black Oak	81	8.14*	9.76	2.16	19.14	8.8
Shortleaf Pine	54	7.53*	12.20	3.33	23.91	20.3
Hickory	81	5.69*	7.86	1.74	15.40	13.8
Scarlet Oak	39	20.11*	24.12	7.82	47.28	9.3
Red Oak	49	5.36*	5.35	1.54	10.49	12.6
Post Oak	51	5.94*	7.69	2.14	15.07	11.8
All species[5]	145	26.74*	24.78	4.06	48.58	34.4

[1]Include species with fewer than 50 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average number of trees per acre for plots where species group were observed at the end of all cycles
[5]Species with fewer than 50 plot observations have been omitted
[*]Mean error is different from zero ($\alpha = 0.05$)

Table 3K. Forty-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated number of trees per acre by species for NoINCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs TPA[4]
White Oak	91	4.03*	6.68	1.40	13.09	14.2
Black Oak	81	8.05*	9.65	2.13	18.91	8.8
Shortleaf Pine	54	7.50*	12.31	3.36	24.14	20.3
Hickory	81	5.65*	7.81	1.73	15.32	13.8
Scarlet Oak	39	19.15*	21.25	6.89	41.64	9.3
Red Oak	49	5.34*	5.32	1.53	10.43	12.6
Post Oak	51	5.60*	7.50	2.11	14.71	11.8
All species[5]	145	26.29*	23.49	3.86	46.05	34.4

[1]Include species with fewer than 50 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed average number of trees per acre for plots where species group were observed at the end of all cycles
[5]Species with fewer than 50 plot observations have been omitted
*Mean error is different from zero (α = 0.05)

Table 3L. Ten-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated basal area per acre (ft^2) by species for INCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs BA[4]
White Oak	137	1.28*	4.06	0.69	7.97	11.6
Black Oak	180	2.97*	7.52	1.28	14.74	12.9
Shortleaf Pine	116	1.21*	2.14	0.44	4.19	13.8
Hickory	152	1.18*	2.47	0.46	4.83	7.7
Scarlet Oak	126	3.20*	6.35	1.23	12.45	12.6
Red Oak	91	1.48*	4.11	0.97	8.06	10.9
Post Oak	79	1.60*	3.07	0.79	6.01	6.5
All species[5]	244	8.79*	11.85	1.73	23.22	44.6

[1]Include species with fewer than 75 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average basal area (feet) for plots where species group were observed at the end of all cycles
[5]Species with fewer than 75 plot observations have been omitted
[*]Mean error is different from zero ($\alpha = 0.05$)

Table 3M. Ten-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated basal area per acre (ft^2) by species for NoINCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs BA[4]
White Oak	137	1.39*	4.05	0.68	7.94	11.6
Black Oak	180	3.17*	7.59	1.29	14.88	12.9
Shortleaf Pine	116	1.96*	3.23	0.67	6.33	13.8
Hickory	152	1.32*	2.52	0.47	4.94	7.7
Scarlet Oak	126	3.53*	6.61	1.28	12.96	12.6
Red Oak	91	1.72*	4.44	1.05	8.70	10.9
Post Oak	79	1.70*	3.02	0.77	5.92	6.5
All species[5]	244	9.84*	12.01	1.76	23.54	44.6

[1]Include species with fewer than 75 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average basal area (feet) for plots where species group were observed at the end of all cycles
[5]Species with fewer than 75 plot observations have been omitted
[*]Mean error is different from zero ($\alpha = 0.05$)

Table 3N. P Values for one-sided t-test of ten-year BA predictions ($\alpha = 0.05$). H_0: H_0: $\mu\{|NoINCR| - |INCR|\} \leq 0$; H_A: $\mu\{|NoINCR| - |INCR|\} > 0$. Where |NoINCR| is absolute value of the basal area prediction error for NoINCR and |INCR| is absolute value of the basal area prediction error for INCR. **Bold** values indicate a rejection of H_0

Species Group	No. of Plots[1]	P
White Oak	137	0.0517
Black Oak	180	**0.0127**
Shortleaf Pine	116	**0.0013**
Hickory	152	**0.0000**
Scarlet Oak	126	**0.0117**
Red Oak	91	**0.0074**
Post Oak	79	**0.0085**
All species[2]	244	**0.0000**

[1]Species with fewer than 75 plot observations have been omitted
[2]Include species with fewer than 75 plot observation

Table 3O. Forty-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated basal area per acre (ft^2) by species for INCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs BA[4]
White Oak	91	5.96*	11.44	2.38	22.42	14.7
Black Oak	81	12.29*	14.35	3.17	28.12	9.9
Shortleaf Pine	54	6.44*	7.63	2.08	14.95	16.4
Hickory	81	4.82*	5.60	1.24	10.98	8.6
Scarlet Oak	39	26.65*	24.06	7.80	47.16	11.5
Red Oak	49	8.47*	9.65	2.77	18.91	15.4
Post Oak	51	6.15*	7.80	2.19	15.28	8.1
All species[5]	145	32.85*	26.08	4.28	51.11	29.9

[1]Include species with fewer than 50 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average basal area (feet) for plots where species group were observed at the end of all cycles
[5]Species with fewer than 50 plot observations have been omitted
*Mean error is different from zero ($\alpha = 0.05$)

Table 3P. Forty-year mean error (Bias), standard deviation (SD) of mean error, 95% confidence interval (CI), and 95% prediction interval (PI) for estimated basal area per acre (ft^2) by species for NoINCR.

Species Group	No. of Plots[1]	Bias	SD	CI[2]	PI[3]	Obs BA[4]
White Oak	91	6.91*	12.01	2.50	23.53	14.7
Black Oak	81	12.69*	15.24	3.37	29.86	9.9
Shortleaf Pine	54	7.82*	11.09	3.03	21.73	16.4
Hickory	81	5.07*	5.99	1.32	11.74	8.6
Scarlet Oak	39	28.45*	27.32	8.86	53.56	11.5
Red Oak	49	9.68*	11.11	3.19	21.78	15.4
Post Oak	51	6.87*	8.93	2.49	17.51	8.1
All species[5]	145	35.97*	28.32	4.63	55.51	29.9

[1]Include species with fewer than 50 plot observation
[2]Half-width, 95% confidence interval for the mean error (bias)
[3]Half-width, 95% prediction interval for a single future event
[4]Observed Average basal area (feet) for plots where species group were observed at the end of all cycles
[5]Species with fewer than 50 plot observations have been omitted
*Mean error is different from zero ($\alpha = 0.05$)

Table 3Q. P Values for one-sided t-test of forty-year BA predictions ($\alpha = 0.05$). H_0: H_0: $\mu\{|NoINCR| - |INCR|\} \leq 0$; H_A: $\mu\{|NoINCR| - |INCR|\} > 0$. Where |NoINCR| is absolute value of the basal area prediction error for NoINCR and |INCR| is absolute value of the basal area prediction error for INCR. **Bold** values indicate a rejection of H_0

Species Group[1]	No. of Plots[1]	P
White Oak	91	**0.0013**
Black Oak	81	0.0912
Shortleaf Pine	54	**0.0414**
Hickory	81	0.1201
Scarlet Oak	39	**0.0120**
Red Oak	49	**0.0144**
Post Oak	51	0.0791
All species[2]	145	**0.0000**

[1]Species with fewer than 35 plot observations have been omitted
[2]Include species with fewer than 35 plot observation

Table 3R. Number of calibrated plots in ten year INCR simulations.

Species Group[1]	Number of Plots Calibrated	Total Number of Plots	Percentage of Plots Calibrated
White Oak	61	184	33%
Black Oak	64	180	36%
Shortleaf Pine	47	117	39%
Hickory	42	152	28%
Scarlet Oak	50	128	39%
Red Oak	27	91	30%
Post Oak	14	79	18%
All Plots	185	244	76%

[1]Species with fewer than 75 plot observations have been omitted

Table 3S. Number of calibrated plots in forty year INCR simulations.

Species Group[1]	Number of Plots Calibrated	Total Number of Plots	Percentage of Plots Calibrated
White Oak	17	91	19%
Black Oak	17	81	21%
Shortleaf Pine	19	54	35%
Hickory	23	81	28%
Scarlet Oak	13	39	33%
Red Oak	10	49	20%
Post Oak	13	51	25%
All Plots	86	145	59%

[1]Species with fewer than 35 plot observations have been omitted

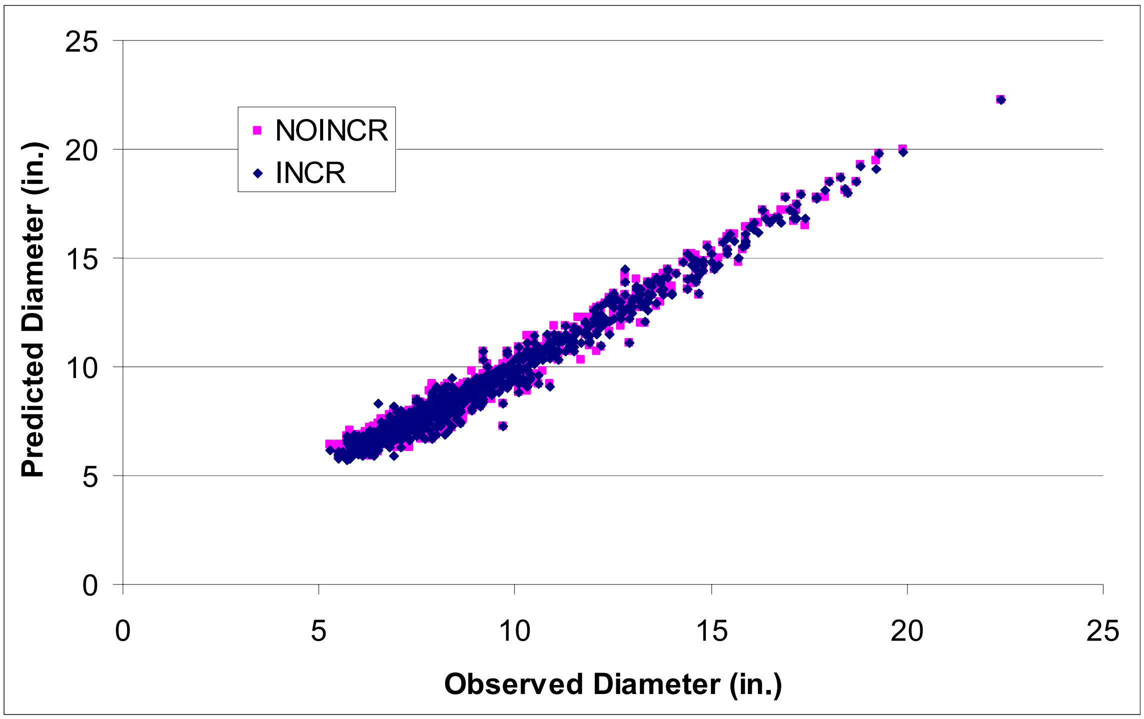

Figure 3A. Ten year observed versus predicted diameters for INCR and NoINCR simulations.

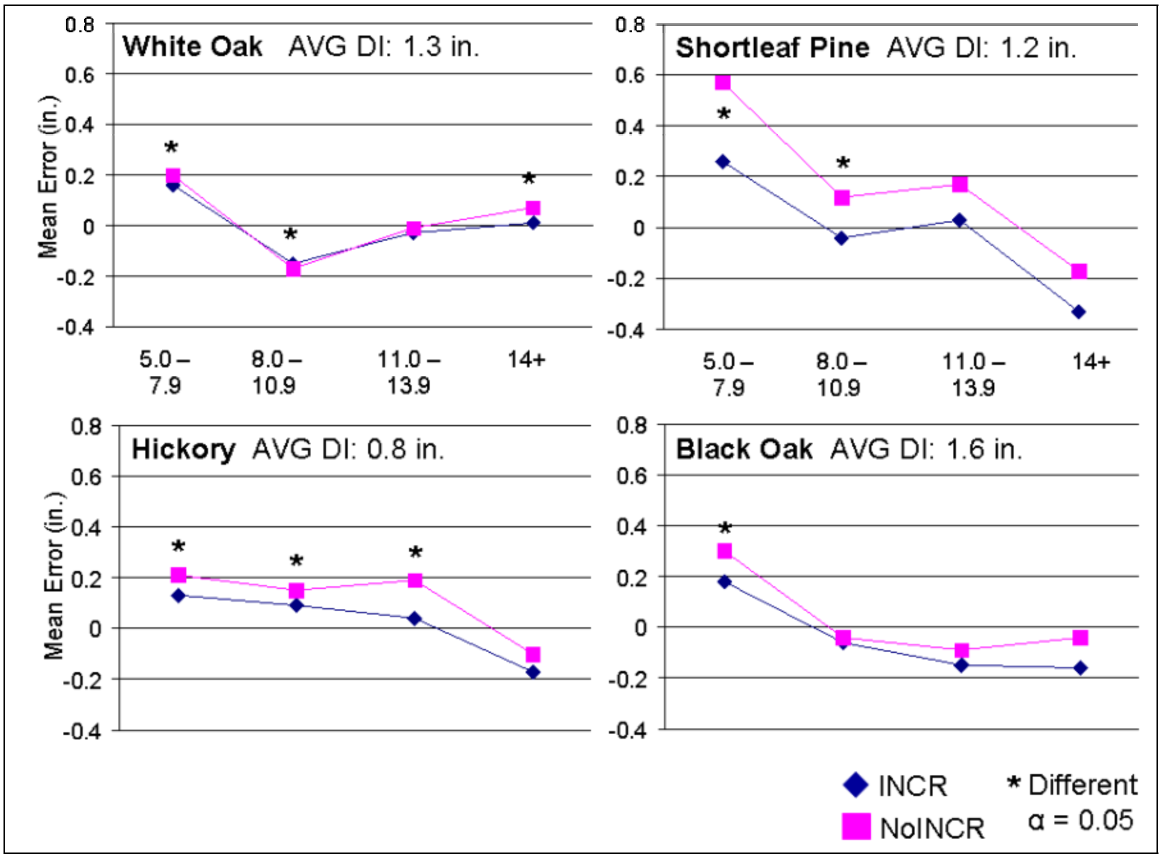

Figure 3B. Ten year mean diameter prediction errors for select species groups by diameter class. * indicates absolute value of mean diameter prediction error for INCR simulations is statistically smaller than NoINCR simulations. AVG DI: indicates average diameter increment for all trees of the species indicated.

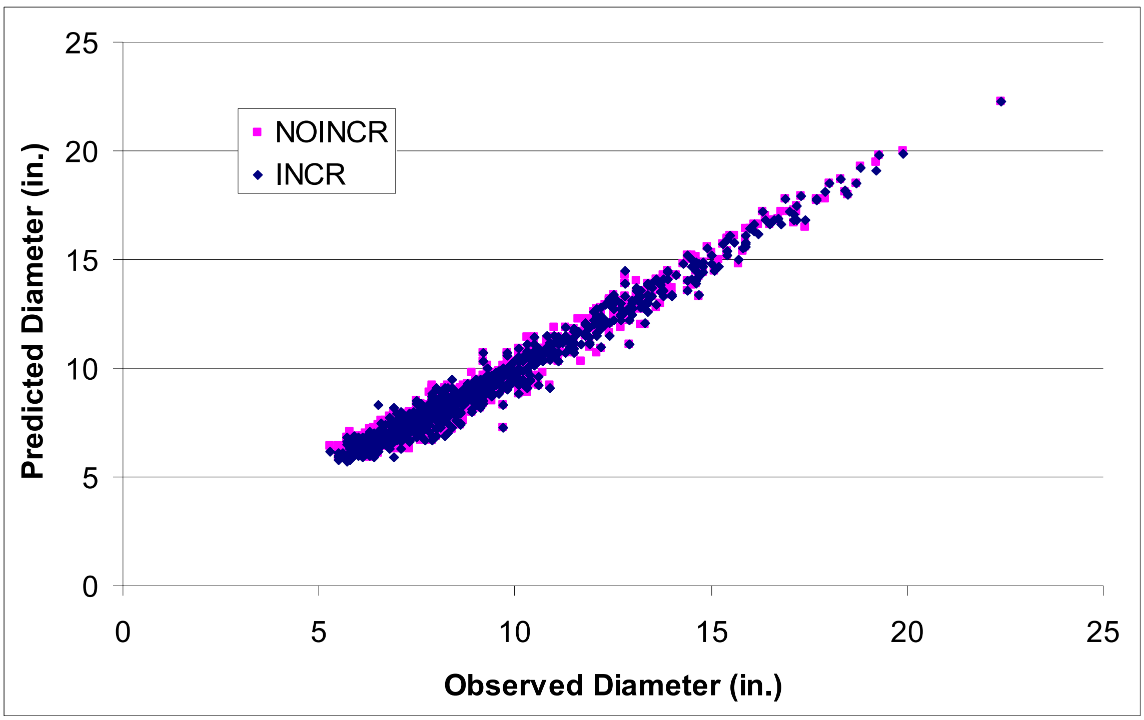

Figure 3C. Forty year observed versus predicted diameters for INCR and NoINCR simulations.

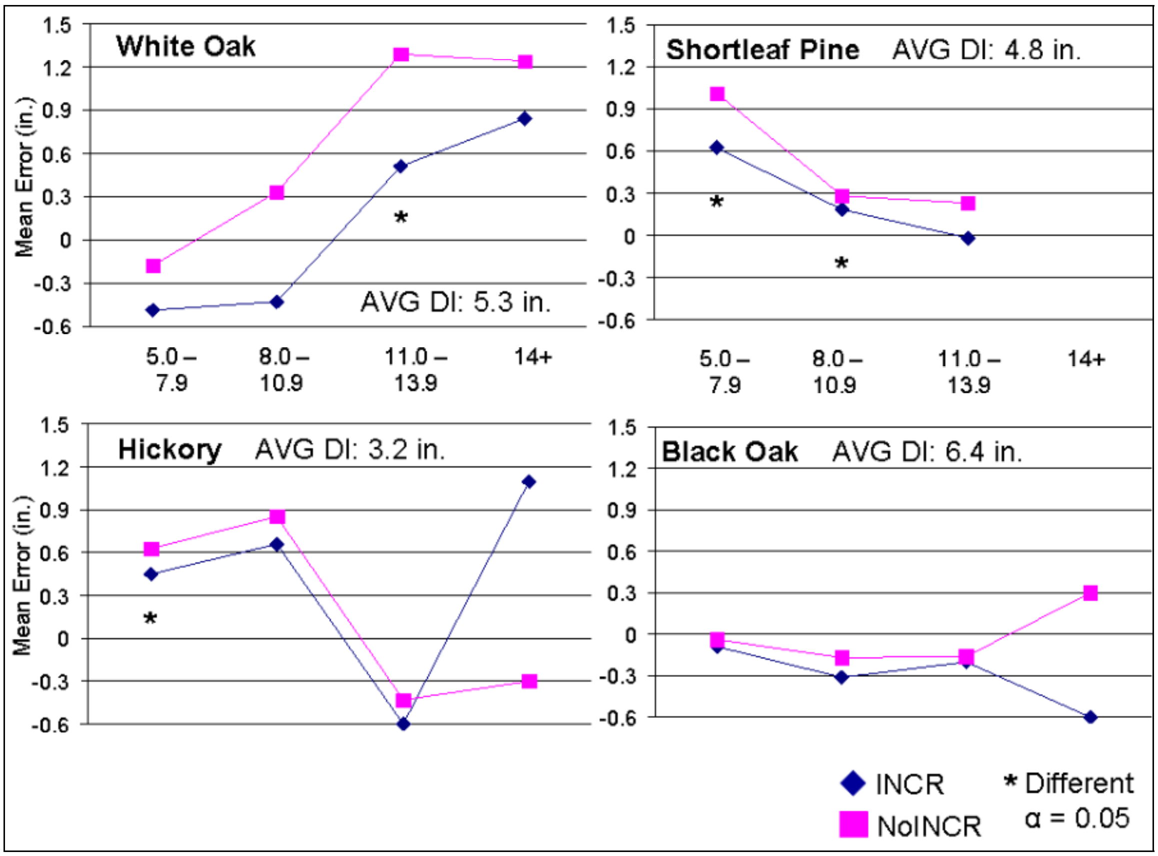

Figure 3D. Forty year mean diameter increment errors for select species groups by diameter class. * indicates absolute value of mean diameter prediction error for INCR simulations is statistically smaller than NoINCR simulations. AVG DI: indicates average diameter increment for all trees of the species indicated.

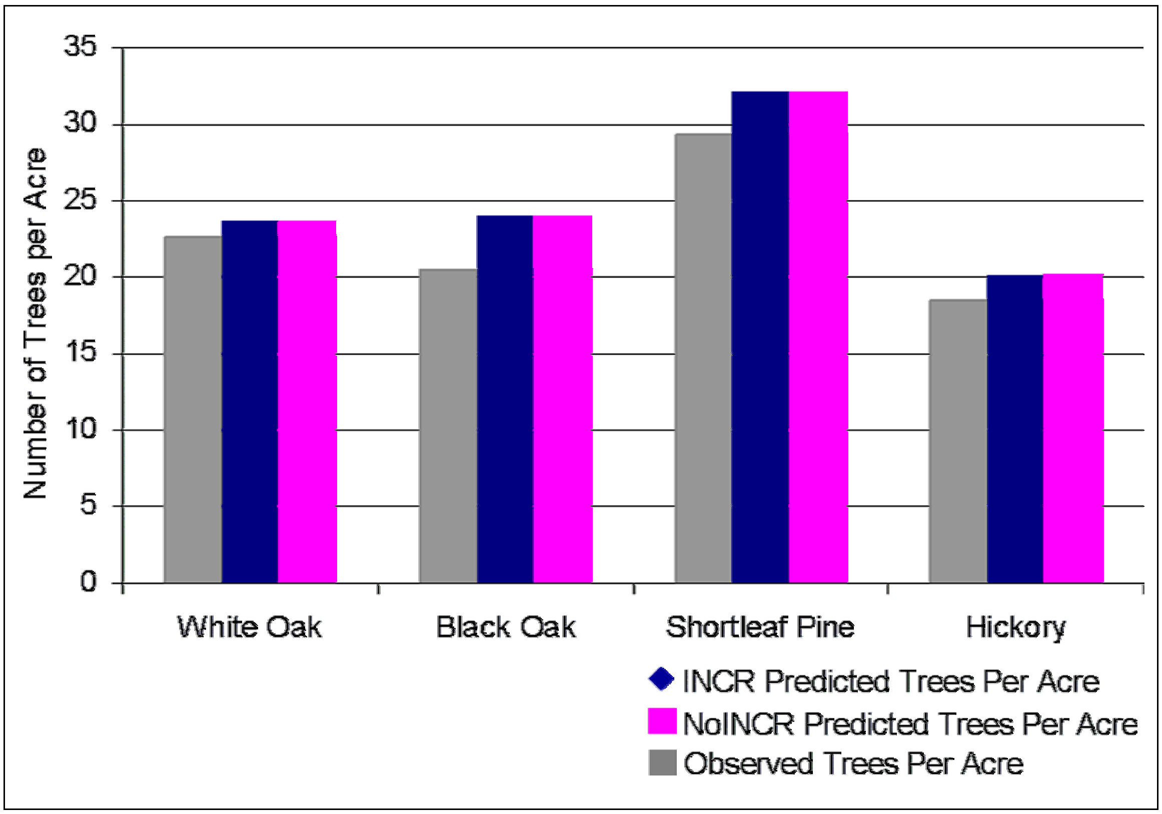

Figure 3E. Ten year mean trees per acres observations and predictions for select species groups.

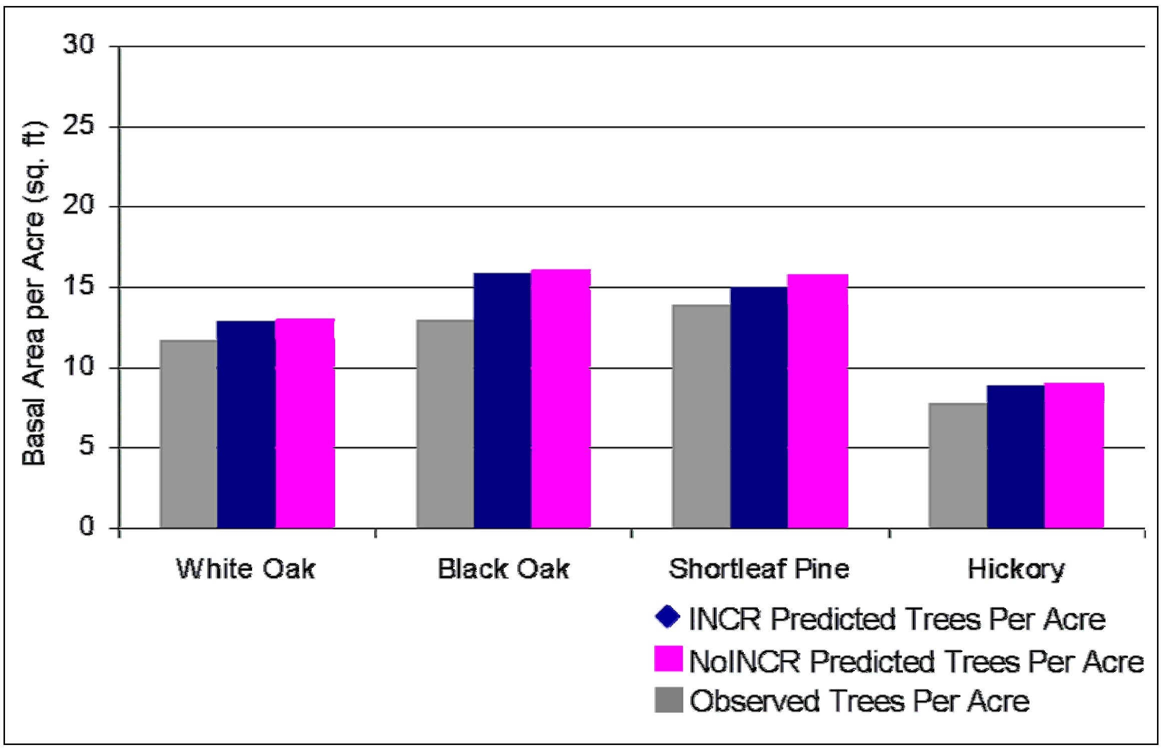

Figure 3F. Forty year mean trees per acres observations and predictions for select species groups.

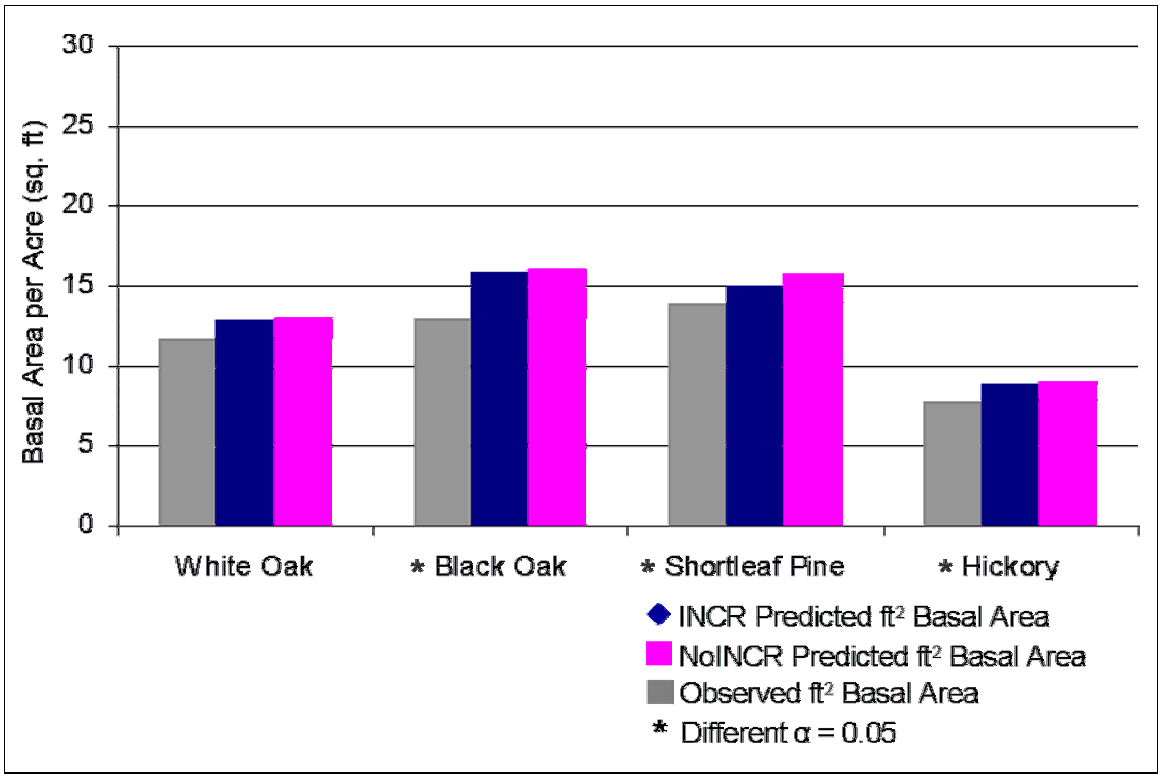

Figure 3G. Ten year mean basal area (square feet) per acre observations and predictions for select species groups. * indicates mean basal area per acre error for INCR simulations is smaller than NoINCR.

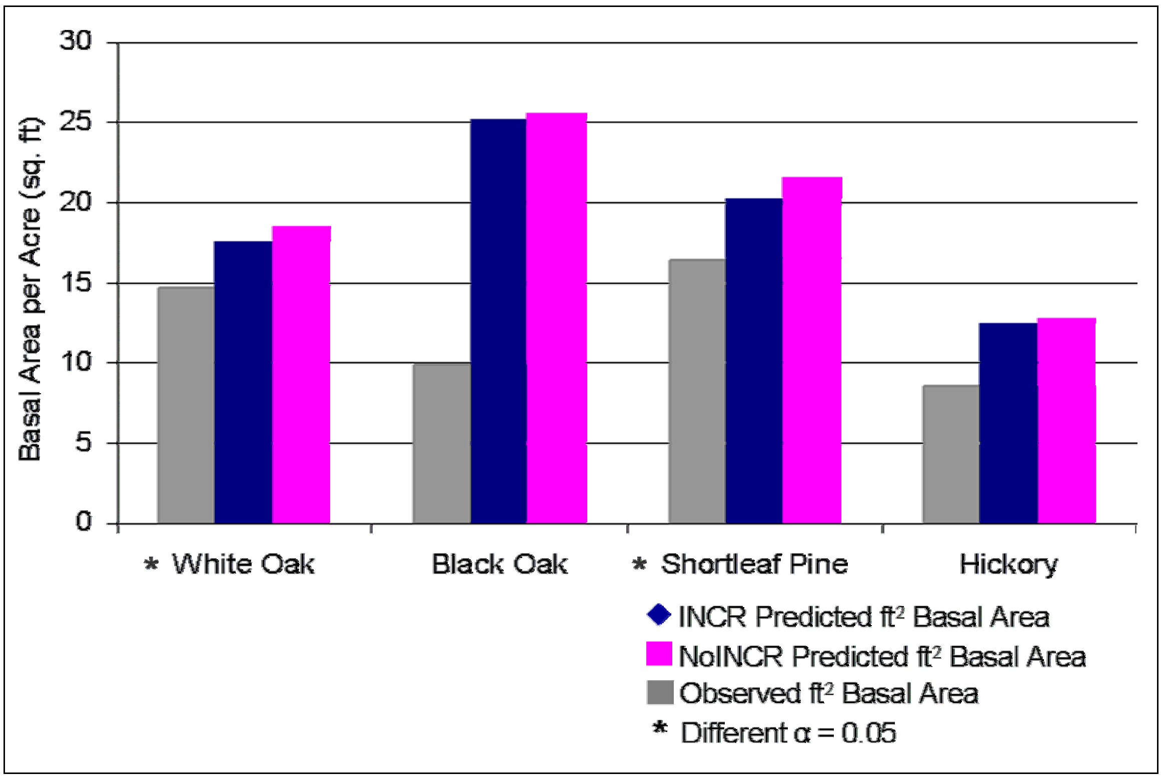

Figure 3H. Forty year mean basal area (square feet) per acre observations and predictions for select species groups. * indicates mean basal area per acre error for INCR simulations is smaller than NoINCR.

≤ 0; H_A: $\mu\{|NoINCR| - |INCR|\} > 0$. Where |NoINCR| is basal area per acre prediction error for NoINCR and |INCR| is mean basal area per acre prediction error for INCR. Mean INCR basal area errors were shown to be smaller for all species groups.

Forty-Year Simulations

Tables 3O. and 3P. show the forty-year mean error for basal area. As in the ten-year predictions, all biases are overpredictions. In both INCR and NoINCR simulations, all species groups' mean errors are significantly different from zero. Similar to the ten-year simulations, scarlet oak had the largest bias of an individual species group with more than 50 plot observations. Table 3Q presents the results of the one-sided t-test to determine if mean errors are smaller for INCR simulations. Mean errors for white oak, shortleaf pine, scarlet oak, red oak, and the aggregate all species group were found to be significantly smaller in the INCR simulation. Figure 3H presents the observed basal area per acre, and the predicted values for both INCR and NoINCR forty year simulations.

Discussion

Diameter Growth

Ten-Year Simulations

The purpose of this study was to evaluate the accuracy of the models within CS-FVS when used to predict growth of an uneven-aged, oak-dominated forest in the Missouri Ozark Highlands. For ten-year periods, CS-FVS generally overpredicted diameter growth, particularly in the NoINCR simulations and the smaller diameter classes. As expected, the addition of periodic diameter increment (DG) generally improved diameter growth prediction. Prediction errors for INCR simulations were statistically smaller for all diameter classes and all but one species group with more than 50 observations.

Forty-Year Simulations

Evaluating the forty-year predictions, species-specific trends become much more apparent. White oak provides an interesting example. In the ten-year simulations, both simulations overpredicted diameter growth for white oak. In the forty-year simulations, CS-FVS underpredicted average diameter for the smallest diameter class by 0.49 inches for INCR, and 0.18 for NoINCR. DG values provided for the forty-year simulations were obtained from the time period 1957-1967. Conditions on the forest, specifically relating to white oak stocking changed greatly during this time (Loewenstein 1996). Many of the large diameter white oaks were removed from the forest during this time, thus changing the growing conditions for the residual small diameter trees that comprise this smallest simulation diameter class. In the absence of calibration, the NoINCR simulation predicted mean diameters that were not significantly different from the observed values.

For the larger diameter classes, INCR predictions were generally more accurate than NoINCR. These diameter classes followed the ten-year predictions, in that CS-FVS overpredicted their growth. This relatively small pool of trees, initially 11 inches or larger, and present for the entire forty years, may have been less affected by the structural changes or were more accurately predicted by the model.

Other species, especially the other oak species groups were predicted more accurately. For INCR simulations, none of the mean errors were significantly different from zero for any diameter class, or the aggregated groups. In comparing INCR and NoINCR, only the red oak species group, and the aggregated chinkapin species groups were significantly different. Mean diameters for shortleaf pine, which was the second most-abundant species in the forty-year simulations, were generally overpredictioned. Prediction was improved under the INCR simulations for the two smallest diameter classes and the aggregated, all diameter group.

Trees Per Acre

Ten-Year Simulations

Comparing residual trees per acre trees per acre allows one to evaluate the mortality component of a growth system. When a model *overpredicts* the number of trees per acre, it *underpredicts* tree mortality. CS-FVS overpredicted trees per acre for all species groups, simulations, and simulation lengths. This bias can be partially explained by the design of the model. In FVS-based models, all tree records will receive some level of mortality in a projection (Dixon 2004).

To use an example from the data, plot 27 on the Pioneer Forest had 21 trees present in the 1/5 acre plot, greater than or larger than 5 inches in 1977, or 105 trees per acre. During the ten years of simulation, one tree was harvested, reducing the trees per acre by 5. All of the other trees survived, resulting in 100 trees per acre of surviving trees. The predicted number of trees per acre for the INCR simulation was 99.462 trees per acre. Each tree in the plot contributed to the 0.538 reduction, or mortality. Had one of the trees on the plot died during the simulation, the error would have been and overprediction of 4.462 trees per acre.

Forty-Year Simulations

The smallest bias observed in all simulations was in the white oak group. For species groups analyzed, scarlet oak and black oak had the largest overpredictions. Though mean errors were larger in the forty-years simulations, error relationships were consistent between species. For all species groups and simulation lengths, INCR and NoINCR mean errors were not significantly different. Though not statistically different, the bias for NoINCR trees per acre was actually smaller for most species groups in the smallest diameter class. Canavan and Ramm (2000) noted a similar relationship in the Lake States variant of FVS.

One potential source of error in the trees per acre analysis is the recording of mortality trees in the forest inventory. Many studies evaluating growth models reject plots with signs of disturbance (Guertin and Ramm 1996, Canavan and Ramm 2000). This study did not eliminate plots that had signs of human disturbance, particularly harvest and regeneration activity, such as under the single-tree selection system practiced on the Pioneer Forest (Loewenstein 1996, Pioneer Forest 2004). In the inventory design, a mortality code is recorded for each tree (Appendix 2). Living trees are coded “0.” When a cause of mortality can be determined, it is coded appropriately. In this analysis, trees with a mortality of “3” or “4,” Logging (Cut) and TSI, respectively were treated as removals. All others, including trees that were no longer inventoried were considered lost to natural mortality (drought, suppression, insects, disease, fire, or wind). While the CFI system installed on the Pioneer Forest was well designed and maintained, it can often be difficult to determine the cause of mortality of a tree up to five years after its mortality event. A misidentified cause of mortality can affect the predicted number of trees per acre significantly.

One important thing to remember is that this study did not consider ingrowth. Over long periods, such as the forty year time period used in this study, ingrowth can become an important component of the stand. Recruitment of trees in to the five-inch class and larger over forty year varied widely by plot. These additional trees compete for resources and growing space in the actual stand. Undoubtedly, their inclusion in the simulation would alter the models estimation of mortality, as individual tree mortality in the model is driven by basal area per acre, and basal area of larger trees. CS-FVS permits the user to supply numerous adjustment factors, including a mortality adjustment factor that could be useful in adjusting these estimates, especially in the absence of ingrowth information.

Basal Area

Ten-Year Simulations

Basal area for a simulated tree is the product of two factors, the predicted diameter and the tree per acre expansion factor. As the value of dbh is squared in the calculation of basal area, so diameter prediction errors are generally magnified as basal area prediction errors. Basal area was overpredicted for all species groups, simulations, and simulation lengths. In the ten-year simulations, all species groups but white oak had significantly smaller INCR errors. However, white oak's P-value was only 0.0517, narrowly missing the α of 0.05.

Forty-Year Simulations

As was seen in the trees per acre results, black oak and scarlet oak had the largest mean errors for an individual species group. Again, as in the trees per acre simulations, the forty-year biases were similar to the ten-year results, only larger. Forty-year INCR biases were smaller for four of the seven species groups, and the aggregated species group. This is similar to the forty-year diameter results in the number of significantly smaller INCR predictions.

Conclusions

Overall the model predicted diameter growth and mortality fairly well for many species, especially when DG information was provided. In other evaluations of TWIGS-based growth models, reviewers have generally used the mean diameter prediction error of ±0.5 inches over a ten-year period as an acceptable measure of performance (Holdaway and Brand 1983, Miner et al. 1988, and Canavan and Ramm 2000). The results of this study indicate that for all species groups and diameter classes, with the exception of elm and ash, which account for fewer than two percent of the trees sampled, CS-FVS performed satisfactorily for ten-year diameter growth.

Smith (1983) recommended annual diameter increment adjustment factors for the STEMS model, when applied in the Upper Midwest Peninsula of Michigan, to compensate for local errors compared the regionally-derived results of STEMS. While this study was not specifically designed to determine the species- and size specific error adjustments, it may be useful to the reader to have a general “rules of thumb” for adjusting predicted diameter increments. In general, when applied to forests similar to the Pioneer Forest, ten year upland hardwood species diameter increment should be reduced by ten percent. Similarly, shortleaf pine increment should be reduced by 25 percent. And while numbers were relatively small in this sample, bottomland hardwood species, such as elm and ash should be reduced by fifty percent. As stated previously, these are local “rules of thumb,” and should not be applied to other forest types, or other portions of the Central States region.

When the time frame was expanded out to forty years, mean prediction errors did increase for most species and groups. However, in the INCR simulations, many mean predictions errors were not significantly different from zero. And while some diameter class errors were statistically significant, for all species groups and the aggregated species group, the mean diameter prediction error was at or below the ±0.5 inch threshold. It is the recommendation of the author that locally observed values of periodic diameter increment (DG) be used whenever possible to adjust model estimates and improve diameter prediction.

Trees per acre predictions showed that CS-FVS underestimated mortality for all species groups. Prediction of white oak mortality was more accurate than other species groups in both the ten- and forty-year simulations. Mortality errors were much larger for black oak and scarlet oak, especially in the forty-year simulations. Oak decline, which affects these two species groups primarily, may help explain the larger than predicted mortality in these groups (Woodall et al. 2005, Moser et al. 2004).

The simulations produced an overestimation of basal area for all species groups and time-periods. Many of the same reasoning used to explain the diameter and mortality errors apply to basal area. Black oak and scarlet oak had large biases for basal area, especially in the forty-year simulations. The addition of the DG information did improve prediction for scarlet oak in both time-periods and for ten-year black oak, but not the forty-year black oak estimates. Again, these errors are likely related to oak decline on the forest and the region.

Site index values were not available for all plots in the inventory, so they were excluded from the plot-level inputs. Other studies of TWIGS-based FVS models (Canavan and Ramm 2000) suggest that including can improve prediction, depending upon the relationship of the plot site index to the default FVS. For CS-FVS, when no site index is provided, the model defaults to a white oak site index of 65 (Bush 1995). For site index trees available from the inventory, average white oak site index was only 54 feet. Using actual site index values may alter the predicted diameter growth estimates.

SUMMARY

The purpose of this study was to develop height-diameter equations for the Ozark Highlands area of Missouri, and to evaluate a standard growth and yield model (CS-FVS) for this same region. The height-diameter models presented in Chapter 2 did a good job predicting the mean height-diameter trend for each species (pseudo-R^2 values ranged from 0.56 to 0.88). The equations can be used for common species found in the state of Missouri, within the diameter ranges used to calibrate the coefficients.

Along with the height-diameter equations produced by Colbert et al. (2004), height prediction for CS-FVS may be able to be improved, over the currently used height-dubbing models, developed by Ek et al (1984). According to Bush (1995), the current equation "…was developed for the Lake States and will be replaced when new equations are developed." Further models may need to be developed beyond the models presented in Chapter 2 and Colbert et al. (2004), to insure that model coefficients are available for all species groups within CS-FVS.

While previous studies have examined the performance of CS-TWIGS in the Ozark Highlands of Missouri (Wang 1995), none have evaluated CS-FVS over the time-steps used, or evaluated the calibration capacity. Chapter 3 shows that for ten-year periods, CS-FVS predicts diameter growth and mortality reasonably well for common species groups in the Missouri Ozark Highlands. The inclusion of periodic diameter increment (DG) was shown to improve diameter growth prediction over both time-periods for most species groups and diameter classes.

Mortality estimation was better for some species (white oak) and poorer for others (scarlet oak and black oak). As suggested in Chapter 3, oak decline in scarlet oak and black oak may have greatly reduced accuracy in these species groups. For other variants of FVS extensions are available to assist in modeling mortality events associated with insects and disease complexes (Dixon 2004). One area of potential improvement for the TWIGS-based variants of FVS, would be an oak decline extension. Including DG information did not improve mortality prediction for either ten-year or forty-year simulations.

Basal area was generally overpredicted for all species and time-periods. As basal area is the product of both diameter and trees per acre, this is to be expected based on other findings for diameter growth and TPA. Another goal of Chapter 3 was to determine if the addition of periodic diameter increment (DG) would improve model prediction. For most species groups and diameter classes, this was the case. This suggests that CS-FVS can provide acceptable results, which can be significantly improved with the addition of diameter increment information. Also, the addition of site index, when available will likely improve prediction even more.

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APPDENDIX ONE

Standard Deviations of dbh Errors by Species, Diameter Class, and INCR

Table A1-1. Standard deviation of dbh errors in 10 years by species and diameter class for INCR projections.

Species Group[1]	No. of Trees[2]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	822	0.39	0.50	0.50	0.44	0.47
Black Oak	760	0.39	0.55	0.58	0.58	0.54
Shortleaf Pine	655	0.55	0.55	0.71	0.55	0.60
Hickory	536	0.34	0.40	0.38	0.36	0.37
Scarlet Oak	520	0.49	0.54	0.71	0.59	0.59
Red Oak	287	0.34	0.62	0.59	0.67	0.59
Post Oak	217	0.40	0.35	0.33	0.69	0.40
Blackjack Oak	85	0.40	0.40	0.28	*	0.38
Chinkapin Oak	59	0.29	0.46	0.24	0.26	0.36
Tupelo	59	0.32	0.42	0.35	0.43	0.38
Elm	55	0.58	0.78	0.81	0.25	0.68
White & Green Ash	51	0.55	0.58	0.55	*	0.56
All[3]	4256	0.53	0.60	0.56	0.53	0.45
Percent trees in diameter class		37	38	17	9	100

[1]Species groups from Miner et al 1988.
[2]Species with fewer than 50 observations have been omitted
[3]Include species with fewer than 50 observations
*Only one or fewer samples present in the diameter class.

Table A1-2. Standard deviation of dbh errors in 10 years by species and diameter class for NoINCR projections.

Species Group[1]	No. of Trees[2]	Diameter Class (inches) 5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	822	0.44	0.54	0.54	0.48	0.52
Black Oak	760	0.46	0.58	0.65	0.61	0.59
Shortleaf Pine	655	0.63	0.64	0.71	0.56	0.68
Hickory	536	0.36	0.41	0.38	0.42	0.39
Scarlet Oak	520	0.50	0.63	0.77	0.68	0.65
Red Oak	287	0.42	0.68	0.70	0.69	0.65
Post Oak	217	0.41	0.38	0.34	0.71	0.42
Blackjack Oak	85	0.37	0.44	0.22	*	0.37
Chinkapin Oak	59	0.28	0.48	0.15	0.26	0.35
Tupelo	59	0.32	0.44	0.35	0.43	0.39
Elm	55	0.54	0.80	0.80	0.25	0.66
White & Green Ash	51	0.42	0.30	0.55	*	0.45
All[3]	4256	0.50	0.59	0.64	0.59	0.58
Percent trees in diameter class		37	38	17	9	100

[1]Species groups from Miner et al 1988.
[2]Species with fewer than 50 observations have been omitted
[3]Include species with fewer than 50 observations
*Only one or fewer samples present in the diameter class.

Table A1-3. Standard deviation of dbh errors in 40 years by species and diameter class for INCR projections.

		Diameter Class (inches)				
Species Group[1]	No. of Trees[2]	5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	230	1.76	1.76	1.69	1.13	1.77
Shortleaf Pine	223	1.76	1.69	1.76	*	1.75
Hickory	205	1.27	1.24	1.56	*	1.28
Post Oak	114	1.44	1.24	1.59	*	1.39
Black Oak	97	1.80	2.06	2.25	*	1.87
Red Oak	82	2.16	2.62	1.67	1.41	2.34
Chinkapin Oak	26	1.33	1.11	3.16	*	1.63
Scarlet Oak	26	2.20	0.88	*	*	2.28
All[3]	1078	1.79	1.91	2.03	1.44	1.83
Percent trees in diameter class		67	25	6	1	100

[1]Species groups from Miner et al 1988.
[2]Species with fewer than 25 observations have been omitted
[3]Include species with fewer than 25 observations
*Only one or fewer samples present in the diameter class.

Table A1-4. Standard deviation of dbh errors in 40 years by species and diameter class for NoINCR projections.

		Diameter Class (inches)				
Species Group[1]	No. of Trees[2]	5.0 - 7.9	8.0 - 10.9	11.0 - 13.9	14 +	All Classes
White Oak	230	1.93	1.98	1.48	0.74	1.94
Shortleaf Pine	223	2.00	1.85	1.79	*	1.98
Hickory	205	1.33	1.13	2.14	*	1.33
Post Oak	114	1.51	1.25	1.55	*	1.46
Black Oak	97	1.92	2.03	2.20	*	1.93
Red Oak	82	2.42	3.06	1.03	0.71	2.60
Chinkapin Oak	26	1.15	1.32	3.18	*	1.60
Scarlet Oak	26	2.11	1.96	*	*	2.39
All[3]	1078	1.94	1.99	2.05	1.43	1.95
Percent trees in diameter class		67	25	6	1	100

[1]Species groups from Miner et al 1988.
[2]Species with fewer than 25 observations have been omitted
[3]Include species with fewer than 25 observations
*Only one or fewer samples present in the diameter class.

APPDENDIX TWO

Mortality classes for Pioneer Forest Continuous Forest Inventory

Table A2-1. Causes of mortality from the Pioneer Forest Continuous Forest Inventory.

Mortality Code	Cause of Mortality
0	Living Tree
1	Fire
2	Wind
3	Logging (cut)
4	TSI (Timber Stand Improvement)
5	Insects
6	Disease
7	Suppression
8	Drought
9	Lightning