SENSITIVITY ANALYSIS of the FOREST VEGETATION SIMULATOR SOUTHERN VARIANT (FVS-Sn) for SOUTHERN APPALACHIAN HARDWOODS

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Abstract

The FVS-Sn model was developed by the USDA Forest Service to project and report forest growth and yield predictions for the Southern United States. It is able to project forest growth and yield for different forest types and management prescriptions, but it is a relatively new, complex, and untested model. These limitations notwithstanding, FVS-Sn once tested and validated could meet the critical need of a comprehensive growth and yield model for the mixed hardwood forests of the southern Appalachian region.

In this study, sensitivity analyses were performed on the FVS-Sn model using Latin hypercube sampling. Response surfaces were fitted to determine the magnitudes and directions of relationships between FVS-Sn model parameters and predicted 10-year basal area increment. Model sensitivities were calculated for five different test scenarios for both uncorrelated and correlated FVS-Sn input parameters and sub-models.

Predicted 10-year basal area increment was most sensitive to parameters and sub-models related to the stand density index and, to a lesser degree, the large tree diameter growth sub-model. The testing procedures and framework developed in this study will serve as a template for further evaluation of FVS-Sn, including a comprehensive assessment of model uncertainties, followed by a recalibration for southern Appalachian mixed hardwood forests.

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Introduction

Forests and trees provide a number of goods and services essential to society's needs. Forests provide raw materials for building, manufacturing, packaging and many other industries, as well as a range of non-timber goods and services including food, wildlife habitat, biodiversity, recreation, and clean water. Due to the range of commodities and services humans obtain from forests, efforts to manage forest resources must have the flexibility to account for the range of needs and uses. Effective management requires models that can accurately predict future forest conditions. These models must be flexible to account for the range of forest management practices in use today or in the near future.

The southern United States poses substantial challenges for forest management and modeling of forest resources. The region is comprised of approximately 201 million acres of timberland and alone produces 60% of the United States total timber production, more timber than any other single country (Prestemon and Abt 2002). The majority of timberland ownership is private, 89%, of which 69% is non-forest industry (Wear and Greis 2002). In the last decade, private non-industrial timberland ownership has steadily increased, while forest industry ownership has decreased. Within the private non-industrial sector, corporate ownership has increased. At the same time, the average private ownership tract has decreased in size (Connor and Hartsell 2002). As the number of private forest landowners increases, so does the potential for changing forest management objectives. Such circumstances motivate the need for accurate, yet flexible growth and yield models to guide management of the region's forest resources.

The most abundant timber type in the South is the upland hardwood-oak-hickory forest type, covering 74.4 million acres or 37% of the region's 201 million acres of timberland. The majority of land covered by this forest type is found in the Southern Appalachian Mountains, where 58.9 million acres are classified as oak-hickory timberland (Connor and Hartsell 2002). The southern Appalachian region spans the Appalachian Mountain range from Virginia to central Georgia and eastern Alabama, extending west into Kentucky and Tennessee. This area is comprised of the Appalachian Highlands physiographic region and the Ridge and Valley, Blue Ridge, Piedmont, and Appalachian Plateau (Cumberland Plateau section) physiographic provinces (Fenneman 1938). The region's 123.1 million acres of timberland is comprised of the Southeastern Mixed forest, Eastern Broadleaf, and Central Appalachian Broadleaf forest ecological provinces (Keys et al. 1995). Approximately one-half of the total timberland acreage in the southern Appalachian provinces consists of the oak-hickory forest type (Table 1).

Table 1. Acreage of total timberland and upland hardwoods within the Southern Appalachian Region in millions of acres. (Connor and Hartsell 2002)

Ecological Province	Total timberland	Oak-Hickory forest type	Percentage of oak-hickory forest type to total timberland
Southeastern mixed	79.5	26.8	33.7
Eastern broadleaf (Oceanic and Continental)	29.3	21.8	74.4
Central Appalachians	14.3	10.3	72
Total	123.1	58.9	47.8

A number of prediction models have been developed for modeling forest growth and yield of southern Appalachian forests: FVS-Sn (Donnelly et al. 2001; Stage 1973), G-HAT (Harrison et al. 1986), Y-POP (Knoebel et al. 1986), SILVAH (Marquis 1986), OAKSIM (Hilt 1985), and GROAK (Dale 1972). Other lesser known models have been developed, but have received little interest or support in recent years (Beck and Della-Bianca 1972; Yandle et al. 1987). Still others may not be widely available, such as the SE TWIGS model developed by Bolton and Meldahl (Bolton and Meldahl 1990).

While the hardwood forests of the southern Appalachians are diverse and expansive, typical models for southern hardwoods are limited to narrow sets of conditions. For example, the models G-HAT, Y-POP, OAKSIM, and GROAK apply only to stands that have been thinned. In most oak-hickory stands, however, thinning is not economically feasible or widely practiced. Other models, such as Y-POP apply only to single species, so their use in modeling mixed species forests is limited. Models developed from site-specific data sets may be limited geographically and thus can produce poor results when used outside of their intended range. Data used to develop growth and yield models have often come from relatively productive timber sites, which is the case with G-HAT and Y-POP. In contrast, many oak-hickory forest stand sites are of moderate or poor quality (Van Lear 2002). A likely consequence of using these models on poor sites would be over prediction of growth and yield.

Perhaps the most comprehensive model that has been developed to date for the southern Appalachian region is FVS-Sn, Forest Vegetation Simulation Southern variant (Donnelly et al. 2001). FVS-Sn is not limited to a particular management prescription such as thinning and it is capable of modeling 90 different tree species, and covers a wide geographic range. It was developed from extensive datasets covering a diverse set of sites and conditions from across the southern United States. Documentation and technical support for FVS-Sn are provided by the U.S. Forest Service making the model available at no cost to a wide range of users.

Despite the advantages associated with FVS-Sn, some limitations have been noted. It is a relatively new model that has not been extensively tested and is fairly complicated to understand and operate. The basal area projections of FVS-Sn have been found to be high and even unrealistic in some cases (Johnson 1997), and unreasonable mortality predictions have been noted when using the default model settings (Gartner 2002). These limitations notwithstanding, FVS-Sn is capable of predicting forest growth and yield for mixed hardwood forests of the southern Appalachian region under a wide variety of growing conditions and management scenarios. If subjected to additional testing and validation, FVS-Sn could serve a critical need in the modeling of southern Appalachian upland hardwood forests.

Objectives

The purpose of this research was to conduct a sensitivity analysis (SA) of FVS-Sn as an initial step to a comprehensive uncertainty assessment that will follow in the future. Specific goals of the proposed SA include: 1) computing sensitivity indices to catalog and quantify uncertainties in model coefficients and inputs; 2) developing error budgets that group sensitivities of coefficients and inputs by their potential effects on stand level predictions; 3) conducting a response-surface analysis to summarize the magnitudes and directions of the relationships between model inputs and outputs of interest, accounting for uncertainties, and correlated inputs; and 4) developing a framework for further testing of FVS-Sn for different forest types in the southern Appalachians.

Background

Forest Vegetation Simulator (FVS)

The Forest Vegetation Simulator (FVS) is a computer software modeling system developed by the USDA Forest Service to aid in the prediction of forest growth and yield, as well as to simulate a variety of silvicultural treatments for the dominant forest species and types found in the United States. FVS is also used by the USDI Bureau of Land Management, Bureau of Indian Affairs, state agencies, private industries and non-industrial forest landowners. It is chiefly used to report current stand conditions and project future stand conditions and statistics, as well as predict disease and fire potential.

The FVS framework was adapted from the *Prognosis* (Stage 1973) single tree model, developed for forest stands within the Inland Empire region of the western United States. Stage envisioned the *Prognosis* model to use tree growth interactions to direct the course of forest stand development under different silvicultural treatments, while remaining applicable to mixed stands of varying age structures, both even and uneven-aged, and remain sufficiently flexible to adapt to new management techniques (Stage 1973).

The development and evolution of *Prognosis* into FVS required over 30 years of coordinated effort led by the Forest Service and involving corporate and university researchers. The original fitting and design of the large tree growth model within the *Prognosis* model is attributed to Stage (1975), while the mortality model was developed by Hamilton and Edwards (1976). Over time, the potential of the *Prognosis* model was realized and a version was released to the public in 1982 (Wykoff et al. 1982).

Since the original development and first release of *Prognosis*, many additions and updates have taken place. The growth model has been extensively adjusted (Hamilton 1986, 1990; Stage and Wykoff 1998; Wykoff 1990) and small and large tree diameter increment models were added (Wykoff 1983). Regeneration and establishment models were developed and added to the model (Ferguson et al. 1986), and then revised (Ferguson and Carlson 1993; Ferguson and Crookston 1991). Also, the economic evaluation tool CHEAPO (Medema and Hatch 1982) was implemented in 1982 and then revised in 1986 (Horn et al. 1986). Crookston (1985) developed the “Event Monitor” extension which allows for the scheduling of management activities during the projection cycle. The “Event Monitor” was later expanded

(Crookston 1990) and ultimately led to the development of a “Parallel Processing” extension (Crookston and Stage 1991) which allowed for the simultaneous projection of many stands. With the inception and incorporation of extensions, *Prognosis* evolved into a system capable of modeling most aspects of natural resource management. The *Prognosis* model name was changed to FVS in the mid-1990’s to convey the idea that the Forest Service has adopted a national forest growth and yield modeling system.

During the revising and updating of the *Prognosis* model, the FVS framework was being expanded to other regions and forests types outside of the original Intermountain region. Due to the improvement and availability of personal computers, developing a uniform model framework able to support many different forest types throughout the United States was possible. Since the early 1980’s twenty different variants have been developed that follow the *Prognosis*-FVS framework and cover every forest type within the United States, with each variant corresponding to a specific geographic region of the nation. The Forest Service’s Forest Management Service Center (FMSC) in Fort Collins, Colorado (http://www.fs.fed.us/fmsc/) serves as the primary agency that maintains, develops, and distributes all components of FVS and its variants.

Extensions and Keywords

Dixon (2002) defines an extension as, “an additional part of the FVS system that ‘extends’ the capabilities of the base model to either simulate forest dynamics other than tree growth and mortality, or adds additional analysis capabilities such as those for landscape and economic analyses.” FVS contains extensions pertaining to insects and pathogens, shrub and canopy structure, economics, fuel loading, and fire effects, as well as linkages to other databases. Extensions associated with potential pest outbreaks and mortality include: Western Root Disease (Frankel 1998), White Pine Blister Rust (McDonald et al. 1981), Douglas-fir Beetle (Marsden et al. 1994), Westwide Pine Beetle (Beukema et al. 1997), Tussock Moth (Monserud and Crookston 1982), Western Spruce Budworm (Sheehan et al. 1989), Gypsy Moth, and Oak Decline. The COVER extension (Moeur 1995) describes the canopy structure, understory vegetation height, and summarizes the stand biomass. The CHEAPO II extension (Medema and Hatch 1982) performs economic predictions based on management. Also, the Parallel Processing extension (Crookston and Stage 1991) allows for the simultaneous projection of multiple stands.

Each extension is comprised of keywords which direct the functions contained within the extension by referencing associated parameters pertaining to the activity initiated by the keyword. Other directions not related to the FVS extensions are also conveyed by keywords. The activities and functions carried out by keywords is diverse (Van Dyck 2000), including functions that refer to data entry (NOTRIPLE), model output (SUMLIST), thinning (THINDBH), mortality (FIXMORT), stand visualization (SVS), and more (STOP, STATS).

SUPPOSE User Interface

SUPPOSE is a graphical user interface (GUI) computer application used to control the FVS modeling system. SUPPOSE simplifies a user's control over a particular modeling scenario carried out using FVS, while providing the capability to simulate management prescriptions for many stands on a landscape across many forest habitat types at once. SUPPOSE also allows for spatial and temporal aspects of forest management to be incorporated into FVS projections. Finally, it bridges the gap between forest management and computer modeling by displaying terms forest managers would generally be familiar with rather than modeling jargon or computer programming terminology.

FVS-Sn

The variant of interest in this study is FVS-Sn, which was developed by Donnelly et al. (2001) for use in the southeastern United States, including Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Tennessee, Kentucky, and parts of Texas and Oklahoma. The variant is based on age and distance independent individual-tree model equations that dictate the recruitment, growth, and mortality of each tree (Donnelly et al. 2001). While stand-level predictions are the primary concern to most users of FVS-Sn, the sub-models that lead to these predictions were developed from tree-level considerations and fitted to individual tree data to give greater flexibility and consistency to operate within the FVS framework.

FVS-Sn was developed through the cooperation of the Southern Research Station of the Forest Service and the FMSC. Forest inventory and analysis (FIA) and Bureau of Indian Affairs data from the 13 states comprising the Southern region were used to develop the model. Donnelly et. al. (2001) determined that 76 unique coefficient sets were suitable to describe the diameter increment of the 90 most common forest tree species in the southern United States. In all, 555,376 tree diameter increment measurements were used to estimate 1,726 regression coefficients for the 76 species-specific forms relating tree diameter growth to a number of tree, stand, environment, and management variables (Table 2, Table 3).

$$\ln(\text{dds}) = f(\text{tree, stand, environment, management variables}) \qquad [1]$$

where:

dds is the change in squared inside-bark diameter (inches squared)
f denotes a linear function of the predictors

A number of equations in FVS-Sn are used to simulate forest growth and yield under a range of management scenarios in five-year cycles unless otherwise specified. Models that determine the large tree (dbh ≥ 5”) diameter increment growth, tree mortality, height-dbh relationships, tree crown size, and small tree (dbh < 5”) growth and establishment drive FVS-Sn projections. The FVS framework allows equations or sub-models to operate together to arrive at stand-level predictions, including stem density per unit area, basal area, diameter distributions, and species composition.

Table 2. Number of observations used to fit each species-specific large tree diameter increment equations for 76 southern species. (Donnelly et al. 2001)

N	Species Code	Species
4132	60	red cedar
820	107	sand pine
26008	110	shortleaf pine
18736	111	slash pine
884	115	spruce pine
9190	121	longleaf pine
735	126	pitch pine
2590	128	pond pine
2602	129	eastern white pine
92313	131	loblolly pine
9860	132	Virginia pine
6428	221	bald cypress
5578	222	pond cypress
1141	260	hemlock
455	311	Florida maple
1426	313	box elder
28402	316	red maple
2763	318	sugar maple
277	330	buckeye, horse chestnut
2107	370	birch sp.
3513	391	American hornbeam
24404	400	hickory sp.
4485	460	hackberry sp.
482	471	eastern redbud
7775	491	flowering dogwood
1219	521	persimmon
4953	531	American beech
5463	540	ash
1989	541	white ash
3958	544	green ash
588	552	honey locust
1483	555	loblolly-bay
89	580	silver bell
3417	591	American holly
941	602	black walnut
38847	611	sweet gum
19207	621	yellow-poplar
376	651	cucumber tree
938	652	southern magnolia
6729	653	sweetbay
539	680	mulberry sp.
6104	691	water tupelo
10328	693	black gum
17098	694	swamp tupelo
840	701	eastern hophornbeam
5689	711	sourwood
1953	721	redbay
1892	731	sycamore
972	740	cottonwood
2944	762	black cherry
27487	802	white oak
6009	806	scarlet oak
13442	812	southern red oak
4239	813	cherry bark oak
2764	819	turkey oak
8105	820	laurel oak
2960	822	overcup oak
3605	824	blackjack oak
1504	825	swamp chestnut oak
831	826	chinkapin oak
24356	827	water oak
12188	832	chestnut oak
8401	833	northern red oak
505	834	Shumard oak
14841	835	post oak
10119	837	black oak
2916	838	live oak
1990	901	black locust
2134	920	willow
1577	931	sassafras
763	950	basswood
3230	970	elm
2294	971	winged elm
2024	972	American elm
791	975	slippery elm
639	999	unknown or not listed

Table 3. Tree species that have identical large tree diameter increment equations.

Species Code	Species	Growth equation used
1	misc. softwoods	red cedar
4	misc. hardwoods	eastern hophornbeam
10	fir sp.	pond cypress
90	spruce	hemlock
123	table mountain pine	Virginia pine
317	silver maple	red maple
372	sweet birch	birch sp.
450	catalpa	cottonwood
543	black ash	green ash
601	butternut	black walnut
650	magnolia sp.	sweetbay
654	big leaf magnolia	southern magnolia
660	apple sp.	mulberry sp.
743	big tooth aspen	cottonwood

FVS-Sn Sub-models

FVS-Sn sub-models are equations or algorithms that perform tasks needed to predict components of forest growth and yield. FVS-Sn is compromised of four main forest growth and yield sub-models: 1) large tree diameter growth (≥ 5” dbh); 2) small tree diameter growth (< 5” dbh); 3) mortality; and 4) regeneration and establishment. Additional model routines are present within the main sub-models. For instance, the large tree sub-model contains routines to estimate and calculate both height growth and crown ratio when no values are provided. These procedures are sometimes referred to as height and crown ratio “dubbing”. The mortality sub-model also contains multiple routines for determining tree mortality, depending on the stand conditions and likely causes of mortality.

The most prominent FVS-Sn sub-models are the large tree and mortality sub-models, which are the concentration of this thesis. The large tree and mortality sub-models are the biological and statistical foundation of growth and yield because of their direct relationship to basal area growth, and thus are the basis of understanding the core performance of FVS-Sn. While volume growth is certainly a key concern, it also depends on several complicating factors such as merchantability standards and volume units. In general, the volume growth of forests is closely related to the simpler measure of basal area, therefore predictions of volume will not be explicitly examined in this study.

Large Tree Diameter Growth Sub-model

The large tree diameter growth model for FVS-Sn was derived from four factors considered essential to tree diameter growth (Wykoff et al. 1982). The first factor is related to tree size and vigor in terms of its initial diameter, height, and crown ratio. Second, relationships among neighboring trees play a role in simulating the competitive environment for tree growth. Third, factors corresponding to the environment such as site quality, ecosystem unit classification, slope, and aspect influence tree growth. Fourth, management prescriptions such as thinning, fertilization, and rotation length determine tree vigor and growth as well.

The large tree diameter growth sub-model plays a primary role in simulations since FVS-Sn relies on the patterns of diameter increment to aid in the prediction of other tree characteristics (Crookston and Dixon 2005). Diameter increment is not predicted directly in FVS-Sn. Instead the dependent variable takes the form of the logarithmic transformation ln(dds), where dds is the change in squared inside bark diameter (in^2). The independent variable is predicted using the functional form of Eq. [1], with several variables used as predictors for each of the broad categories that influence tree growth (Table 4).

Table 4. Model terms used in Eq. [1] to predict ln(dds) in FVS-SN. (Donnelly et al. 2001)

Model component	Predictor term	Predictor description
ln(dds) =	b_0	Intercept
Individual tree variables	+ b_1*lndbh	natural log of dbh (at beginning of estimation period)
	+ b_2*dbh^2	squared dbh
	+ b_3*lncrwn	natural log of percent crown ratio
Site/stand/plot neighboring tree variables	+ b_4*hrel	relative height
	+ b_5*isiown	site index for the species
	+ b_6*plttbac	plot basal area per acre
	+ b_7*pntbalcx	plot basal area in tree larger than subject tree
Surrounding environment variables	+ b_8*tanslp	tangent of slope in degrees
	+ b_9*fcos	function of slope and cosine of aspect
	+ b_{10}*fsin	function of slope and sine of aspect
	+ b_{11}*fortype	categorical variable for forest type group
Management variables	+ b_{12}*ecounit	categorical variable for ecological unit group
	+ b_{13}*plant	categorical variable for plantation or natural stands

Once the change in the squared inside-bark diameter is calculated from the ln(dds) equation, the incremental change inside-bark diameter is calculated, Eq. [2].

$$dg = (dib^2 + dds)^{1/2} - dib \qquad [2]$$

where:

dg = incremental change in inside-bark diameter
dds = change in squared inside-bark diameter
dib = diameter inside bark at the beginning of the estimation period

Height, crown width, and crown ratio estimation

Tree height and crown ratio are important state variables used to compute diameter increment as well as modify growth in Eq. [1]. Each FVS-Sn projection requires a tree list. A tree list is a formatted dataset containing sample data information, from each tree within the stand to be simulated. The minimum requirements of the FVS-Sn tree list are the species and dbh of each tree. So, if no height or crown information is provided, the values must be estimated. Tree height can be estimated in FVS-Sn in two ways. The default Curtis-Arney Eq. [3] (Arney 1985; Curtis 1967) or by Eq. [4] developed by Wykoff (1982).

$$Height = 4.5 + p_2 e^{-p_3 DBH^{p4}} \qquad [3]$$

where:

$Height$ = total height in feet
p_2-p_4 = parameters to be estimated

$$Height = 4.5 + e^{b_0 + b_1\left(\frac{1}{DBH+1}\right)} \qquad [4]$$

where:

$Height$ = total height in feet
b_0-b_1 = parameters to be estimated

The Curtis-Arney form is used when FVS-Sn is run without model calibration, while the Wykoff form is used only when calibration occurs. Since no calibration will take place in this study, the Curtis-Arney form will be the only method of concern.

Crown width is estimated from the dbh of each tree, unless a measured value is included in the tree list. Crown width values are estimated by:

$$CW = b_o + b_1 * DBH^{b_2} \qquad [5]$$

where:

CW = crown width in feet
DBH = diameter at breast height in inches
b_0-b_2 = parameters to be estimated

Crown ratio is the ratio of crown length to total tree height. In FVS-Sn crown ratio is a method of expressing tree vigor for the prediction of tree height growth. FVS-Sn crown ratio is predicted using a Weibull function with mean crown ratio (MCR) required (Donnelly et al. 2001). Parameters are estimated from:

$$F_x(\mathrm{x}) = 1 - e^{-\left(\frac{x-a}{b_0+b_1 \cdot MCR}\right)^c} \quad [6]$$

where:
$F_x(x)$ = the Weibull function
b_0-b_1 = parameters to be estimated
a, b, and c are parameters

Individual trees are given crown ratio values from the Weibull distribution according to their diameter distribution rank and then scaled by a density-dependent factor (Dixon 1985).

Mortality sub-model

Mortality is calculated in each projection cycle of FVS-Sn by distinguishing between background mortality and density-related mortality. Background mortality is defined as the occasional mortality not attributed to density, insects, pathogens, fire, or other disturbances. This type of FVS-Sn mortality is applied when current stand density index (SDI) is < 55% of a stands' maximum SDI ($\mathrm{SDI}_{\mathrm{max}}$) and is first calculated yearly as:

$$RI = [1/(1+e^{\beta_0+\beta_1 * dbh})]/2 \quad [7]$$

where:
RI = annual probability of background mortality
dbh = tree diameter at breast height

Accumulated probability of mortality over the projection cycle length is computed using:

$$RIP = 1-(1-RI)^{yrs} \quad [8]$$

where:
RIP = accumulated probability of background mortality over a projection cycle
yrs = number of years in projection cycle

Density-related mortality probabilities are assigned to individual trees based on the relationship of the stand's density to a species-specific $\mathrm{SDI}_{\mathrm{max}}$ (Reineke 1933). Density-related mortality is computed differently depending on the quadratic mean diameter (QMD) (Donnelly et al. 2001). Also, the current stand SDI must be ≥ 55% of the stand $\mathrm{SDI_{max}}$ for any density-related mortality to occur. The maximum stand SDI is found by:

$$\text{Stand SDI}_{\max} = \frac{\mathrm{S_1SDI * S_1BA + S_2SDI * S_2BA + \ldots + S_nSDI * S_nBA}}{\text{Total Stand BA}} \qquad [9]$$

where:

$\mathrm{S_1SDI}$ = maximum SDI for the first species in the stand
$\mathrm{S_1BA}$ = total basal area of species 1 in the stand
$\mathrm{S_2SDI}$ = maximum SDI for the second species in the stand
$\mathrm{S_2BA}$ = total basal area of species 2 in the stand
$\mathrm{S_nSDI}$ = maximum SDI for the nth species in the stand
$\mathrm{S_nBA}$ = total basal area of the nth species in the stand

The current stand SDI is calculated on a tree by tree basis by:

$$Stand\ SDI = \sum [a + b(DBH_i)^2] \qquad [10]$$

$$a = 10^{-1.605} * [1 - (\frac{1.605}{2})] * [\sum \frac{(DBH_i)^2}{N}]^{\frac{1.605}{2}} \qquad [11]$$

$$b = 10^{-1.605} * (\frac{1.605}{2}) * [\sum \frac{(DBH_i)^2}{N}]^{(\frac{1.605}{2})-1} \qquad [12]$$

where:

$\mathrm{DBH_i}$ = diameter at breast height of the $\mathrm{i^{th}}$ tree record
N = total number of per acre in the stand

A series of mortality multipliers are calculated based on the quadratic mean diameter, and projection cycle stand SDI in relation to the stand $\mathrm{SDI_{max}}$.

Regeneration

The regeneration sub-model was not analyzed but it is an important part of FVS-Sn, thus it will be briefly mentioned. Tree regeneration in FVS-Sn occurs either by sprouting of cut trees and/or by specifying the Establishment extension keywords (Donnelly et al. 2001). The overwhelming majority of tree species capable of sprouting after harvest are hardwoods, thus the regeneration sub-model of FVS-Sn automatically generates sprouts for those tree species in Table 5.

The Establishment extension keywords allow the user to direct the regeneration of the stand in a manner that is consistent with what they have observed in past harvests. Keywords in this extension include PLANT or NATURAL which specify if the regeneration was planted or naturally occurred and others which are related to site preparation, insect and pathogen damage, and in-growth.

Table 5. Stump sprouting species in FVS-Sn.

Species
bald cypress
pond cypress
Florida maple
box elder
red maple
silver maple
sugar maple
hickory sp.
flowering dogwood
persimmon
ash
white ash
black ash
green ash
honey locust
loblolly-bay
American holly
butternut
black walnut
sweet gum
yellow-poplar
cucumber tree
southern magnolia
sweetbay
water tupelo
black gum
swamp tupelo
eastern hophornbeam
sourwood
big tooth aspen
sycamore
cottonwood
black cherry
white oak
scarlet oak
southern red oak
cherry bark oak
turkey oak
laurel oak
overcup oak
blackjack oak
swamp chestnut oak
chinkapin oak
water oak
chestnut oak
northern red oak
Shumard oak
post oak
black oak

Sensitivity Analysis (SA)

Models can be thought of as a series of equations, parameters, and variables developed to approximate a process or estimate an output of interest. Presumably, any substantive model quantity contains some degree of associated error, which may arise from a number of sources including uncertainty, natural variation, or observation error. Uncertainty refers to errors arising from an imperfect understanding of the system being modeled, such as may occur when a single parameter is used to explain a relationship involving a host of complex variables and their interactions. Natural variation refers to differences in directly measurable quantities that may vary spatially or temporally. Observation error refers to inaccuracies in the measurement or estimation of a quantity of interest, usually due to the limitations of sampling or the instruments and methods used to make observations. A model input may be subject to any or all three sources of error.

Some model quantities may be subject to only one or two of the sources of error, such as tree dbh and height, which are primarily subject to natural variation and observation error. Other quantities may be affected by all three sources, for example, a regression coefficient in an allometric equation relating tree height to dbh. Regardless of the sources of errors in model inputs sensitivity analysis (SA) aims to quantify how errors in model inputs contribute to errors or uncertainty in model *outputs* - in this case FVS-Sn predictions aggregated to the level of forest stands.

SA is the study of how variation in a model output or outputs can be attributed to the error or variation of model inputs. It is defined as the, “study of relationships between information flowing in and out of the model” (Saltelli et al. 2000) and more generally, it attempts to determine how the uncertainty in the input parameters affects the uncertainty of the output

(Helton and Davis 2003). The focus of SA is to quantify what the sensitivities and magnitudes of variation in outputs are, not what causes the output to arrive at specific values. Some authors emphasize that SA should be conducted on any model as part of its development (Saltelli et al. 2000); it identifies which model factors are important, their interactions, and how they affect the model behavior at different levels (Rabitz 1989).

Due to the inherent errors associated with models, the confidence of the model predictions (outputs) can be uncertain and thus must be addressed. The increased understanding of how model outputs react to perturbed model inputs allows for the modeler and user to gain confidence in the model. In Sensitivity Analysis by Saltelli et. al. (2000) it is stated that all modelers perform SA to determine:

1. if a model resembles the system or processes under study;
2. the factors that contribute to the output variability and that require additional research to strengthen the knowledge base;
3. the model parameters or parts that are insignificant, and thus can be eliminated;
4. if there is some region in the space of input factors for which the model variation is maximum;
5. the optimal regions within the space of the factors for use in a subsequent calibration study;
6. if and which factors interact with each other.

Sensitivity is measured by varying the input parameters some degree, often by some fraction of the parameters' standard deviation, and then analyzing how the variation in parameter value affects the model output. A classic method of measuring sensitivity is to iteratively vary one input parameter, while holding all the other parameters within the model constant. This technique is effective, but is computationally intensive. So, other sampling methods that are more efficient and computationally less intensive are used. Simple random sampling (SRS), Latin Hypercube sampling (McKay et al. 1979), Fourier Amplitude Sensitivity Test (Cukier et al. 1973; Cukier et al. 1978), and Winding Stairs (Chan et al. 2000) are sampling methods that vary all input parameters simultaneously for different model runs, rather than the impractical method of varying one at a time.

SA can be conducted to sift through a large number of parameters to determine those of most importance (factor screening), emphasize only a few input parameters (local SA), or to assign each input parameters influence on the output (global SA). In performing a SA, Monte Carlo analysis is often used when each input parameter is assigned a probability distribution function (pdf) from which n sample values are selected using one of the previously mentioned sampling methods. The model is then run n times, subsequently producing a distribution for the output of interest. For subsequent analysis the sensitivity or influence of each input on the output can then be assessed.

Latin Hypercube Sampling (LHS)

Latin hypercube sampling (LHS) is an efficient method of sampling from the model parameters' distributions for SA, and has been shown to be more effective than random sampling (Iman and Conover 1980). The technique was introduced by McKay, Beckman, and Conover (1979) to analyze the inputs and outputs of a model used to assess nuclear reactor safety. LHS is preferred over other sampling methods such as simple random sampling due to the stability created by stratifying across the entire input parameters distribution (Helton et al. 2005). The simplicity, flexibility, and reliable results of the LHS approach make it a widely accepted method for conducting many model simulations for SA (Iman and Helton 1988).

In general, LHS divides the range of each variable into small intervals of equal probability and selects values at random from each interval. More specifically, in LHS the distribution of every input parameter is divided into n non-overlapping intervals, where n determines the number of model runs to be executed. The number of input parameters is denoted as *k*. For each parameter, a random value is generated within each of the *n* intervals of the distribution; thus, *n* observations are drawn for each parameter. The results of LHS sampling are arranged in a *n* x *k* matrix denoted **R**. Each of the *n* values has both a systematic and random component, so they are dispersed efficiently across the parameters' distributions. Further, LHS, unlike simple random sampling, simultaneously stratifies on all input dimensions (Loh 1996). Assuming the parameter distributions are chosen objectively and in an unbiased fashion, each input parameter is represented equally in the LHS sample, regardless of how it may affect model predictions generated by the *n* simulations (McKay et al. 1979).

Response Surface and Error Budget

Response-surface analysis (RSA) relates a response, the output variable for which the SA took place, to the input parameters that affect the response (Box and Draper 1987). RSA has been applied, with good results, to large models or systems comprised of many variables that affect the model or system outcomes (Myers 1971).

Data sampled from the selection method, e.g. LHS, serve as independent variables or predictors in RSA. The corresponding output values from the model of interest serve as the observed response. Relationships between predictors and the response are approximated by multiple linear regression. Both linear and quadratic terms may be tested in RSA, and rank regression may be used to avoid issues of nonlinearity beyond what can be explained by quadratic terms. Quadratic terms found to be non-significant are removed, along with all non-significant linear terms. When the model fitting is complete and all the terms deemed significant remain, the resulting equation serves as the "response-surface model" or RSM. The RSM then allows for the contributions, negative or positive, of the input parameters towards the response to be readily identified and studied.

An error budget lists the relative importance of each input parameter according to the percentage of total prediction variance explained by the input variable upon the model response. Error budgets based on LHS follow from the results of a RSA that assumes a monotonic relationship between any individual input parameter and the model response (Iman and Conover 1980). The error budget is then determined from the RSM by partitioning the variance into the components that relate directly to each regression coefficient. Predictors are removed one at a time, refitting the RSM to compute the reduced model regression sum of squares (SS_{regred}). The reduced model sum of squares is then subtracted from the full model sum of squares (SS_{reg}) and the difference is divided by the total sum of squares (SS_{tot}) as in Eq. [13]. The resulting quantity, called a parameter's sensitivity index (SI) describes the percentage of the total model response variance attributed to the removed predictor (McKay 1997; McKay et al. 1999).

$$\mathrm{SI} = \left(\frac{SS_{reg} - SS_{regred}}{SS_{tot}} \right) \times 100\% \qquad [13]$$

Data and Methods

To conduct a SA for the FVS-Sn model, a series of steps were carried out that lead to results depicting model sensitivities. The first step involved acquiring a suitable forest inventory dataset and processing that data into a usable format. Second, detailed information concerning FVS-Sn input parameters and their uncertainties was obtained. Where detailed information was unavailable input parameter distributions were inferred from relevant sources or expert knowledge. Third, an efficient method of performing multiple FVS-Sn model simulations was then found, from which the outputs were summarized and analyzed relatively easily and effectively. Finally, analysis is accomplished through the use of statistical software capable of executing database management and statistical procedures which resulted in sensitivity indices, error budgets, and response surfaces.

In this study, several scenarios of SA's were carried out following the general steps laid out in the previous paragraph. These analyses included: 1) an initial test of the input parameters from the FVS-Sn large tree diameter growth model; 2) a scenario that assessed sensitivities in parameters pertaining to the large tree diameter growth sub-model, mortality sub-model, and the crown ratio and height sub-models; 3) a replicate of scenario 2 using a different set of random parameter values; 4) a combination of scenarios 2 and 3; and 5) a fifth scenario assessing sensitivities but accounting for correlations among some of the FVS-Sn parameters. The five scenarios and associated analyses guided the implementation of SA for FVS-Sn and served to accomplish the goal of rigorously testing the FVS-Sn model sensitivities for southern Appalachian hardwood forests.

Forest Inventory Dataset

Stand and tree inventory data are required as a starting point for FVS-Sn growth and yield projections. Inventory data for this study were obtained from the Virginia Tech Fishburn School forest, latitude 37°11'00", longitude 80°29'14". The Fishburn forest, 1,300 acres, is comprised of a typical southern Appalachian upland oak-hickory forest cover type. The inventory consisted of 107 plots, 0.1 acre (.04 hectare) on which species, dbh, and total tree height were measured in the summer of 2006. A total of 2,250 tree measurements were recorded in this inventory representing 33 different tree species. FVS-Sn limits the number of trees per stand in each model run to 1,350, so a random subset of 60 plots was selected to serve as the input dataset. The number of species within the new dataset was reduced to 28 through this sub-sampling step from the 33 found in the full dataset (Table 6).

Table 6. Tree species in Fishburn forest stand FVS-Sn dataset.

Species	
table mountain pine	Pinus pungens
pitch pine	Pinus rigida
eastern white pine	Pinus strobus
Virginia pine	Pinus virgiania
hemlock	Tsuga sp.
red maple	Acer rubrum
buckeye	Aesculus sp.
sweet birch	Betula lenta
American hornbeam	Carpinus caroliniana
hickory	Carya sp.
American beech	Fagus grandifolia
ash	Fraxinus sp.
yellow poplar	Liriodendron tulipifera
black gum	Nyssa sylvatica
sourwood	Oxydendrum arboreum
big tooth aspen	Populus grandidentata
black cherry	Prunus serotina
white oak	Quercus alba
scarlet oak	Quercus coccinea
chestnut oak	Quercus prinus
red oak	Quercus rubra
black oak	Quercus velutina
sassafras	Sassafras albidum
basswood	Tilia sp.
American elm	Ulmus americana
sugar maple*	Acer saccharum
redbud*	Cercis canadensis
dogwood*	Cornus florida
butternut*	Juglans cinerea
black walnut*	Juglans nigra
misc. hardwoods	
unknown	

* Not present in 60 plot sub-sample used for FVS-Sn sensitivity analysis

The forest inventory data are considered state or predictor variables rather than parameters in FVS-Sn. They must be arranged in the form of a tree list when entered into the model. The input tree list can accommodate up to 19 measured inventory variables, but only the species and dbh of each tree are required, (Table 7).

The pre-processor program *Format4FVS*, available from the FMSC website, http://www.fs.fed.us/fmsc/fvs/, was used to reformat the Fishburn Forest data inventory into the proper FVS tree list format, which was saved in an ASCII text file as *FB_rand_plots.fvs* (Appendix A1). The tree list contained a plot identification number, number of trees represented by each record, tree species, and dbh for each tree record involved in the simulation. Height data were excluded due to inconsistencies between FVS-Sn data requirements for the merchantable heights and the inventory, which measured only total tree height. The focus of this SA was the model parameters, not the state variables; therefore the tree list served simply as the starting point for model runs. Thus, the same Fishburn Forest dataset and corresponding input tree list was used for each model run carried out in the SA.

FVS requires three types of files to perform stand projections: the input tree list file (*.fvs*), stand file (*.slf*), and location file (*.loc*). These files are then referenced by a key file (*.key*) which serves as the main processing file for FVS model runs.

The tree list described previously serves as the starting point of the FVS-Sn projection system. The stand file, *FishburnCFI.slf* (Appendix A3), contains stand level information and inventory methods for the stand specified in the location file. There is a possibility of four stand record types A, B, C, and D, with only A and B required in the stand file. In this evaluation of FVS-Sn, only record types A and B were used. Record type A of the *FishburnCFI.slf* is concerned with designating the more general information about the stand of interest (Table 8) while record type B refers to the actual inventory methods and location of the sampled stand.

Table 7. Tree list field information.

Field	Referenced record type information	Information specific to Fishburn.loc
1	Plot ID	Used
2	Tree ID	Unused
3	Number of trees represented by a record	Used
4	Tree history	Unused
5	Species	Required
6	DBH	Required
7	Periodic diameter increment	Unused
8	Tree height	Unused
9	Height to point of top kill	Unused
10	Periodic height increment	Unused
11	Crown ratio code	Unused
12	Damage code 1	Unused
13	Severity code 1	Unused
14	Damage code 2	Unused
15	Severity code 2	Unused
16	Damage code 3	Unused
17	Severity code 3	Unused
18	Short-run prescription class	Unused
19	Tree value class	Unused

Table 8. Stand file record type A information.

Field	Referenced record type information	Information specific to FishburnCFI.slf
1	Record type	A
2	Stand identification code	FishburnCFI
3	Simulation tree list	FB_rand_plots.fvs
4	Independent site data	WithPointData
5	FVS variant	sn
6	Required to end record type	@

Table 9. Stand file record type B information.

Field	Referenced record type information	Information specific to FishburnCFI.slf
1	Record type	B
2	Stand identification code	FishburnCFI
3	Inventory year	2006
4	latitude	37
5	longitude	80
6	Location code	80811
7	Habitat type or plant association	M221Aa
8	Stand year of origin	@
9	Aspect	@
10	Slope	@
11	Elevation (in 100's of feet)	20
12	Large-tree BAF or plot radius (negative value = inverse of fixed radius plot)	-10
13	Inverse of small-tree fixed plot radius	10
14	DBH breakpoint between small and large-tree	3
15	Number of plots in tree list	2
16	Number of non-stockable plots in tree list	@
17	Stand sampling weight	@
18	Stockable proportion of stand	@
19	Diameter growth translation code	@
20	Diameter growth measurement code	@
21	Height growth translation code	@

The location file refers to information pertaining to the specific location of the inventory plots used in the simulation. The location file can accommodate two types of record types, but for this analysis only type A was used. In record type A (Table 10), the location file must have a location name and a stand file specified. The location file for this analysis is *Fishburn.loc* (Appendix A2). The location name was entered as “Fishburn Forest”, in the previously discussed stand file, *FishburnCFI.slf*. A purpose of the location file is to provide a way to name stands used in FVS-Sn projections.

Table 10. Location file information.

Field	Referenced record type information	Information specific to Fishburn.loc
1	Record type	A
2	Location name	Fishburn Forest
3	Stand file access method	@
4	Stand file name	FishburnCFI.slf
5	Map file type identifier	@
6	Name of the map file	@

The SUPPOSE user interface combines the tree list, stand, and location files, into one simulation file, *FB_test.key* (Appendix A4). Once the tree list, stand, and location files were embedded in the key file, it was determined that some keywords were necessary in the simulation to get the desired results. A total of five keywords were added to the key simulation file: NoTriple; NumCycle; TimeInt; EchoSum; and TreeList (Van Dyck 2000). The NoTriple keyword pertains to the formatting of the input files. It changes the default setting of FVS so that a tree's record is not randomized into three separate records, but remains only one tree record. The NumCycle keyword specifies how many cycles are to be run in the prediction; for this simulation only one cycle was desired. TimeInt denotes the length in years of the projection cycle. The cycle length for this analysis was set at 10 years.

The EchoSum and TreeList keywords correspond to how FVS formats output from model simulations. The EchoSum keyword ensures that a summary output file will be generated and saved for the projection. The summary file contains basic stand information about the initial stand as well as the projected stand such as trees per acre, basal area, stand-density index (SDI), height, quadratic mean diameter (QMD), volume information, and mortality. Output containing information for each tree within the tree list is generated and saved when the TreeList keyword is specified. The tree list output file contains the same information as that of the summary output file but produces a record for each tree. Once all the keywords were selected and verified for accuracy the *FB_test.key* file was updated to possess all information needed to execute FVS-Sn model runs.

FVS-Sn Source Code and Batch Programming

The requirement for SA is the execution of multiple model runs while varying the input parameters in order to determine the model's sensitivity to such variation. The SUPPOSE user interface allows for ease of setting up single model runs or runs involving multiple stands, but was not designed to accommodate the need to perform multiple simulations while varying parameter values. As such, it was necessary to execute FVS-Sn in a continuous "batch-mode" and to work with a modified executable program that allowed a means of varying parameter values at run-time. The FMSC supplied a modified version of the source code for FVS-Sn, which possessed the needed capabilities.

The modified source code received from the FMSC was written in FORTRAN and implemented all the standard procedures available in FVS-Sn. In addition, it accessed a supplementary parameter file "*DATAIN.dat*" that contained coefficient values to be assigned to the sub-model equation parameters for a given model run. Due to the dependence of the modified executable program *FVSsn.exe* on the input parameter coefficients, the *DATAIN.dat* file, simulation *.key* file, and the input tree list file must be located in the same computer directory as that of the executable program.

The command-line architecture of the modified executable allowed for the use of MS-DOS batch programming directives to repeatedly run the model as many times as desired. Further, the capability of varying the input parameters for each model run was achieved through the structure of the source code and its call to the *DATAIN* file each time it executes. The

DATAIN file specified the input parameter coefficient values for each FVS-Sn model run. Separate *DATAIN* files were created for each model run containing different input parameter coefficient values. In summary, the modified source code met both requirements of SA, the ability to execute multiple model runs and vary model coefficient values with each model execution. In this study, the number of model runs for each SA scenario was initially set at 5,000. Tests were conducted to determine whether this sample size would give satisfactory results, or whether additional replications would be needed.

Batch programming is a method of using a text file containing a series of commands to be executed at MS-DOS command line. It allows for automatic, sequential execution of programs that use command-line architecture. The batch program referenced a separate file, *sntest.rsp*, which contains a series of text entries that respond to a series of console displayed queries that are normally answered with keyboard entries. The contents of the *sntest.rsp* file are “piped” to the executable program with the “batch-mode” command “<”. The *sntest.rsp* file primarily lists the appropriate key file, input tree list, and output file names (Table 11).

Table 11. Contents of the sntest.rsp file.

File type	Specified file
Simulation	FB_TEST.key
Tree list	FB_rand_plots.fvs
Main output	Output1.out
Tree list output	Output1.tls
Summary output	Output1.sum
CHEAPO output	NUL

The batch program, *runnew.bat*, was created to reference the corresponding *DATAIN.dat* file and FVS-Sn executable, pipe the *sntest.rsp* file containing the required file names, and then specify the output name and location (Figure 1).

```
copy DATAIN0.dat Datain.dat
FVSsn.exe < sntest1.rsp > cmd_line_out0.txt
copy output1.* output0.*
copy DATAIN1.dat Datain.dat
FVSsn.exe < sntest1.rsp > cmd_line_out1.txt
copy output1.* output1.*
copy DATAIN2.dat Datain.dat
FVSsn.exe < sntest1.rsp > cmd_line_out2.txt
copy output1.* output2.*
```

Figure 1. Sample of contents within *runnnew.bat* file.

The *runnew.bat* batch file runs the FVS-Sn model using a unique *DATAIN* file for each run. Model outputs are named sequentially, *Output0.*-Output4999.**, and copied to a specified folder for subsequent analysis. On average the *runnew.bat* batch file took approximately 1.5 hours to perform 5,000 FVS-Sn model runs.

DATAIN Files and Source Code Recompiling

The *DATAIN* file format provided by the FMSC contained text comments and values for the associated input parameter coefficient values for several FVS-Sn sub-models. The input parameters included: crown ratio height modifier coefficients, relative height modifier coefficients, Curtis-Arney height calculation coefficients, budwidth values, bark ratio coefficients, small tree height growth regression coefficients, large tree diameter increment equation (lndds) coefficients, and intolerance coefficients.

For ease of functionality and due to the large number of model runs required in SA, modifications were made to the *DATAIN.dat* file to remove the text comments. Since the original *DATAIN.dat* file was modified, the FVS-Sn source code required recompiling. To simplify re-compilation on a Windows based PC, the *Cygwin* Unix shell was downloaded from http://www.cygwin.com/ and installed. The *Cygwin* shell works much like a Unix command prompt in that one navigates to the folder containing the *DATAIN.dat* file and modified

FORTRAN code by specifying the appropriate file paths. Then one enters the command “make FVSsn” causing the *Cygwin* shell to call a FORTRAN compiler which recompiles the FVS-Sn executable and saves it in a specified folder location. The modified executable was then able to read the modified *DATAIN* file structure that contained only parameter coefficient values (Table 12).

Table 12. Original *DATAIN.dat* parameters and line numbers with no comments.

Parameter Coefficients	Line numbers
Crown ratio height growth modifiers	1
Relative height modifying value and crown ratio factor	2-7
Height growth calculation	8-97
Curtis-Arney height dubbing	98-187
Budwidth	188-196
Bark ratio	197-286
Small tree height growth	286-331
Big tree diameter growth	332-871
Ecological units	530-727
Forest type	728-853
Crown ratio dubbing and crown change	980-1159
Shade intolerance	1160-1168

Since 5,000 model runs were used in the initial analyses, a method was needed to create a different *DATAIN* file for each model run. To accomplish this task, a SAS® script was written to produce *DATAIN.dat* files for each draw of the LHS sample. The resulting *DATAIN* files were named, 0-4999, with *DATAIN0.dat* containing nominal values of the model coefficients to match the results of unmodified FVS-Sn output. The new *DATAIN* files were then referenced by the batch file and copied as *DATAIN.dat* so that the FVS-Sn model will execute using the stated *DATAIN0-4999* files (Figure 1).

FVS-Sn Model Simulations

Scenario 1: Initial test

Initially, a test was performed to develop and verify the sequence of steps needed to conduct an SA of FVS-Sn, and to understand its performance and speed. For this SA scenario, only the large tree diameter growth model parameters were varied using LHS. Dennis Donnelly, retired forester with the FMSC supplied SAS® logs of the FVS-Sn model fitting which contained the standard errors and nominal values of each parameter used in the large tree diameter growth sub-model (Appendix D1). From this information it was possible to simulate normal random deviates for each parameter from which 5,000 values were sampled using LHS. The sampled values of each parameter were then randomly mixed and combined – 2,700 parameters in each *DATAIN* file with 5,000 *DATAIN* files being required for this SA, totaling 13,500,000 coefficient values. The LHS and pairing of each parameter value was implemented in C/C++ based on Radtke (1999). The previously mentioned SAS® script in turn created *DATAIN0-4999*, and thus the batch program was executed creating 5,000 model outputs.

Test scenarios 2, 3, 4 and 5

To account for other sub-models and parameters involved in scenario 1 an expanded set of tests was needed. The number of parameters in the *DATAIN* file was expanded in the second scenario to account for mortality, height, crown, shade tolerance, and SDI model components. Scenarios 2 and 3 involved n = 5,000 model runs again requiring the creation of 5,000 distinct *DATAIN* files, however, the number of parameters tested increased to 3,743. Scenario 3 was identical to scenario 2 except that a different LHS sample was drawn by modifying the random number seed, and scenario 4 served as a combination of scenarios 2 and 3 with n = 10,000. The replication step was intended to test whether the initial LHS sample size (*n*=5,000) was sufficient to draw conclusions for SA.

In scenario 5 pair-wise correlations were specified between certain input parameters. The need to account for correlations in forestry growth model inputs has been widely noted (Guan 2000; Radtke et al. 2002). The following section describes the investigation into uncertainty distributions for FVS-Sn parameters and how some correlations were deemed necessary.

Parameter Information and Distributions

Large tree diameter increment growth

Large tree diameter growth in FVS-Sn is based on the model of Stage, Wykoff, and Crookston (Stage 1973; Wykoff 1990; Wykoff et al. 1982). The model contains a possible thirty estimated parameters - the intercept, three tree related parameters, four site specific variables, ten environment related variables, and twelve management variables - for each of the 90 tree species present in FVS-Sn. In practice no species requires more than thirteen parameters for predicting diameter growth increment, b_0-b_{13} (Table 4). Regression coefficients were reported by Donnelly et al (2001). Standard errors were obtained from Dennis Donnelly (personal communication) who provided regression output summaries that included the coefficient standard errors. Based on regression theory, the parameters in the large tree diameter growth model were determined to have normal distributions with μ and σ corresponding to regression parameter estimates and standard errors (Figure 2, Appendix D1).

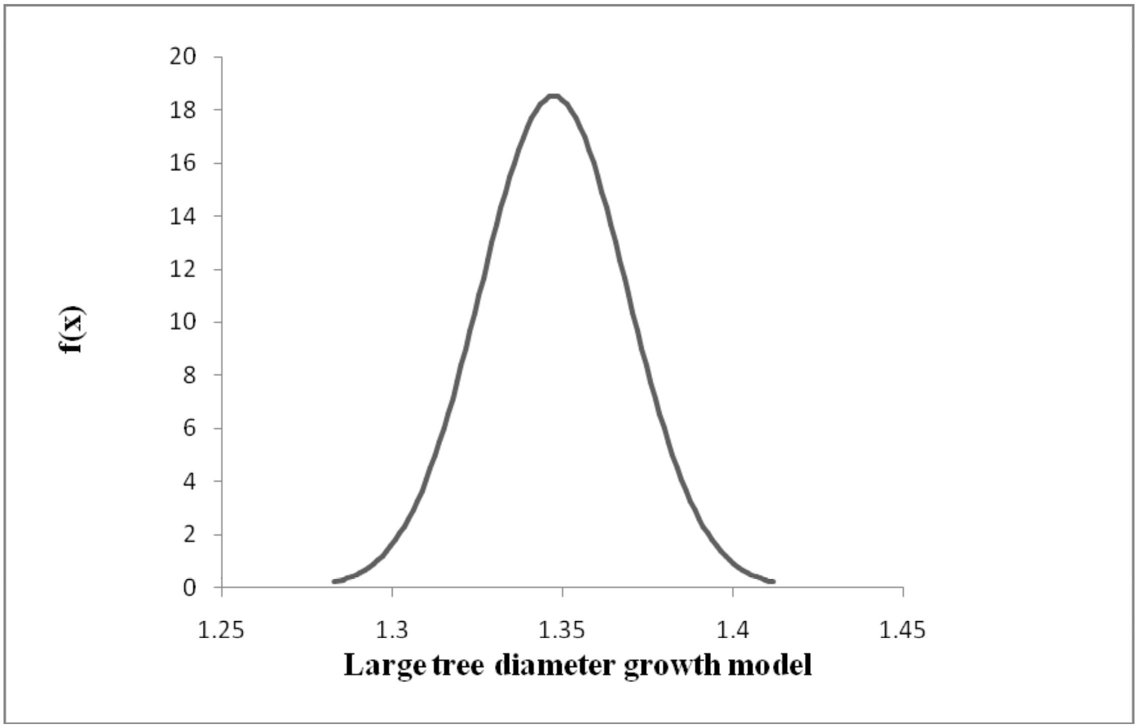

Figure 2. Normal distribution of chestnut oak lndbh (b_1) parameter with a mean of 1.3474 and a standard error of 0.0215.

Height prediction

Height prediction in FVS-Sn employs a functional form Eq. [3] attributed to Curtis (1967) and Arney (1985). The height prediction equation depends on three regression parameters, p_2, p_3, and p_4 that require estimation. Nominal values for parameters p_2, p_3, and p_4 were adopted from Donnelly et al (2001). Variance of the parameters was estimated by fitting Eq. [3] to height versus diameter data using nonlinear OLS regression. The data used for fitting consisted of 3,255 individual tree measurements observed in 1980 on 66 field plots, roughly 0.08 ha (1/5th acre) in size, in mixed-species southern Appalachian hardwoods stands (Bowling et al. 1989). Due to weak height-diameter relationships for several species and to avoid non-convergence of regression analyses, the data were grouped into six species groups: 1) red oaks (*Q. velutina, Q. rubra, Q. coccinea*); 2) white oaks (*Q. alba, Q. prinus*); 3) maples (*Acer* spp.); 4) sourwood (*O. arboreum*); 5) yellow poplar (*L. tulipifera*); and 6) the default group for all remaining species.

Estimated regression parameters $\hat{p}_2$, $\hat{p}_3$, and $\hat{p}_4$ and their respective standard errors $\hat{\sigma}_{p_2}$, $\hat{\sigma}_{p3}$, and $\hat{\sigma}_{p4}$ were used to estimate species-group-specific coefficients of variation for each parameter, e.g, $\hat{C}V(p_2) = \left|\frac{\hat{\sigma}_{p_2}}{\hat{p}_2}\right|$ (Table 13). The CV estimates were then multiplied by the FVS-Sn nominal values from Donnelly et al. (2001) to approximate their respective standard errors. Strong correlations were noted between coefficients $\hat{p}_2$, $\hat{p}_3$, and $\hat{p}_4$. Examination of regression correlation matrices showed average correlation of corr(p_2, p_3) = -0.92, (p_3, p_4) = -0.97, and corr(p_2, p_4) = 0.98. In analyses that accounted for correlated parameters, these values were assigned for all species to account for the observed relationships between regression parameters in the height prediction model.

Table 13. Regression results from height dubbing fitting of Eq. [3] used to estimate standard errors for the parameter values reported by Donnelly et al. (2001).

Species	n*	$\hat{p}_2$	$\hat{\sigma}_{p_2}$	$\hat{C}V(p_1)$	$\hat{p}_3$	$\hat{\sigma}_{p3}$	$\hat{C}V(p_2)$	$\hat{p}_4$	$\hat{\sigma}_{p4}$	$\hat{C}V(p_3)$
maple	338	88.56	6.979	0.079	4.99	1.478	0.296	-1.25	-0.246	0.196
yellow-poplar	369	131.20	17.633	0.134	5.15	1.974	0.383	-0.99	-0.278	0.280
sourwood	31	103.80	67.266	0.648	2.68	0.575	0.215	-0.68	-0.571	0.834
white oaks	800	134.50	15.815	0.118	4.04	0.566	0.140	-0.80	-0.139	0.174
red oaks	682	163.41	31.500	0.193	4.09	0.516	0.126	-0.67	-0.150	0.223
default/all				0.145			0.201			0.220

[*] Total (2,220) does not equal available observations (3,255) because species with weak relationships or whose regression analyses did not converge

Crown ratio

Crown ratio is defined as the ratio of crown length to total tree height. In FVS-Sn crown ratio is predicted, when not supplied in the input tree list, by a Weibull function, Eq. [6]. The equation contains four estimated parameters, a, b_0, b_1, and c. The location parameter a is treated as a constant in FVS-Sn, therefore, its variance is assumed to be zero. Nominal values for parameters b_0, b_1 and c were reported by Donnelly et al (2001). Variance of the parameters was estimated indirectly by fitting Eq. [6] to crown ratio data using OLS nonlinear regression. The data used for fitting consisted of 3,255 individual tree measurements observed in 1980 on 66 field plots, roughly 0.08 ha (1/5th acre) in size, in mixed-species Appalachian hardwoods stands (Bowling et al. 1989).

Estimated regression parameters $\hat{b}_o$, $\hat{b}_1$, and $\hat{c}$ and their respective standard errors $\hat{\sigma}_{b_o}$, $\hat{\sigma}_{b_1}$, and $\hat{\sigma}_c$ were used to estimate species-specific coefficients of variation for each parameter, e.g, $CV(b_o) = \left| \frac{\hat{\sigma}_{b_o}}{\hat{b}_o} \right|$ (Table 14). The FVS-Sn nominal values from Donnelly et al. (2001) were then multiplied by the CV estimates to estimate their respective standard errors. Negative correlation was consistently noted between coefficients $\hat{b}_o$ and $\hat{b}_1$, so the value $\hat{r}$ = corr($\hat{b}_o$, $\hat{b}_1$) = -.98 was adopted for all species to account for the negative relationship between these parameters (Table 14). The average correlations involving parameter c were small, corr(b_0,c) = .015 and corr(b_1,c) = -.04, so we considered them to be negligible and did not account for them in further analysis.

Table 14. Regression results from crown ratio fitting of Eq. [6] used to estimate standard errors for the parameter values reported by Donnelly et al. (2001).

Species	n*	$\hat{b}_o$	$\hat{\sigma}_{b_o}$	$\widehat{CV}(b_o)$	$\hat{b}_1$	$\hat{\sigma}_{b_1}$	$\widehat{CV}(b_1)$	$\hat{r}(b_o,b_1)$	$\hat{c}$	$\hat{\sigma}_c$	$\widehat{CV}(c)$
red maple	338	-6.26	0.764	0.122	1.06	0.022	0.020	-0.97	4.12	0.163	0.040
sweet birch	398	-8.30	0.621	0.075	1.12	0.018	0.016	-0.97	4.25	0.147	0.035
hickory sp.	56	-6.45	2.030	0.315	0.97	0.059	0.061	-0.97	4.73	0.785	0.166
yellow-poplar	369	-3.36	0.516	0.154	0.96	0.017	0.018	-0.97	4.95	0.185	0.037
sourwood	31	10.11	7.268	0.719	0.48	0.229	0.474	-0.99	3.68	0.787	0.214
black cherry	120	-8.01	1.569	0.196	1.09	0.046	0.042	-0.99	5.38	0.373	0.069
white oak	297	-7.73	0.765	0.099	1.11	0.021	0.019	-0.97	4.15	0.163	0.039
scarlet oak	115	-1.88	2.444	1.299	0.92	0.064	0.069	-0.99	4.10	0.313	0.076
chestnut oak	503	-3.22	0.726	0.225	0.98	0.021	0.022	-0.99	4.16	0.116	0.028
northern red oak	459	-5.57	0.872	0.156	1.04	0.023	0.022	-0.99	4.84	0.146	0.030
black oak	108	-8.08	1.459	0.181	1.05	0.038	0.037	-0.98	6.15	0.571	0.093
black locust	118	-1.82	1.535	0.844	0.86	0.054	0.063	-0.98	4.38	0.412	0.094
default/other				0.231			0.031	-0.98			0.047

*Total (2,912) does not equal available observations (3,255) because minor species were omitted.

Background mortality

Background mortality is predicted from a logistic regression model, Eq. [7] and the cumulative probabilities of background mortality over a projection interval are estimated from Eq. [8]. The background mortality equation requires two parameters to be estimated, b_0 and b_1. Nominal values for parameters b_0 and b_1 were adopted from Donnelly et al (2001). Variance of the parameters was estimated by fitting Eqs. [7] and [8] to 52,693 individual-tree measurements observed over a four-year interval from the USDA Forest Service Forest Inventory and Analysis in Tennessee, 1999 – 2003. Tree status (live or dead) and dbh were used in developing regression models for four species groups corresponding to groups used by Donnelly et al. (2001) for background mortality modeling. The four species groups generally include the following tree species categories: 1) commercially unimportant or subordinate hardwood species including red maple, sourwood, magnolia, black gum, dogwood, and others; 2) pines including Virginia pine and eastern white pine; 3) commercially important hardwoods including oaks, hickories and yellow poplar; and 4) eastern redcedar.

Estimated regression parameters for $\hat{b}_o$ and $\hat{b}_1$, and their respective standard errors $\hat{\sigma}_{b_o}$ and $\hat{\sigma}_{b_1}$, were used to estimate species-specific coefficients of variation for each parameter, e.g, $\hat{C}V(b_o) = \left|\frac{\hat{\sigma}_{b_o}}{\hat{b}_o}\right|$ (Table 15). The CV estimates were then multiplied by the FVS-Sn nominal values from Donnelly et al. (2001) to approximate their respective standard errors. In regression analysis, negative correlation was noted between coefficient estimates $\hat{b}_o$ and $\hat{b}_1$, so the value $\hat{r} = \mathrm{corr}(\hat{b}_o, \hat{b}_1) = -0.93$ was adopted for all species to account for the negative relationship between these parameters (Table 15).

Table 15. Regression results from large tree background mortality fitting of Eqs. [7] and [8] used to estimate standard errors for the parameter values reported by Donnelly et al. (2001).

Group	n	b_0	stderr(b_0)	$\widehat{CV}(b_0)$	b_1	stderr(b_1)	$\widehat{CV}(b_1)$	corr
1	16004	2.129	0.084	0.039	0.053	0.010	0.192	-0.932
2	7459	1.627	0.081	0.050	-0.025	0.008	0.336	-0.934
3	26709	2.317	0.077	0.033	0.075	0.008	0.107	-0.930
4	2521	2.320	0.445	0.192	0.136	0.063	0.461	-0.971

Shade intolerance

Each of the 90 tree species within FVS-Sn has an associated shade intolerance parameter (Appendix D2). The shade intolerance values range between 0 and 1, with a value closer to 1 being assigned for species intolerant of shade, and a value closer to 0 being assigned for shade tolerant species. Shade intolerance values are used in FVS-Sn in the prediction of mortality. Unlike the regression parameters described thus far, intolerance coefficients are not determined from regression analysis. Instead, they are determined from widely-accepted principles of tree silvics, such as those documented in (Burns and Honkala 1990). Having no better means of determining shade intolerance distribution these parameters were assumed to follow a beta distribution bounded between [0,1], with each nominal intolerance value (Appendix D2) specified as the mode of the distribution (Figure 3). The variance of each distribution was set at 0.01, thus specifying the beta distributions for each species.

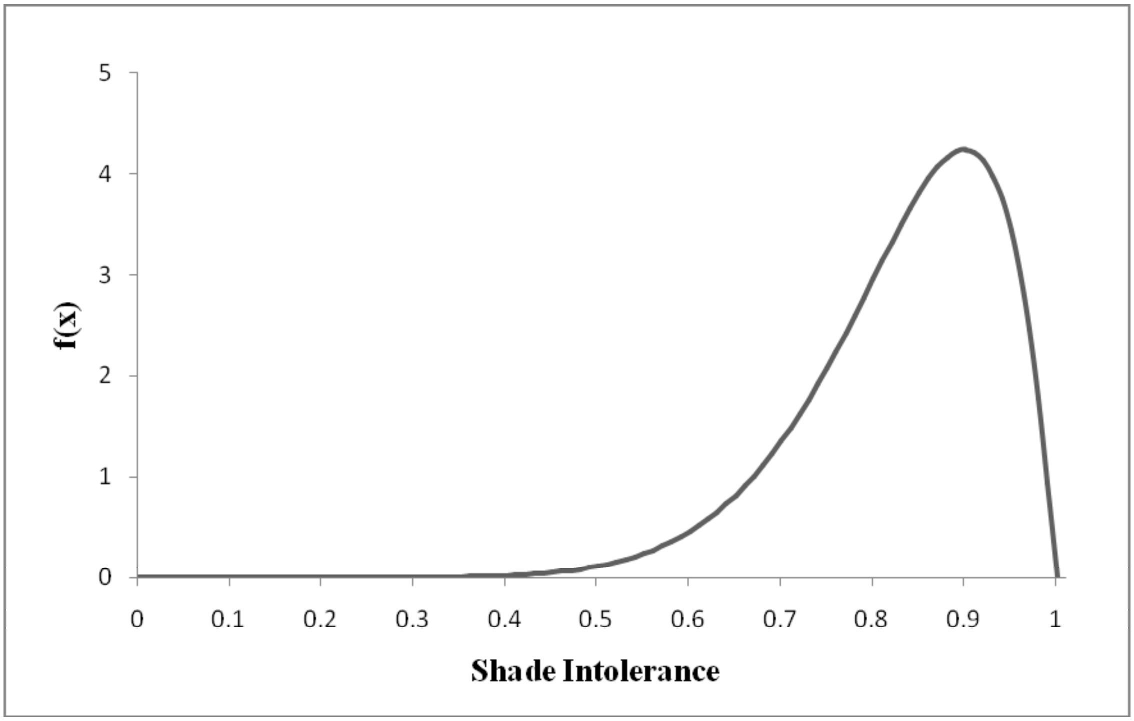

Figure 3. Beta distribution of scarlet oak with nominal shade intolerance of 0.9 and variance of .01.

Maximum SDI values

The default SDI_{max} values in FVS-Sn correspond to the 141 forest types described by Arner et al. (2001) (Appendix D3). Since the SDI_{max} values for each forest type are predetermined values, no standard error estimates were directly or indirectly available. As with the shade intolerance parameters, several simplifying assumption were used to arrive at distributions for SDI_{max} values.

First, a uniform distribution was specified for the SDI_{max} values, as is typical in uncertainty assessments when no better information is available (Green et al. 1999). Nominal values of the SDI_{max} values from Donnelly et al. (2001) were rounded to the nearest tens place, as is done in the FVS-Sn FORTRAN code, and then specified as the upper limit of the uniform distribution (Appendix D). The lower limit uniform distribution was set at 75% of the nominal values.

To demonstrate an example the nominal value of the chestnut oak/black oak/scarlet oak forest type (USDA Forest Service forest type code = 515) reported in Donnelly et al. (2001) was 422. This value rounds to 420 and is set as the upper limit of the uniform distribution for this parameter. The lower limit of the distribution was found by subtracting 25% of 420 from 420, 420 – 105 = 315, and thus the range of the SDI_{max} for forest type 515 from which LHS selected values was 315 to 420, Uniform [315,420] (Figure 4).

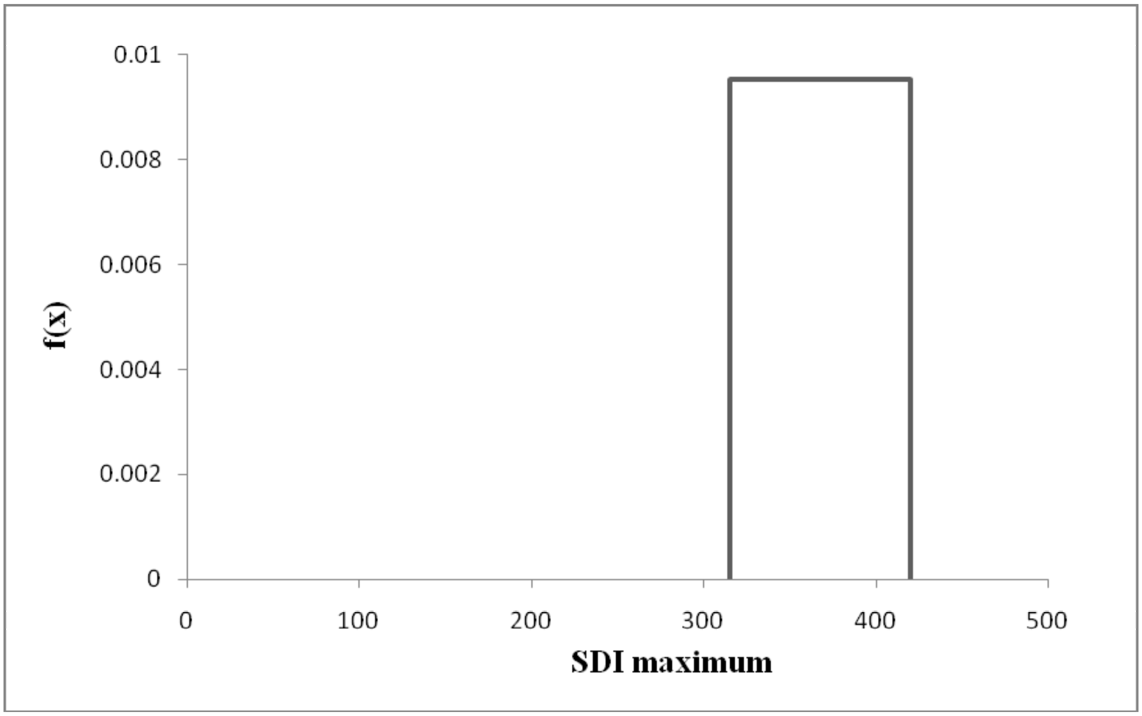

Figure 4. Uniform distribution of the chestnut oak/black oak/scarlet oak forest type with upper and lower limits parameters $u = 420$ and $l = 315$.

SDI threshold values

Mortality rates in FVS-Sn are computed based on one of three stages, based on a stands relationship to maximum SDI. Only background mortality occurs when SDI < 55% of SDI_{max}. An intermediate mortality rate is assigned when SDI ranges between 55% and 85% of SDI_{max}. The highest rate of mortality occurs when SDI > 85%. The threshold values 55 and 85 are likely to represent important model parameters and thus were included here for SA. As with other parameters, the SDI thresholds are not determined by regression, therefore several simplifying assumptions were used to assign their distributions.

First, the upper and lower SDI thresholds were set as beta distributions with modes of 0.55 and 0.85 respectively, and each with a variance of 0.01 (Table 16). The beta random variables selected by LHS were then multiplied by 100 to scale them to the required FVS-Sn model values. To account for the likelihood that the lower and upper thresholds were positively correlated, a value of $r = 0.9$ was assigned. This assumption also minimized the possibility that the minimum threshold exceeded the maximum, which would be numerically possible but heuristically non-sensible. The variance was set at 0.02, thus slightly widening the distribution.

Table 16. SDI threshold beta distribution parameter estimates.

Parameter	alpha	beta	mode	Fvs-Sn scale
Lower	11.85	9.88	0.55	55
Upper	12.37	3.00	0.85	85

Computer Simulation

Information concerning the distributions of each parameter are specified according to their hyper-parameters, that sufficiently describe the corresponding probability distribution functions (pdf). For example, the mean (μ) and standard error (σ) describe a normal distribution's pdf (Figure 2), parameters α and β describe a beta distribution's pdf (Figure 3), and parameters l and u describe a uniform distribution's pdf (Figure 4). The incomplete beta function of Press et al (1992), which employs a modification of Lentz's method (1976) and the normal approximation of Beasley and Springer (1977), were used to obtain beta and normally distributed random variables from the inverse cumulative distribution functions (cdf), respectively.

The number of distributions specified for the LHS sampling was 3,743, of which 2,700 related to the large tree diameter increment growth model coefficients, 270 to the height dubbing model coefficients, 360 to the crown dubbing model coefficients, 180 to the large tree background mortality coefficients, 90 to the intolerance parameters, 141 to the SDI maximum parameter values, and 2 to the SDI threshold values.

The LHS algorithm was implemented in C, using the uniform random number generator *rand1* of Park and Miller (1988). For some simulations in scenario 5, correlations were induced using the algorithm of Iman et al. (1982) specifying correlations as listed in Table 13, Table 14, and Table 15. The FVS-Sn tree list output files, *Output0-4999.tls* from each model run were reformatted and summarized using SAS® data steps, procedures, and macro language (Appendix C2). The tree list outputs were aggregated from the tree-level to the stand-level. Computing stand-level statistics for each run such as stem density, basal area, tree mortality, quadratic mean diameter, and 10-year basal area increment.

To calculate sensitivity indexes, a series of regression analyses was carried out. This was accomplished by arranging the SA coefficient values for each model run in a dataset format with one field containing the SA run number (1-5,000), another field containing the variable of interest, 10-year stand basal area per acre increment, and 3,743 coefficient fields, each containing the coefficient values of the corresponding SA model run. The resulting data base had 5,000 records and 1,146 fields that corresponded to the run number, the 10-year stand basal area increment response, and the 1,144 model coefficients associated with each species found in the input tree list.

A series of 1,144 regressions were performed in the SAS proc reg function with the 10-year stand basal area increment as the response; one for the full model (all 1,144 variables) and a series of reduced models each of which excluded a single parameter from the full model (Appendix C3). Equation [13] was employed to compute the sensitivity for each parameter. The sensitivities were further summarized by grouping into species, parameter, and sub-model groups. The full model of scenarios 4 and 5 served as the response surface for examining the magnitudes and directions of marginal relationships between parameters and the response, 10-year basal area increment.

Results

Initial FVS-Sn SA Test Scenario

Table 17 lists FVS-Sn large tree diameter growth sub-model parameter sensitivities in the initial test that accounted only for the distributions in that sub-model. The sensitivity of each parameter value attributed to FVS-Sn 10-year stand basal area increment was found using Eq.[13]. The results demonstrate the sub-model's high sensitivity to only five influential parameters, while the remaining 25 parameters account for only about 4.5% of the total model sensitivity (Table 17).

Table 17. FVS-Sn large tree diameter increment growth sub-model parameter sensitivities.

FVS-Sn Parameter	Total Model Parameter Sensitivity
Intercept	26.42
Log of percent crown ratio	21.95
Log of DBH	14.81
Relative height	7.52
Species site index	4.36
other parameters	4.52
Total model sensitivity	79.58

To examine sub-model sensitivities by species, the individual sensitivities were summed across all model parameters (Table 18). Comparisons were made between the initial species basal area per acre and the total FVS-Sn species sensitivity (Table 18). The initial stand basal area per acre was comprised of approximately two-thirds oak, specifically chestnut and scarlet oaks. Softwoods such as eastern white pine, pitch pine, and hemlock accounted for a third of the remaining basal area per acre and about one-tenth of the total. Most of the model sensitivity is related to only a few species including chestnut oak, pitch pine, scarlet oak, and eastern white pine (Table 18).

As might be expected, the greatest sensitivity corresponds to chestnut oak, the species with the highest initial basal area in model projections. Beyond that, however, basal area dominance rankings do not directly correspond to species sensitivity rankings. Comparisons of the rankings show that pitch pine, a relatively minor component of the stand, accounts for more than a quarter of the total model sensitivity, while white oak, a major component of the initial stand, accounts for only one percent of the total model sensitivity (Table 18).

Table 18. Species sensitivity attributed to the FVS-Sn large tree diameter increment growth sub-model.

Species	Basal area per acre	Total Sensitivity	Dominance rank	Sensitivity rank
chestnut oak	33.13	28.29	1	1
scarlet oak	16.51	10.56	3	3
white oak	12.81	1.07	4	8
black oak	7.10	1.83	5	7
eastern white pine	5.23	10.22	6	4
pitch pine	3.28	21.15	7	2
hemlock	2.69	3.68	8	5
remaining species	23.60	2.79	2	6
Total	104.35	79.58		

A further break down of FVS-Sn sensitivities (Table 19) for each parameter by species reinforces the observation that relatively few parameters and species account for the majority of FVS-Sn large tree diameter growth sub-model sensitivity. Generally, the species with the most total sensitivity also contributed the largest sensitivity for each parameter. The intercept and log of percent crown ratio (lncrwn) parameter ranks mirror those of the total model sensitivity, for which chestnut oak has the highest ranking, followed by pitch pine, scarlet oak, and eastern white pine. In contrast the log of dbh (lndbh) parameter shows pitch pine having the highest sensitivity index, followed by chestnut oak, scarlet oak, and eastern white pine. Rankings of species specific sensitivities for the relative height (hrel) and remaining parameters differ somewhat from the ranking of total species sensitivities (Table 19).

Table 19. FVS-Sn species sensitivity attributed to each parameter.

Species	Intercept	lncrwn	lndbh	hrel	Remaining parameters	Total species sensitivity
chestnut oak	9.84	8.96	4.64	2.50	2.35	28.29
scarlet oak	3.83	2.61	1.70	1.04	1.38	10.56
white oak	0.31	0.25	0.23	0.12	0.16	1.07
black oak	0.63	0.36	0.36	0.14	0.35	1.83
eastern white pine	3.62	2.18	1.64	1.54	1.24	10.22
pitch pine	6.03	5.81	5.55	1.50	2.26	21.15
hemlock	1.30	1.26	0.39	0.44	0.29	3.68
remaining species	0.86	0.52	0.31	0.23	0.86	2.79
Total parameter sensitivity	26.42	21.95	14.81	7.52	8.88	79.58

Further analysis of the dominance and sensitivity rankings revealed different relationships for initial basal area per acre and total species sensitivity for that of hardwoods and softwoods (Figure 5). In general, softwood species had a disproportionately higher sensitivity relative to their initial basal area than hardwood species. Pitch pine, eastern white pine, and hemlock show a relatively high sensitivity in relation to their basal area dominance in the stand. The relationship between total species sensitivity and initial basal area of hardwoods generally increased.

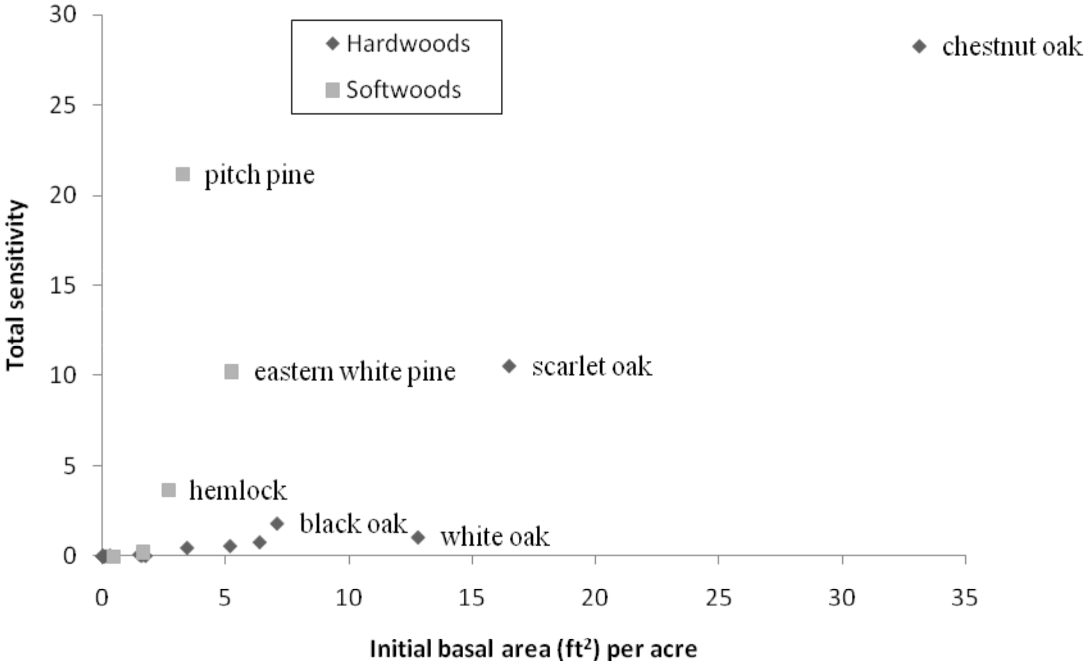

Figure 5. Comparison of initial species basal area per acre and calculated FVS-Sn large tree diameter increment growth sub-model sensitivity by species.

Uncorrelated SA Scenarios 2, 3 and 4

Upon completion of the initial test scenario of the large tree diameter growth sub-model, additional sub-models were tested for their influence on 10-year stand basal area per acre increment. The total sensitivities for each scenario were smaller than those of the initial test scenario: scenario 1 = 79.58%, scenario 2 = 55.51%, scenario 3 = 53.70%, and scenario 4 = 57.73%. Furthermore, the sensitivities attributed to the large tree diameter increment growth sub-model (Table 20) for scenarios 2-4 were much lower than that of scenario 1, however the same four parameters showed the highest sensitivity values in each scenario (Table 17, Table 20).

The LHS procedure was structured so that environmental and management effects were varied in each model run, regardless of whether those predictions were relevant to the stand being projected. Because of this, some parameters could not possibly influence the FVS-Sn 10-year stand basal area increment in any meaningful way. Nevertheless, all FVS-Sn large tree diameter increment growth sub-model parameters were sampled by LHS in each scenario. These parameters gave insight into which SA results were significant and which ones were not. The sensitivities of the inconsequential parameters were calculated and serve as a baseline to determine if parameters have a significant influence on FVS-Sn (Table 20). The sensitivity value at which the parameters known to not have any bearing on the FVS-Sn model seemed to decrease as the number of samples increased. For example scenario 2 used n = 5,000 and the baseline value was .24%. In scenario 3 n = 10,000 and the baseline scenario was .12% (Table 20).

Table 20. FVS-Sn Large tree diameter increment growth sub-model sensitivities (%) of scenarios 2-4.

Variable group	Parameter	Scenario 2	Scenario 3	Scenario 4
	Intercept	2.30	2.45	2.56
Tree	lncrwn	2.23	1.50	1.92
	lndbh	1.35	1.19	1.35
	dbh^2	0.17	0.23	0.13
Site	hrel	0.85	0.71	0.77
	site index	0.63	0.67	0.52
	Plot BA per acre	0.48	0.46	0.30
	Plot BA in tree larger than subject tree	0.28	0.31	0.17
Environment	f(x) of slope and cosine of aspect	0.38	0.22	0.19
	Oak-pine forest	0.24	0.23	0.11
	Tangent of slope in degrees	0.23	0.44	0.15
	Upland oak forest	0.23	0.14	0.10
	Northern hardwoods	0.19	0.24*	0.12*
	f(x) of slope and sine of aspect	0.17	0.20	0.09
	Spruce-fir-hemlock-pine	0.15	0.21	0.08
	Yellow pine	0.12	0.21	0.07
	Upland hardwoods	0.11	0.23	0.09
	Lowland hardwoods	0.10	0.13	0.06
Management	Gulf Piedmont mixed forest	0.25*	0.17	0.11
	Ouachita mixed forest	0.23	0.06	0.08
	Eastern broadleaf forest (Oceanic)	0.22	0.18	0.12
	Eastern broadleaf forest (Continental)	0.17	0.09	0.06
	Atlantic Piedmont mixed forest	0.17	0.17	0.08
	Outer coastal plain mixed forest	0.16	0.14	0.07
	Lower Mississippi Riverine forest	0.13	0.11	0.05
	Central Appalachian broadleaf	0.11	0.06	0.05
	Ozark broadleaf forest	0.11	0.11	0.04
	Prairie Parkland	0.09	0.10	0.06
	Everglades	0.01	0.02	0.00
	Planted stands	0.00	0.00	0.00

*Highest sensitivity of a parameter known to have no effect on FVS-Sn model predictions

Table 21 lists the accumulated sensitivities across all species by sub-model. The SDI threshold sub-model consistently showed the highest sensitivity in predicting 10-year stand basal area increment in FVS-Sn. In each scenario tested the SDI threshold parameters accounted for approximately 50% of the total model sensitivity (Table 21), with the $SDI_{thresupper}$ having the highest overall parameter sensitivity. The parameter with the second highest sensitivity across all the scenarios is the forest type SDI_{max}. When the three largest sensitivity values are added together in scenarios 2 and 3 they make up at least 74% of the total allocated model sensitivity. In scenario 3 they account for over 80% of the total model sensitivity.

Although there is some variation in each parameter's calculated sensitivity in each scenario, the sensitivities can essentially be considered equivalent. A case in point is the p_4 height estimation parameter, which had the largest range of one parameter's sensitivities of any parameter across scenarios 2-4, except for that of the parameters related to SDI (Table 21). The range of sensitivities for this parameter across the three scenarios is .22%, which is less than the .25% baseline sensitivity value found in the first scenario (Table 20) to have no influence on FVS-Sn, thereby, signifying that the difference between the three scenarios sensitivities was negligible.

Table 21. FVS-Sn sub-model sensitivities (%) for scenarios 2-4.

FVS-Sn sub-model	Parameter	Scenario 2	Scenario 3	Scenario 4
Curtis-Arney height dubbing	Height dubbing ($p3$)	0.58	0.46	0.45
	Height dubbing (p_4)	0.55	0.33	0.36
	Height dubbing (p_2)	0.26	0.36	0.20
Weibull crown dubbing	Crown dubbing (b_1)	0.20	0.15	0.06
	Crown dubbing (b_0)	0.19	0.33	0.18
	Crown dubbing (c)	0.14	0.19	0.06
Intolerance	Intolerance	0.23	0.29	0.12
Background mortality	Large tree mortality (b_0)	0.24	0.09	0.06
	Large tree mortality (b_1)	0.15	0.20	0.10
Forest type SDI maximum	SDI_{max}	13.17	14.25	16.09
SDI threshold values	$SDI_{thresupper}$	17.50	15.91	18.78
	$SDI_{threslower}$	10.45	10.17	11.78

When comparing sensitivities without regard to sub-models, parameters referring to SDI have the largest sensitivities, followed by several parameters associated with the large tree diameter growth sub-model (Table 22). The large tree diameter growth sub-model parameters listed in Table 22 follow the same order as those shown in scenario 1 (Table 17). The top nine parameters of scenarios 2 and 3 account for approximately 88% of the total model sensitivity, while in scenario 3 they account for roughly 94% of the total model sensitivity.

Table 22. FVS-Sn model parameters with the highest model sensitivity (%) for scenarios 2-4.

Parameter	Scenario 2	Scenario 3	Scenario 4
$SDI_{thresupper}$	17.50	15.91	18.78
SDI_{max}	13.17	14.25	16.09
$SDI_{threslower}$	10.45	10.17	11.78
Intercept	2.30	2.45	2.56
Log of percent crown ratio	2.23	1.50	1.92
Log of DBH	1.35	1.19	1.35
Relative height	0.85	0.71	0.77
Site index	0.63	0.67	0.52
Height dubbing (p_3)	0.58	0.46	0.45
Total	49.05	47.31	54.22

The species summed model sensitivities were much lower in scenarios 2-5 than those found in the initial test scenario (Table 23, Table 18). This result reflects that the additional sub-model parameters such as SDI_{max} and the SDI threshold estimates are not assigned to individual species. Species such as butternut, black walnut, eastern redbud, flowering dogwood, and sugar maple were not present in the tree list used in scenarios 1-5. Thus, the highest sensitivity calculated for any of these species serves as an indicator of "insignificant" values for any other species. A number of minor species represented in the initial tree list had values smaller than those of the "not present" species.

Table 23. FVS-Sn species sensitivities (%) for scenarios 2, 3, and 4.

Species	Scenario 2	Scenario 3	Scenario 4
American beech	0.17	0.18	0.05
American elm	0.26	0.17	0.09
American hornbeam	0.37	0.20	0.11
ash sp.	0.21	0.31	0.11
basswood	0.27	0.26	0.14
bigtooth aspen	0.20	0.18	0.10
black cherry	0.14	0.24	0.10
black oak	0.33	0.45	0.28
black walnut *	0.17	0.18	0.09
blackgum	0.33	0.18	0.08
buckeye	0.16	0.15	0.09
butternut *	0.16	0.24*	0.10
chestnut oak	2.39	2.45	2.56
eastern redbud*	0.18	0.19	0.09
eastern white pine	1.27	1.05	1.19
flowering dogwood*	0.19*	0.18	0.13*
misc hardwoods	0.17	0.18	0.06
hemlock	0.70	0.51	0.63
hickory sp.	0.34	0.23	0.19
northern red oak	0.27	0.41	0.21
pitch pine	2.20	1.91	2.11
red maple	0.44	0.21	0.17
sassafras	0.29	0.13	0.09
scarlet oak	0.80	1.05	0.96
sourwood	0.35	0.31	0.20
southern red oak	0.20	0.23	0.15
sugar maple *	0.13	0.13	0.05
sweet birch	0.30	0.23	0.18
table mountain pine	0.30	0.30	0.10
unknown	0.32	0.16	0.15
Virginia pine	0.28	0.27	0.20
white oak	0.26	0.32	0.21
yellow-poplar	0.23	0.17	0.10
Total	14.21	13.14	10.94

*Highest sensitivity of a species known to have no effect on FVS-Sn model predictions

The top five highest species specific sensitivities were the same for scenarios 2-4 and also are in the same order as scenario 1. These species accounted for approximately 50% of the total model sensitivity (Table 24). A difference between the softwood and hardwood sensitivities was recognizable when the two groups were plotted against their initial stand basal areas (Figure 6). Although the sensitivity values are much lower for scenario 4 (Table 24), when compared to those found in scenario 1 (Table 19), the trends of both the softwood and hardwood species are essentially the same. The softwoods display a much stronger influence on basal area growth regardless of their relatively low composition in the initial tree list.

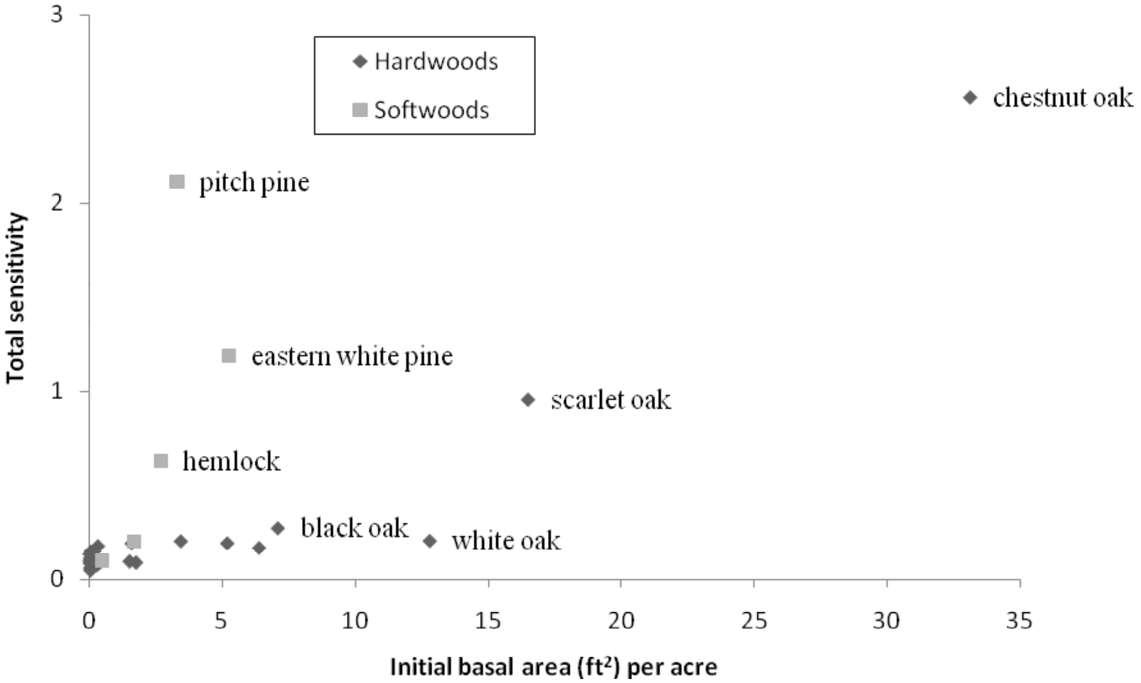

Figure 6. Comparison of species basal area per acre and calculated FVS-Sn sensitivity of scenario 4.

Table 24. FVS-Sn species with the highest model sensitivity (%) for scenario 2, 3, and 4.

Species	Scenario 2	Scenario 3	Scenario 4
chestnut oak	2.39	2.45	2.56
pitch pine	2.20	1.91	2.11
eastern white pine	1.27	1.05	1.19
scarlet oak	0.80	1.05	0.96
hemlock	0.70	0.51	0.63
Total	7.37	6.97	7.45

Uncorrelated and Correlated Sub-model Scenarios 4 and 5

The results shown in Tables 17-24 were computed by summing individual sensitivities across species, parameters, or sub-models. A disadvantage of summing individual sensitivities arises when multiple predictors interact in their effects on the model output, in this case stand-level basal area increment. An alternative calculation, based on Eq. [14], reduces the full regression RSM sum of squares by a group of predictors.

$$\mathrm{SI}_{\mathrm{group}} = \left(\frac{SS_{reg} - SS_{regredgrp}}{SS_{tot}} \right) \times 100\% \qquad [14]$$

where:

$\mathrm{SS}_{\mathrm{regredgrp}}$ = the group-reduced model regression sum of squares

If no interactions are present, $\mathrm{SI}_{\mathrm{group}}$ will be equal to the sum of individual parameters' sensitivity values for predictors within that group, $\mathrm{SI}_{\mathrm{summed}}$. If group interactions are positive, e.g. $\mathrm{SI}_{\mathrm{group}} > \mathrm{SI}_{\mathrm{summed}}$, the parameters have an enhanced effect on the model output . In contrast, if group interactions are negative, e.g. the parameters have a dampening effect on the model output, then $\mathrm{SI}_{\mathrm{group}} < \mathrm{SI}_{\mathrm{summed}}$.

Scenario 4 resulted in nearly equivalent sensitivities for the summed and grouped methods, e.g. total sensitivity of 57.73% and 59.41% respectively (Table 25). This difference,

$SI_{group} > SI_{summed}$, indicated some positive interactions, specifically in the large tree diameter growth and SDI related sub-models. Scenario 5, correlated parameters, resulted in summed and grouped sensitivities of 15.06% and 50.23% respectively (Table 25). This difference indicated negative interactions between parameters, namely the large tree diameter growth and SDI threshold sub-models. It also can be noted that a positive interaction exists between scenario 5 summed and grouped sensitivities for the SDI_{max} parameters. A comparison of scenarios 4 and 5 indicated negative interactions for both summed and grouped sensitivities (Table 25).

Table 25. FVS-Sn summed sensitivities, SI_{summed}, and sub-model grouped, SI_{group}, sensitivities for scenario 4 and 5.

Sub-model	Scenario 4		Scenario 5	
	Summed	Grouped	Summed	Grouped
Large tree diameter growth	9.50	10.20	4.58	5.03
Curtis-Arney height	1.01	1.02	0.34	0.81
Weibull crown	0.29	0.29	0.64	0.59
Intolerance	0.12	0.12	0.11	0.10
Background mortality	0.16	0.15	0.30	0.35
SDI_{max}	16.09	16.90	8.97	1.39
SDI thresholds	30.56	30.74	0.11	41.96
Total	57.73	59.41	15.06	50.23

Response Surface

Regression parameter estimates of the RSM depict the magnitude of the relationship between the FVS-Sn model parameters and the model response of 10-year stand basal area increment, as well as the error and significance associated with the term (Table 26). Separate response surfaces were created for the parameters of ungrouped, uncorrelated scenario 4 and the ungrouped, correlated scenario 5.

The majority of parameter estimate values of scenario 4 have p-values < 0.0001, while the majority of parameter estimate values of scenario 5 do not. The parameter estimate values of scenario 5 which are considered significant, chestnut oak intercept, log of percent crown ratio, and relative height, are only slightly significant since their p-values are just less than the predetermined significance value of .05 (Table 26). The standard error of scenarios 4 and 5 differ greatly as well. The scenario 4 standard errors are much smaller than that of scenario 5 standard errors (Table 26). For example the largest standard error found in the reported scenario 4 response surface parameter estimates is 3.70, while the smallest standard error reported for scenario 5 is 1.15 with the largest for this scenario being 86.12 (Table 26).

The response surface parameter estimate values and their associated standard errors and p-value do not refer to individual tree species but to default SDI maximum values corresponding to FVS-Sn model forest type and to percentage values of the SDI maximum to determine how mortality will occur (Table 27). All response surface parameters were found to be significant with low standard errors for both scenario 4 and 5.

Table 26. Parameter estimates, standard errors, and p-values for the parameters and species with the most model sensitivity across scenario 4 and 5.

Species	intercept			lncrwn			lndbh			hrel		
	Value	St. error	p-value	Value	St. error	p-value	Value	St. error	p-value	Value	St. error	p-value
Scenario 4												
chestnut oak	5.64	0.38	<.0001	21.63	1.64	<.0001	14.82	1.38	<.0001	4.78	0.66	<.0001
scarlet oak	2.79	0.33	<.0001	10.02	1.48	<.0001	6.66	1.09	<.0001	2.63	0.51	<.0001
white oak	2.57	0.70	<.0001	4.00	3.70	<.0001	6.76	2.14	<.0001	-0.03	0.98	0.9759
black oak	1.98	0.39	<.0001	7.51	2.11	0.0004	4.44	1.39	0.0014	1.21	0.66	0.0691
eastern white pine	1.94	0.17	<.0001	5.72	0.85	<.0001	3.05	0.68	<.0001	2.05	0.26	<.0001
pitch pine	0.95	0.08	<.0001	4.61	0.37	<.0001	2.22	0.20	<.0001	0.55	0.12	<.0001
hemlock	0.74	0.12	<.0001	3.77	0.54	<.0001	2.63	0.55	<.0001	0.30	0.19	0.1129
Scenario 5												
chestnut oak	22.06	11.45	0.0542	75.89	37.72	0.0443	54.02	27.29	0.0478	12.26	6.14	0.0459
scarlet oak	-11.22	9.75	0.2499	-39.58	34.17	0.2468	-26.55	21.55	0.218	-4.76	4.76	0.0522
white oak	36.38	21.29	0.0876	148.46	86.12	0.0848	79.22	42.72	0.0637	18.08	9.31	0.3181
black oak	6.16	11.88	0.604	22.01	48.99	0.6533	22.28	27.70	0.4214	2.59	6.27	0.6792
eastern white pine	7.36	5.18	0.1556	28.14	19.70	0.1531	15.63	13.38	0.243	4.29	2.41	0.0756
pitch pine	-0.92	2.35	0.6951	-1.50	8.44	0.859	-1.20	3.99	0.7628	-0.05	1.15	0.966
hemlock	-5.68	3.43	0.0979	-20.87	12.23	0.0881	-14.42	10.66	0.1764	-2.38	1.76	0.1763

Table 27. Parameter estimate values, standard errors, and t-values for the sub-models referring to SDI parameters across scenarios 4 and 5.

FVS-Sn sub-model	Scenario 4			Scenario 5		
	Value	Standard error	p-value	Value	Standard error	p-value
SDI_{max}	0.06	0.0010	<.0001	0.07	0.0061	<.0001
$SDI_{thresupper}$	0.22	0.0030	<.0001	0.29	0.0078	<.0001
$SDI_{threslower}$	0.16	0.0028	<.0001	0.03	0.0073	<.0001

Discussion

The FVS-Sn model has the potential to be the most readily available and comprehensive growth and yield model in the southern United States. The model has the flexibility to predict a wide range of forest types and sites, but most importantly it addresses the need for a growth and yield model in the southern Appalachian region. At present, however, FVS-Sn remains a relatively new (Donnelly et al. 2001) and essentially untested model. The large number of species and predictors incorporated into FVS-Sn also substantiate claims that testing is needed. Certain projections of the FVS-Sn model, such as basal area predictions have been found to be overestimated (Johnson 1997). This research was conducted to bring to light the FVS-Sn model sensitivities and point to those parameters, species, or sub-models where future evaluation efforts should be focused.

The scenario 1 test involving only the large tree diameter growth sub-model was conducted primarily as a test to determine the necessary number of model runs for SA. It also served as an exploratory test to determine model sensitivities of the sub-model parameters and of southern Appalachian tree species on the 10-year stand basal area increment. The first scenario also allowed for the development and testing of algorithms, input databases, FVS-Sn model structure, and SA execution sequence.

The results of scenario 1 revealed that the number of model parameters found to have influential sensitivities was small compared to the total number of model parameters (Table 17). Many of the parameters had no effect on the response of interest. The intercept, lncrwn, and lndbh had the highest sensitivities values for predicted 10-year stand basal area. The intercept has the greatest effect on predicting 10-year stand basal area increment, since a large intercept directly correlates to large basal area increments. In contrast a small intercept estimate equates to small basal area increment.

Scenario 1 demonstrated the species with the higher initial stand basal areas did not necessary have the greatest sensitivity (Table 18). Species such as white oak and black oak had the third and fourth highest initial basal area respectively, but had the lowest and second lowest amount of species specific sensitivities (Table 18). Pitch pine and eastern white pine had the sixth and seventh highest initial basal area and the second and fourth greatest species specific sensitivity. Further analysis showed that separate trends existed for the softwoods and hardwoods species. The softwood species, eastern white pine, pitch pine, and hemlock, had a much higher sensitivity compared to their initial basal areas as a group then did the hardwood species, chestnut oak, scarlet oak, white oak, and black oak (Figure 5).

The results of scenarios 2-4 were very similar to each other, therefore indicating no problems were related to an insufficient LHS sample size (Table 20, Table 21). The three scenarios have roughly equivalent total model sensitivities, but they are all approximately 25% lower than that of scenario 1 (Table 20, Table 21). This is most likely due to the added sub-model parameters and the increased number of possible interactions among parameters. The SS_{tot} and SS_{reg} terms in Eqs. [13] and [14] were computed using multiple linear regression, in which no interactions between FVS-Sn predictors were specified. In reality, interactions between parameters do exist and account for the fact that the full model RSM R^2 does not equal 1.0. Since a total of 371 additional parameters were added to scenarios 2, 3, and 4 there were many more possible interactions, thus causing the total sensitivities to be less than in scenario 1. Specifying interaction terms in the RSM full model would have been infeasible due to the large number of possible terms.

The largest sensitivities are associated with the forest type SDI_{max} and SDI threshold values (Table 21, Table 22). The structure of FVS-Sn is such that SDI is a substantial factor in determining mortality. Since mortality is negatively correlated with growth, it is directly subtracted from growth. The reliance of the FVS-Sn mortality calculations on the SDI parameters and the subsequent effect on basal area growth cause the parameters associated with SDI to have the largest sensitivity (Table 21, Table 25).

The largest sensitivity value of a species not found in the input tree list used in the FVS-Sn SA (Table 2, Table 6) serves as a baseline sensitivity value (Table 23). Any value that is less than or equal to the baseline value has no influence on the 10-year stand basal area growth model predictions. The baseline value of scenario 4 was noticeably lower than that of scenarios 2 and 3. It seems possible that when more model runs are performed such as n =10,000 in scenario 4 compared to n = 5,000 in scenarios 2 and 3 the non-present species sensitivities become increasingly smaller. For example, the baseline species-specific sensitivities of scenarios 2 and 3 were .19% and .24%, respectively, compared to a baseline value of .13% for scenario 4.

Scenario 5 was performed to account for the correlations that exist between parameters in FVS-Sn sub-models, while scenario 4 sub-model sensitivities were used as a comparison. Summed “one-at-a-time” sub-model sensitivities were much higher in scenario 4 than in scenario

5 (Table 25). This was undoubtedly due to the correlated parameters interactive effects on predicted stand-level basal area increment. Since the parameters of scenario 5 were correlated with each other, they have little sensitivity when removed individually. When grouped by sub-model and then removed as a group the sub-model sensitivities were comparable to the "one-at-a-time" method of calculating group sensitivities in scenario 4 (Table 25).

The magnitude and parameter relationship of the RSM to the 10-year basal area increment of scenario 4 was found be primarily positive and to have all but three parameters considered significant. In contrast, scenario 5 summed RSM was found to have the majority of species parameter relationships to not be significant and also to have many more negative values. This was due to the specified correlations in scenario 5. In scenario 4 no correlations were specified and thus no interactions are present, so when uncorrelated parameters are removed one at a time to determine sensitivity the full amount of sensitivity attributed to that parameter is found. Therefore, the response surface coefficient estimates are found to be significant. In contrast, if correlations are specified like in scenario 5, but removed one a time to determine sensitivity for the individual parameter is small because interactions have been specified in the correlations. Therefore, most of the coefficient estimates of the scenario 5 response surface were found to be insignificant.

It has been found that when conducting a SA, the input dataset should be tested as well as the model itself. The testing of the input dataset analyzes the variation within the sample input dataset from which it then can be determined if the model sensitivity is attributed to the model or to the input dataset. Despite this the input tree list used throughout all scenarios remained constant. This was done due to the complexity of the FVS-Sn model structure and the number of parameters used within the model, which makes testing the input dataset impractical from a time and organizational stand point.

Conclusions

The increasing number of forest landowners, especially private landowners, in the southern Appalachian region, and the continual need of forest resources requires a growth and yield model such as FVS-Sn to produce accurate predictions while maintaining the flexibility to predict over a wide range of forest sites and management situations. FVS-Sn possesses all these qualities, but, with further testing, it could be ideally suited to manage the forests of the southern Appalachian region. A comprehensive SA of FVS-Sn model input parameters was the primary goal of this study which brought to the forefront FVS-Sn model prediction dependencies.

The model prediction of basal area increment is most influenced by SDI related parameters, specifically SDI_{max}, and the SDI high and low thresholds. The SDI parameters directly influence mortality and in turn affect basal area growth, due to the direct correlation of growth and mortality. The softwood species employed in the model have a proportionally greater influence on FVS-Sn basal area prediction than do the hardwood species. This finding should be addressed and analyzed further due to the composition of the southern Appalachian region being primary hardwoods.

This investigation and SA only serves as a first step to address the most influential FVS-Sn input parameters. The results of this study can then be used to guide further validation and calibration of FVS. The concentration of further work should be on that of the SDI_{max}, SDI high and low threshold values, and the FVS-Sn mortality sub-models. The large tree diameter growth sub-model warrants additional consideration due to its importance and correlation to the mortality sub-models.

The procedures and methods developed to perform the SA of FVS-Sn proved to be flexible, accurate, and reliable. These methods can be used for future analysis of FVS-Sn forest types in the southern Appalachian region or for any other forest region as well.

Recommendations

The following is a recommended list of future research topics stimulated by this research and introduced in earlier sections of this thesis:

- Testing of additional forest types in the southern Appalachian region
- Performing a sensitivity analysis on the input tree list used in the FVS-Sn sensitivity analysis
- Test assumptions of SDI-related parameters
- Comparison of FVS-Sn basal area growth to similar models such as G-HAT
- Recalibration of FVS-Sn for southern Appalachian mixed hardwood forests

References

Arner, S.L., S. Woudenberg, S. Waters, J. Vissage, C. MacLean, M. Thompson, and M. Hansen. 2001. National algorithms for determining stocking class, stand size class, and forest type for forest inventory and analysis plots. *Unpublished report*. USDA Forest Service, Northeastern Research Station, Newtown Square, PA. 46 p.

Arney, J.D. 1985. A modeling strategy for the growth projection of managed stands. *Canadian Journal of Forest Research* 15(3):511-518.

Beasley, J.D., and S.G. Springer. 1977. Algorithm AS III. The percentage points of the normal distribution. *Applied Statistics* 26:118-121.

Beck, D.E., and L. Della-Bianca. 1972. Growth and yield of thinned yellow-poplar. USDA Forest Service, Southeastern Forest Experiment Station, Research Paper SE-101, Asheville, NC.

Beukema, S.J., J.A. Greenough, D.C.E. Robinson, W.A. Kurz, E.L. Smither, and B.B. Eav. 1997. The westwide pine beetle model: a spatially-explicit contagion model. *in* Forest Vegetation Simulator Conference, Teck, R., M. Moeur, and J. Adams (eds.). USDA Forest Service, Intermountain Research Station, General Technical Report INT-373, Ogden, UT.

Bolton, R.K., and R.S. Meldahl. 1990. Users guide to a multipurpose forest projection system for southern forests. Auburn University, Alabama Agricultural Experiment Station, Station Bulletin 603, Auburn, AL.

Bowling, E.H., H.E. Burkhart, T.E. Burk, and D.E. Beck. 1989. A stand-level multispecies growth model for Appalachian hardwoods. *Canadian Journal of Forest Research* 19(4):405-412.

Box, G.E.P., and N.R. Draper. 1987. Empirical model-building and response surfaces. John Wiley & Sons, New York, NY. 669 p.

Burns, R.M., and B.H. Honkala. 1990. Silvics of North American: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654 USDA Forest Service, Washington, DC.

Chan, K., A. Saltelli, and S. Tarantola. 2000. Winding Stairs: A sampling tool to compute sensitivity indices. *Statistics and Computing* 10(3):187-196.

Connor, R.C., and A.J. Hartsell. 2002. Forest area and conditions. P. 357-402 in *Southern Forest Resource Assessment*, Wear, D.N., and J.G. Greis (eds.). USDA Forest Service, Southern Research Station, General Technical Report SRS-53, Asheville, NC.

Crookston, N.L. 1985. Users guide to the event monitor: an addition to the Prognosis model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-196, Ogden, UT.

Crookston, N.L. 1990. User's guide to the event monitor. USDA Forest Service, Intermountain Research Station, General Technical Report INT-275, Ogden, UT.

Crookston, N.L., and G.E. Dixon. 2005. The forest vegetation simulator: A review of its structure, content, and applications. *Computers and Electronics in Agriculture* 49(1):60-80.

Crookston, N.L., and A.R. Stage. 1991. Users guide to the parallel processing extension of the Prognosis model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-281, Ogden, UT.

Cukier, R.I., C.M. Fortuin, K.E. Schuler, A.G. Petschek, and J.H. Schaibly. 1973. Study of the sensitivity of coupled reaction systems to uncertainties in rate coefficients. I. Theory. *Journal of Chemical Physics* 59:3873-3878.

Cukier, R.I., H.B. Levine, and K.E. Schuler. 1978. Nonlinear sensitivity analysis of multiparameter model systems. *Journal of Computational Physics* 26:1-42.

Curtis, R.O. 1967. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. *Forest Science* 1320(4):365-375.

Dale, M.E. 1972. Growth and yield predictions for upland oak stands. USDA Forest Service, Northeastern Research Station, Research Paper NE-241, Upper Darby, PA.

Dixon, G. 1985. Crown ratio modeling using stand density index and the Weibull distribution. *Unpublished report*. USDA Forest Service, Forest Management Service Center, Fort Collins, CO. 13 p.

Dixon, G.E. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. *Internal report*. USDA Forest Service, Forest Management Service Center, Fort Collins, CO. 208 p.

Donnelly, D., B. Lilly, and E. Smith. 2001. The Southern Variant of the Forest Vegetation Simulator. *Internal report*. USDA Forest Service, Forest Managment Service Center, Fort Collins, CO. 61 p.

Fenneman, N. 1938. Physiography of eastern United States. McGraw-Hill Book Company, Inc, New York, NY. 714 p.

Ferguson, D.E., and C.E. Carlson. 1993. Predicting regeneration establishment with the Prognosis model. USDA Forest Service, Intermountain Research Station, Research Paper INT-467, Ogden, UT.

Ferguson, D.E., and N.L. Crookston. 1991. Users guide to version 2 of the regeneration establishment model: part of the Prognosis model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-279, Ogden, UT.

Ferguson, D.E., A.R. Stage, and R.J. Boyd. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. *Forest Science* Monograph 26:41.

Frankel, S.J. 1998. User's guide to the western root disease model, version 3.0. USDA Forest Service, Pacific Southwest Research Station, General Techincal Report PSW-165, Albany, CA.

Gartner, D. 2002. The effect of data quality on short-term growth model projections. *in* Proceedings of the Fourth Annual Forest Inventory and Analysis Symposium, McRoberts, R., G. Reams, P. Van Deusen, W. McWilliams, and C. Cieszewski (eds.). USDA Forest Service North Central Research Station, St. Paul, MN.

Green, E.J., D.W. MacFarlane, H.T. Valentine, and W.E. Strawderman. 1999. Assessing uncertainty in a stand growth model by Bayesian synthesis. *Forest Science* 45(4):528-538.

Guan, B.T. 2000. Effects of correlation among parameters on prediction quality of a process-based forest growth model. *Forest Science* 46(2):269-276.

Hamilton, D.A. 1986. A Logistic Model of Mortality in Thinned and Unthinned Mixed Conifer Stands of Northern Idaho. *Forest Science* 32(4):989-1000.

Hamilton, D.A. 1990. Extending the range of applicability of an individual tree mortality model. *Canadian Journal of Forest Research* 20(8):1212-1218.

Hamilton, D.A., and B.M. Edwards. 1976. Modeling the probability of individual tree mortality. USDA Forest Service. Intermountain Research Station, Research Paper INT-185, Ogden, UT.

Harrison, W.C., H.E. Burkhart, T. Burk, and D.E. Beck. 1986. Growth and yield of Appalachian mixed hardwoods after thinning. *Publiciaton No. FWS-1-86*. Virginia Tech, Blacksburg, VA. p.

Helton, J.C., and F.J. Davis. 2003. Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems. *Reliability Engineering & System Safety* 81(1):23-69.

Helton, J.C., F.J. Davis, and J.D. Johnson. 2005. A comparison of uncertainty and sensitivity analysis results obtained with random and Latin hypercube sampling. *Reliability Engineering & System Safety* 89(3):305-330.

Hilt, D.E. 1985. OAKSIM: An individual tree growth and yield simulator for managed even-aged, upland oak stands. USDA Forest Service, Northeastern Research Station, Research Paper NE-562, Broomall, PA.

Horn, J.E., R.L. Medema, and E.G. Schuster. 1986. Users guide to CHEAPO II - economic analysis of stand Prognosis model outputs. USDA Forest Service, Intermountain Research Station, General Technical Report INT-211, Ogden, UT.

Iman, R.L., and W.J. Conover. 1980. Small sample sensitivity analysis techniques for computer-models, with an application to risk assessment. *Communications in Statistics Part A-Theory and Methods* 9(17):1749-1842.

Iman, R.L., and W.J. Conover. 1982. A distribution-free approach to inducing rank correlation among input variables. *Communications in statistics. Simulation and computation* 11(3):311-334.

Iman, R.L., and J.C. Helton. 1988. An investigation of uncertainty and sensitivity analysis techniques for computer models. *Risk Analysis* 8(1):71-90.

Johnson, R.R. 1997. A historical perspective of the forest vegetation simulator. P. 3-4 *in* Proceedings of the Forest Vegetation Simulator Conference, Teck, R., M. Moeur, and J. Adams (eds.). USDA Forest Service, Intermountain Research Station, General Technical Report INT-373, Fort Collins, CO.

Keys, J., C. Carpenter, S. Hooks, F. Koenig, W.H. McNab, W. Russell, and M.-L. Smith. 1995. Ecological units of the eastern United States - first approximation (cd-rom). USDA Forest Service, Region 8, Technical Publication, R8-TP-21 Atlanta, GA.

Knoebel, B.R., H.E. Burkhart, and D.E. Beck. 1986. A growth and yield model for thinned stand of yellow-popular. *Forest Science*.

Lentz, W.J. 1976. Generating Bessel function in Mie scattering calculations using continued fractions. *Applied Optics* 15:668-671.

Loh, W.L. 1996. On Latin hypercube sampling. *Annals of Statistics* 24(5):2058-2080.

Marquis, D.A. 1986. SILVAH. *The Compiler* 4(3).

Marsden, M.A., B.B. Eav, and M.K. Thompson. 1994. User's guide to the Douglas-fir beetle impact model. USDA Forest Service, Rocky Mountain and Range Experimental Station, General Technical Report, RM-250, Fort Collins, CO.

McDonald, G.I., R.J. Hoff, and W.R. Wykoff. 1981. Computer simulation of white pine blister rust epidemics I. Model formulation. USDA Forest Service, Intermountain Research Station, Research Paper INT-258, Ogden, UT.

McKay, M.D. 1997. Nonparametric variance-base methods of assessing uncertainty importance. *Reliability Engineering & System Safety* 57:267-279.

McKay, M.D., R.J. Beckman, and W.J. Conover. 1979. A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code. *Technometrics* 21(2):239-245.

McKay, M.D., J.D. Morrison, and S.C. Upton. 1999. Evaluating prediction uncertainty in simulation models. *Computer Physics Communications* 117(1-2):44-51.

Medema, R.L., and C.R. Hatch. 1982. Computerized help for economic analysis of Prognosis Model outputs: a user's manual. *Contribution No. 227*. University of Idaho, Forest, Wildlife, and Range Experiment Station, Moscow, ID. 72 p.

Moeur, M. 1995. COVER: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-190, Ogden, UT.

Monserud, R.A., and N.L. Crookston. 1982. A user's guide to the combined Stand Prognosis and Douglas-fir tussock moth outbreak model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-127, Ogden, UT.

Myers, R.H. 1971. Response surface methodology. Allyn and Bacon, Inc, Boston, MA. 246 p.

Park, and Miller. 1988. Random number generators: Good ones are hard to find. *Communications of the ACM* 31:1192-1201.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. Numerical Recipes in C: The Art of Scientific Computing. 2nd edition. Cambridge University Press, Cambridge. 994 p.

Prestemon, J.P., and R.C. Abt. 2002. Timber products supply and demand. P. 299-325 in *Southern forest resource assessment*, Wear, D.N., and J.G. Greis (eds.). USDA Forest Service, Southern Research Station, General Technical Report SRS-53, Asheville, NC.

Rabitz, H. 1989. System analysis at molecular scale. *Science* 246:221-226.

Radtke, P.J. 1999. Uncertainty Assessment, Calibration and Sensitivity Analysis of Process-Based Forest Ecosystem Computer Simulation Models. Unpublished PhD. dissertation, University of Minnesota. 331 p.

Radtke, P.J., T.E. Burk, and P.V. Bolstad. 2002. Bayesian melding of a forest ecosystem model with correlated inputs. *Forest Science* 48(4):701-711.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. *Journal of Agriculture Research* 46(7):627-638.

Saltelli, A., K. Chan, and E.M. Scott. 2000. Sensitivity Analysis. John Wiley & Sons Ltd., Chichester. 475 p.

Sheehan, K.A., W.P. Kemp, J.J. Colbert, and N.L. Crookston. 1989. The western spruce budworm model: structure and content. USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-241, Portland, OR.

Stage, A.R. 1973. Prognosis model for stand development. USDA Forest Service, Intermountain Research Station, Research Paper INT-37, Ogden, UT.

Stage, A.R. 1975. Prediction of height increment for models of forest growth. USDA Forest Service, Intermountain Research Station, Research Paper INT-164, Ogden, UT.

Stage, A.R., and W.R. Wykoff. 1998. Adapting Distance-Independent Forest Growth Models to Represent Spatial Variability: Effects of Sampling Design on Model Coefficients. *Forest Science* 44(2):15.

Van Dyck, M.G. 2000. Keyword reference guide for the forest vegetation simulator. USDA Forest Service, Forest Management Service Center, Fort Collins, CO.

Van Lear, D.H. 2002. Upland oak ecology and management. P. 65-71 *in* Upland Oak Ecology Symposium: History, Current Conditions, and Sustainability, Spetich, M.A. (ed.). USDA Forest Service, Southern Research Station, General Technical Report SRS-073, Asheville, NC.

Wear, D.N., and J.G. Greis. 2002. Southern forest resource assessment: A summary report. USDA Forest Service, Southern Research Station, General Technical Report SRS-54, Asheville, NC.

Wykoff, W.R. 1983. Predicting basal area increment for individual northern Rocky Mountain conifers. P. 127-143 *in* Proceedings of the meeting of IUFRO working group S4.01-00 (Mensuration, Growth and Yield), Pollanschutz, J. (ed.), Vienna, Austria.

Wykoff, W.R. 1990. A Basal Area Increment Model for Individual Conifers in the Northern Rocky Mountains. *Forest Science* 36(4):28.

Wykoff, W.R., N.L. Crookston, and A.R. Stage. 1982. User's Guide to the Stand Prognosis Model. USDA Forest Service, Intermountain Research Station, General Technical Report INT-122, Ogden, UT.

Yandle, D.O., J.R. Myers, J.H. Mayo, and N.I. Lamson. 1987. Development and application of a stand-based growth model for mixed hardwood stands. *in* IUFRO Forest Growth Modeling and Prediction Conference, Ek, A.R., S.R. Shifley, and T. Burk (eds.). USDA Forest Service, North Central Forest Experiment Station, General Technical Report NC-120, St. Paul, MN.

Appendices

Appendix A. FVS-Sn Control Files

1. FVS-Sn simulation tree list input file, FB_rand_plots.fvs

```
   2  11.00001WO 14.7                           0
   2  21.00001CO 11.7                           0
   2  31.00001CO 19.7                           0
   2  41.00001CO  6.6                           0
   2  51.00001CO 11.1                           0
   2  61.00001CO 12.2                           0
   2  71.00001OT  7.6                           0
   2  81.00001CO 11.0                           0
   2  91.00001CO 12.1                           0
   2 101.00001WO 13.5                           0
   2 111.00001CO 12.2                           0
   2 121.00001CO  4.1                           0
   2 131.00001CO  8.5                           0
   2 141.00001CO 17.6                           0
   3 151.00001RM  4.3                           0
   3 161.00001RM  3.1                           0
   3 171.00001HI  3.9                           0
   3 181.00001HI  9.2                           0
   3 191.00001YP  3.4                           0
   3 201.00001WP  3.1                           0
   3 211.00001RM  3.0                           0
   3 221.00001HI  5.9                           0
   3 231.00001RM  5.3                           0
   3 241.00001VP  5.4                           0
   3 251.00001VP  4.8                           0
   3 261.00001HI  3.6                           0
   3 271.00001WO  4.8                           0
   3 281.00001RM  4.3                           0
   3 291.00001YP  3.4                           0
   9 301.00001SD  8.0                           0
   9 311.00001WO  9.0                           0
   9 321.00001RM  3.3                           0
   9 331.00001WP  7.5                           0
   9 341.00001WO 11.4                           0
   9 351.00001WP  3.2                           0
   9 361.00001CO  3.1                           0
   9 371.00001WO 19.1                           0
   9 381.00001RM  4.5                           0
   9 391.00001SB  4.4                           0
   9 401.00001WO 11.3                           0
.
.
.
```

2. FVS-Sn Simulation Location File, Fishburn.loc

```
A "Fishburn Forest" @ FishburnCFI.slf @
```

3. FVS-Sn Simulation Stand File, FishburnCFI.slf

```
A FishburnCFI FB_rand_plots.fvs WithPointData sn @
B FishburnCFI 2006 37 80 80811 M221Aa @ @ @ 20 -10 10 3 @ @ @ @ @ @ @ @ @ @ @ @ @ @ @ @ @ @
```

4. FVS-Sn Simulation Key File, FB_test.key

```
!!Suppose 1.0 sn 0 0
!!Top
Comment
Starting year for simulation is 2006
Ending year for simulation is   2016
Min and Max inventory years are 2006 2006
Common cycle length is          10
End
!!End
!!Stand FishburnCFI 0
StdIdent
FishburnCFI Stand FishburnCFI at Fishburn Forest
!!SK sn
Screen
InvYear        2006
StdInfo        80811    M221Aa                                      20
Locate            37        80
Design           -10        10         3        61
!!End
!!TK
TimeInt            1        15
NumCycle           2
!!End
!!C Base FVS system: EchoSum~21 2 -1 sn base All 0
!!SW GPKeyword
!!P Base FVS system: EchoSum~keyword.base.EchoSum~4.  0.0000 Fmax 4.00 NoB~.
!!K
EchoSum           4.
!!End
!!C Base FVS system: NoTriple~22 2 -1 sn base All 0
!!SW GPKeyword
!!P Base FVS system: NoTriple~keyword.base.NoTriple~ ~.
!!K
NoTriple
!!End
!!C Base FVS system: NumCycle~23 2 -1 sn base All 0
!!SW GPKeyword
!!P # 1 Base FVS system: NumCycle~keyword.base.NumCycle~1.  1.0000 40.0000 1.0.
!! 0 NoB~.
!!K
NumCycle          1.
!!End
!!C Base FVS system: TimeInt~24 2 -1 sn base All 0
!!SW GPKeyword
!!P # 1 Base FVS system: TimeInt~keyword.base.TimeInt~1.  0.0000 40.0000 1.00 .
!! NoB~10.  1.0000 25.0000 10.00 NoB~.
!!K
TimeInt           1.       10.
!!End
!!C Base FVS system: TreeList~26 2 -1 sn base All 0
!!SW GPKeyword
!!P # 1 Base FVS system: TreeList~keyword.base.TreeList~0 2001 0 ~3.  0.0000 F.
!! max 3.00 NoB~1~1~0~0~.
!!K
TreeList        2001        3.         1         1         0         0
!!End
!!TR
Open               2
```

```
FB_rand_plots.fvs
TreeData           2         1
Close              2
!!End
SPLabel
   All, &
   !StandsInNoDefinedGroup
Process
!!EndStand

STOP
!!G !StandsInNoDefinedGroup 1
!!S FishburnCFI 0
!!Subset
!!G All 0
!!End
```

5. FVS-Sn sntest.rsp File

```
FB_TEST.key
FB_rand_plots.fvs
Output1.out
Output1.tls
Output1.sum
NUL
```

Appendix B. FVS-Sn Model Output Files

1. FVS-Sn main output file

```
FOREST VEGETATION SIMULATOR     VERSION 1.00 -- SOUTHERN U.S. PROGNOSIS                RV:01.27.06    06-09-2007  13:21:52

----------------------------------------------------------------------------------------------------------------------------------

                                                OPTIONS SELECTED BY INPUT

KEYWORD FILE NAME: FB_TEST.key
----------------------------------------------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
--------   -----------------------------------------------------------------------------------------------------------------------

COMMENT
           Starting year for simulation is 2006
           Ending year for simulation is   2016
           Min and Max inventory years are 2006 2006
           Common cycle length is          10

END

STDIDENT
           STAND ID= FishburnCFI                       Stand FishburnCFI at Fishburn Forest

SCREEN     SUMMARY TABLE WILL BE PRINTED TO DATA SET REFERENCE NUMBER     6 AS RUN PROGRESSES.

INVYEAR    INVENTORY YEAR= 2006

           PLANT ASSOCIATION CODE USED IN THIS PROJECTION IS M221AA

STDINFO    FOREST-LOCATION CODE=   80811; ECOLOGICAL UNIT=  M221AA  ; AGE=    0; ASPECT AZIMUTH IN DEGREES=   0.; SLOPE=   5.%
           ELEVATION(100'S FEET)= 20.0; LATITUDE IN DEGREES=  37.

LOCATE     LATITUDE =  37.0000;  LONGITUDE =   80.0000;  STATE CODE =  0;  COUNTY CODE =   0

DESIGN     BASAL AREA FACTOR=  -10.0; INVERSE OF FIXED PLOT AREA=   10.0; BREAK DBH=    3.0
           NUMBER OF PLOTS=    61; NON-STOCKABLE PLOTS=     0; STAND SAMPLING WEIGHT=    61.00000
           PROPORTION OF STAND CONSIDERED STOCKABLE=  1.000
           SEE "OPTIONS SELECTED BY DEFAULT" FOR FINAL DESIGN VALUES.

TIMEINT    CYCLE=  1; PERIOD LENGTH= 15

NUMCYCLE   NUMBER OF CYCLES=  2

ECHOSUM    SUMMARY OUTPUT WILL BE WRITTEN TO FILE REFERENCED BY NUMBER  4
```

```
NOTRIPLE

NUMCYCLE   NUMBER OF CYCLES=  1

TIMEINT    CYCLE=  1; PERIOD LENGTH= 10

TREELIST   DATE/CYCLE= 2001; DATA SET REFERENCE NUMBER =  3.; HEADING SUPPRESSION CODE = 1.
           (0=WITH HEADING, OTHER VALUES=SUPPRESS HEADING).
           CYCLE ZERO TREELIST SUPPRESSED.

OPEN       DATA SET REFERENCE NUMBER =     2; BLANK=ZERO; STATUS=UNKNOWN
           MAXIMUM RECORD LENGTH (IGNORED ON SOME MACHINES) = 150; FILE FORM= 1 (1=FORMATTED, 2=UNFORMATTED)
           DATA SET NAME = FB_rand_plots.fvs

TREEDATA   DATA SET REFERENCE NUMBER=  2
           PLOT SPECIFIC SITE DATA READ FROM TREE RECORDS.

CLOSE      DATA SET REFERENCE NUMBER =     2

SPLABEL    STAND POLICY LABEL SET:
           All, !StandsInNoDefinedGroup

PROCESS    PROCESS THE STAND.
-----------------------------------------------------------------------------------------------------------------------------------

                                                OPTIONS SELECTED BY DEFAULT

-----------------------------------------------------------------------------------------------------------------------------------

TREEFMT    (I4,T1,I7,F6.0,I1,A3,F4.1,F3.1,2F3.0,F4.1,I1,3(I2,I2),2I1,I2,2I3,2I1)


DESIGN     BASAL AREA FACTOR=  -10.0; INVERSE OF FIXED PLOT AREA=   10.0; BREAK DBH=    3.0
           NUMBER OF PLOTS=    61; NON-STOCKABLE PLOTS=     0; STAND SAMPLING WEIGHT=    61.00000
           PROPORTION OF STAND CONSIDERED STOCKABLE=  1.000

PROCESS    FOREST-LOCATION CODE=   80811; ECOLOGICAL UNIT=  M221AA  ; AGE=    0; ASPECT AZIMUTH IN DEGREES=   0.; SLOPE=   5.%
           ELEVATION(100'S FEET)= 20.0; LATITUDE IN DEGREES=  37.

           ALPHA SPECIES - FIA CODE CROSS REFERENCE:
            FR=  010 ;  JU=  057 ;  PI=  090 ;  PU=  107 ;  SP=  110 ;  SA=  111 ;  SR=  115 ;  LL=  121 ; TM=  123
            PP=  126 ;  PD=  128 ;  WP=  129 ;  LP=  131 ;  VP=  132 ;  BY=  221 ;  PC=  222 ;  HM=  260 ; FM=  311
            BE=  313 ;  RM=  316 ;  SV=  317 ;  SM=  318 ;  BU=  330 ;  BB=  370 ;  SB=  372 ;  AH=  391 ; HI=  400
            CA=  450 ;  HB=  460 ;  RD=  471 ;  DW=  491 ;  PS=  521 ;  AB=  531 ;  AS=  540 ;  WA=  541 ; BA=  543
            GA=  544 ;  HL=  552 ;  LB=  555 ;  HA=  580 ;  HY=  591 ;  BN=  601 ;  WN=  602 ;  SU=  611 ; YP=  621
            MG=  650 ;  CT=  651 ;  MS=  652 ;  MV=  653 ;  ML=  654 ;  AP=  660 ;  MB=  680 ;  WT=  691 ; BG=  693
            TS=  694 ;  HH=  701 ;  SD=  711 ;  RA=  721 ;  SY=  731 ;  CW=  740 ;  BT=  743 ;  BC=  762 ; WO=  802
```

```
            SO=  806 ;  SK=  812 ;  CB=  813 ;  TO=  819 ;  LK=  820 ;  OV=  822 ;  BJ=  824 ;  SN=  825 ; CK=  826
            WK=  827 ;  CO=  832 ;  RO=  833 ;  QS=  834 ;  PO=  835 ;  BO=  837 ;  LO=  838 ;  BK=  901 ; WI=  920
            SS=  931 ;  BW=  950 ;  EL=  970 ;  WE=  971 ;  AE=  972 ;  RL=  975 ;  OS=  298 ;  OH=  998 ; OT=  999

SITECODE   SITE INDEX INFORMATION:
            FR=   77.;  JU=   55.;  PI=   62.;  PU=   82.;  SP=   70.;  SA=   70.;  SR=   78.;  LL=   85.; TM=   53.
            PP=   70.;  PD=   70.;  WP=   87.;  LP=   82.;  VP=   79.;  BY=   75.;  PC=   75.;  HM=   63.; FM=   53.
            BE=   53.;  RM=   60.;  SV=   68.;  SM=   68.;  BU=   58.;  BB=   60.;  SB=   53.;  AH=   28.; HI=   55.
            CA=   60.;  HB=   53.;  RD=   28.;  DW=   30.;  PS=   43.;  AB=   60.;  AS=   71.;  WA=   69.; BA=   60.
            GA=   70.;  HL=   73.;  LB=   33.;  HA=   40.;  HY=   53.;  BN=   60.;  WN=   60.;  SU=   78.; YP=   83.
            MG=   80.;  CT=   76.;  MS=   80.;  MV=   45.;  ML=   80.;  AP=   28.;  MB=   35.;  WT=   68.; BG=   70.
            TS=   65.;  HH=   28.;  SD=   43.;  RA=   38.;  SY=   75.;  CW=   83.;  BT=   61.;  BC=   70.; WO=   70.
            SO=   76.;  SK=   71.;  CB=   78.;  TO=   45.;  LK=   45.;  OV=   65.;  BJ=   45.;  SN=   65.; CK=   55.
            WK=   73.;  CO=   76.;  RO=   76.;  QS=   70.;  PO=   55.;  BO=   76.;  LO=   48.;  BK=   60.; WI=   63.
            SS=   48.;  BW=   63.;  EL=   63.;  WE=   63.;  AE=   63.;  RL=   63.;  OS=   44.;  OH=   35.; OT=   35.
           SITE SPECIES=WO CODE=   63
-----------------------------------------------------------------------------------------------------------------------------------


                                                            ACTIVITY SCHEDULE

STAND ID= FishburnCFI                   MGMT ID= NONE    Stand FishburnCFI at Fishburn Forest

-----------------------------------------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  --------  ----  ---------------------------------------------------------------------------------------------

   1   2006
              BASE      TREELIST  2001        3.00      1.00      1.00
-----------------------------------------------------------------------------------------------------------------------------------

SPECIES      FR      JU      PI      PU      SP      SA      SR      LL      TM      PP
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES      PD      WP      LP      VP      BY      PC      HM      FM      BE      RM
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES      SV      SM      BU      BB      SB      AH      HI      CA      HB      RD
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES      DW      PS      AB      AS      WA      BA      GA      HL      LB      HA
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES      HY      BN      WN      SU      YP      MG      CT      MS      MV      ML
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES      AP      MB      WT      BG      TS      HH      SD      RA      SY      CW
```

```
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES       BT      BC      WO      SO      SK      CB      TO      LK      OV      BJ
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES       SN      CK      WK      CO      RO      QS      PO      BO      LO      BK
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.

SPECIES       WI      SS      BW      EL      WE      AE      RL      OS      OH      OT
SDI MAX     420.    420.    420.    420.    420.    420.    420.    420.    420.    420.


CALIBRATION STATISTICS:


                                                 WO    CO    OT    RM    HI    YP    WP    VP    SD    SB    BG

SO    BO    HM    RO    BU    AS    PP    TM    SS    SK    BW

AH    BC    BT    OH    AE    AB
                                                ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----
---  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----
---  ----  ----  ----  ----  ----

NUMBER OF RECORDS PER SPECIES                  114   329     2   166    36    37    59    29   104    15    68

                                               188    60    27    16     4     1    32     5     2     1     1

                                                 1     7     1     2     1     1

NUMBER OF RECORDS WITH MISSING HEIGHTS         114   329     2   166    36    37    59    29   104    15    68

                                               188    60    27    16     4     1    32     5     2     1     1

                                                 1     7     1     2     1     1

NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS       0     0     0     0     0     0     0     0     0     0     0

                                                 0     0     0     0     0     0     0     0     0     0     0

                                                 0     0     0     0     0     0

NUMBER OF RECORDS WITH MISSING CROWN RATIOS    114   329     2   166    36    37    59    29   104    15    68

                                               188    60    27    16     4     1    32     5     2     1     1

                                                 1     7     1     2     1     1
```

```
NUMBER OF RECORDS AVAILABLE FOR SCALING
THE DIAMETER INCREMENT MODEL                       0     0     0     0     0     0     0     0     0     0     0

                                                   0     0     0     0     0     0     0     0     0     0     0

                                                   0     0     0     0     0     0

RATIO OF STANDARD ERRORS
(INPUT DBH GROWTH DATA : MODEL)                 1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00

WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN
DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED    0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

                                                0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

                                                0.00  0.00  0.00  0.00  0.00  0.00

INITIAL SCALE FACTORS FOR THE
DBH INCREMENT MODEL                             1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00

NUMBER OF RECORDS AVAILABLE FOR SCALING
THE SMALL TREE HEIGHT INCREMENT MODEL             0     0     0     0     0     0     0     0     0     0     0

                                                  0     0     0     0     0     0     0     0     0     0     0

                                                  0     0     0     0     0     0

INITIAL SCALE FACTORS FOR THE SMALL TREE
HEIGHT INCREMENT MODEL                          1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00  1.00

                                                1.00  1.00  1.00  1.00  1.00  1.00

NUMBER OF RECORDS WITH MISTLETOE                   0     0     0     0     0     0     0     0     0     0     0

                                                   0     0     0     0     0     0     0     0     0     0     0

                                                   0     0     0     0     0     0
```

```
        FOREST VEGETATION SIMULATOR     VERSION 1.00 -- SOUTHERN U.S. PROGNOSIS                RV:01.27.06    06-09-2007  13:21:54

STAND ID: FishburnCFI                   MGMT ID: NONE    Stand FishburnCFI at Fishburn Forest


STAND POLICIES:   All, !StandsInNoDefinedGroup

                                        STAND COMPOSITION (BASED ON STOCKABLE AREA)
--------------------------------------------------------------------------------------------------------------------------
                            PERCENTILE POINTS IN THE
                     DISTRIBUTION OF STAND ATTRIBUTES BY DBH      TOTAL/ACRE
        STAND       -----------------------------------------     OF STAND        DISTRIBUTION OF STAND ATTRIBUTES BY
YEAR  ATTRIBUTES      10     30     50     70     90    100      ATTRIBUTES      SPECIES AND 3 USER-DEFINED SUBCLASSES
----  -----------   ------ ------ ------ ------ ------ ------   --------------  ------------------------------------------
                                 (DBH IN INCHES)


2006  TREES           4.3    5.4    7.2    9.6   14.0   38.2      215. TREES     25.% CO3,  14.% SO3,  13.% RM3,   9.% WO3
      VOLUME:
        MERCH         6.9   10.6   13.5   17.3   23.0   38.2     2474. CUFT      30.% CO3,  16.% SO3,  14.% WO3,   7.% BO3
        SAWLG        12.6   14.8   17.4   21.2   25.4   38.2     1413. CUFT      31.% CO3,  18.% WO3,  14.% SO3,   9.% BO3
        SAWLG        12.7   15.2   17.9   21.8   25.7   38.2     9411. BDFT      31.% CO3,  18.% WO3,  15.% SO3,   9.% BO3


      ACCRETION       6.8    9.5   12.0   15.0   20.5   38.2       93. CUFT/YR   31.% CO3,  17.% SO3,  10.% WO3,   9.% WP3
      MORTALITY       4.7    6.8    8.5   10.3   12.8   38.2        2. CUFT/YR   26.% SO3,  16.% WO3,  11.% RM3,   8.% PP3


2016  TREES           5.0    6.4    8.3   11.1   15.8   38.5      211. TREES     26.% CO3,  14.% SO3,  13.% RM3,   9.% WO3
      VOLUME:
        MERCH         7.9   11.9   14.6   18.7   24.9   38.5     3385. CUFT      31.% CO3,  16.% SO3,  13.% WO3,   7.% BO3
        SAWLG        13.1   15.0   17.6   21.4   26.8   38.5     2187. CUFT      32.% CO3,  16.% WO3,  14.% SO3,   9.% BO3
        SAWLG        13.3   15.5   18.6   22.1   27.2   38.5    14644. BDFT      32.% CO3,  15.% WO3,  15.% SO3,   9.% WP3
```

```
        FOREST VEGETATION SIMULATOR     VERSION 1.00 -- SOUTHERN U.S. PROGNOSIS                RV:01.27.06    06-09-2007  13:21:55

STAND ID: FishburnCFI                   MGMT ID: NONE    Stand FishburnCFI at Fishburn Forest


STAND POLICIES:   All, !StandsInNoDefinedGroup

-------------------------------------------------------------------------------------------------------------------------------
                     ATTRIBUTES OF SELECTED SAMPLE TREES                 ADDITIONAL STAND ATTRIBUTES (BASED ON STOCKABLE AREA)
      -----------------------------------------------------------------  ------------------------------------------------------
      INITIAL                           LIVE   PAST DBH  BASAL   TREES          QUADRATIC   TREES    BASAL  TOP HEIGHT  CROWN
      TREES/A            DBH    HEIGHT  CROWN   GROWTH   AREA     PER   STAND    MEAN DBH    PER     AREA     LARGEST   COMP
YEAR   %TILE  SPECIES (INCHES)  (FEET)  RATIO  (INCHES)  %TILE    ACRE   AGE     (INCHES)    ACRE   (SQFT/A) 40/A (FT)  FACTOR
----  ------- ------- -------- -------- ------ --------- ------- ------  -----  ---------   ------ --------- ---------  -------

2006                                          (  5 YRS)

        10     RM3       4.30    39.84    25     0.34      1.8    0.16
        30     S03       5.40    45.26    40     0.48      7.1    0.16
        50     HM3       7.20    45.83    56     0.71     16.2    0.16
        70     S03       9.60    60.18    52     0.58     31.9    0.16
        90     S03      14.00    70.51    58     1.35     62.1    0.16
       100     W03      38.20   102.15    80     0.16    100.0    0.16
                                                                           0       9.4      215.     104.       71.8    175.8

2016                                          ( 10 YRS)

        10     RM3       4.84    47.34    23     0.50      1.4    0.16
        30     S03       6.27    51.60    39     0.76      7.0    0.16
        50     HM3       9.22    57.98    58     1.85     21.5    0.16
        70     S03      10.76    69.20    51     1.05     31.7    0.16
        90     S03      15.30    78.27    56     1.19     61.1    0.16
       100     W03      38.48   102.35    76     0.26    100.0    0.16
                                                                          10      10.7      211.     131.       78.8    206.1
```

```
        FOREST VEGETATION SIMULATOR     VERSION 1.00 -- SOUTHERN U.S. PROGNOSIS                RV:01.27.06    06-09-2007  13:21:55

STAND POLICIES:   All, !StandsInNoDefinedGroup

STAND ID: FishburnCFI                   MGMT ID: NONE    Stand FishburnCFI at Fishburn Forest


                                SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)
--------------------------------------------------------------------------------------------------------------------------------------
               START OF SIMULATION PERIOD                     REMOVALS             AFTER TREATMENT    GROWTH THIS PERIOD
         --------------------------------------------- ----------------------- ---------------------  ------------------   MAI  ------
         NO OF              TOP      MERCH SAWLG SAWLG NO OF MERCH SAWLG SAWLG              TOP  RES  PERIOD ACCRE MORT   MERCH FOR SS
YEAR AGE TREES  BA  SDI CCF HT  QMD  CU FT CU FT BD FT TREES CU FT CU FT BD FT  BA  SDI CCF HT   QMD  YEARS   PER  YEAR   CU FT TYP ZT
---- --- ----- --- ---- --- --- ---- ----- ----- ----- ----- ----- ----- ----- --- ---- --- --- ----  ------ ----  -----  ----- ------
2006   0   215 104  196 176  72  9.4  2474  1413  9411     0     0     0     0 104  196 176  72  9.4      10   93     2     0.0 515 12
2016  10   211 131  234 206  79 10.7  3385  2187 14644     0     0     0     0 131  234 206  79 10.7       0    0     0     0.0 515 12

NOTE:  2 LINES OF SUMMARY DATA HAVE BEEN WRITTEN TO THE FILE REFERENCED BY LOGICAL UNIT  4



                                                     ACTIVITY SUMMARY

STAND ID= FishburnCFI                   MGMT ID= NONE    Stand FishburnCFI at Fishburn Forest

----------------------------------------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  ACTIVITY DISPOSITION  PARAMETERS:
-----  ----  ---------  --------  ----  --------------------  --------------------------------------------------------------------

   1   2006
               BASE     TREELIST  2001  DONE IN 2015                3.00      1.00      1.00
----------------------------------------------------------------------------------------------------------------------------------
```

2. FVS-Sn Tree List Output File

```
-999 1309    1 2016 FishburnCFI                  NONE SN 1.00 06-09-2007 13:21:55 T 10 0.6100000E+02 01.27.06   00000000000
  214466   466 TM  9  3  0  24    0.158    0.006  10.6  0.85  51.8  3.3 43 17.1  0  30.74    31   12.5   11.0    71.0  0  0    0
  214472   472 TM  9  3  0  24    0.159    0.005  11.5  0.98  53.2  3.0 44 18.4  0  35.43    18   15.1   13.8    91.0  0  0    0
  214473   473 TM  9  3  0  24    0.158    0.006  10.0  0.58  51.2  3.3 41 16.1  0  26.91    37   10.9    9.1    59.0  0  0    0
  214476   476 TM  9  3  0  24    0.161    0.003  13.3  0.59  56.8  2.1 46 21.1  0  46.08     0   21.6   20.8   141.0  0  0    0
  269811   811 TM  9  3  0  39    0.158    0.006  10.3  0.82  51.2  3.3 42 16.6  0  29.12   107   11.6    9.9    64.0  0  0    0
  197329   329 PP 10  3  0  18    0.157    0.007  10.5  1.70  57.9  8.9 88 19.3  0  29.92    27   13.4   11.6    73.0  0  0    0
  197330   330 PP 10  3  0  18    0.157    0.007  10.3  1.62  57.5  8.9 87 19.0  0  29.05    33   12.8   10.9    68.0  0  0    0
  197336   336 PP 10  3  0  18    0.155    0.009   6.3  0.69  45.4  8.1 62 11.9  0   7.35   118    3.6    0.0     0.0  0  0    0
  197339   339 PP 10  3  0  18    0.159    0.005  15.4  3.99  64.1  8.2 95 26.9  0  61.38     0   33.1   32.2   226.0  0  0    0
  197341   341 PP 10  3  0  18    0.157    0.007   8.1  0.42  54.7  8.9 76 15.2  0  16.03   102    7.2    0.0     0.0  0  0    0
  198361   361 PP 10  3  0  19    0.158    0.006  10.5  0.96  60.5  8.7 88 19.4  0  30.21    56   14.0   12.2    75.0  0  0    0
  199362   362 PP 10  3  0  20    0.160    0.004  13.7  1.81  65.8  7.8 95 24.4  0  51.25    11   26.4   25.3   168.0  0  0    0
  199363   363 PP 10  3  0  20    0.158    0.006  11.5  1.44  61.6  8.6 91 20.9  0  35.25    53   17.1   15.7    99.0  0  0    0
  199371   371 PP 10  3  0  20    0.158    0.006  11.9  2.27  60.0  8.8 91 21.5  0  37.62    38   17.9   16.6   107.0  0  0    0
  199372   372 PP 10  3  0  20    0.156    0.008   9.4  2.04  52.5  8.9 79 17.3  0  22.99    87    9.8    0.0     0.0  0  0    0
  199375   375 PP 10  3  0  20    0.155    0.009   7.6  2.07  42.8  7.8 64 13.8  0  12.70   120    4.9    0.0     0.0  0  0    0
  199378   378 PP 10  3  0  20    0.159    0.005  13.5  2.31  64.1  8.2 95 24.0  0  48.50    21   24.9   23.9   158.0  0  0    0
  199383   383 PP 10  3  0  20    0.155    0.009   7.6  1.39  47.5  8.4 72 14.3  0  12.74   117    5.5    0.0     0.0  0  0    0
  199391   391 PP 10  3  0  20    0.159    0.005  11.5  0.44  64.5  8.1 91 21.0  0  35.69    45   18.0   16.4   102.0  0  0    0
  210395   395 PP 10  3  0  21    0.159    0.005  14.2  3.27  63.1  8.4 95 25.1  0  55.59    89   27.4   26.5   180.0  0  0    0
  210404   404 PP 10  3  0  21    0.161    0.003  15.8  2.12  69.0  6.7 95 27.5  0  63.53    41   37.3   36.2   252.0  0  0    0
  210411   411 PP 10  3  0  21    0.161    0.002  14.7  1.01  69.2  6.6 95 25.8  0  57.70    55   31.8   30.7   207.0  0  0    0
  213458   458 PP 10  3  0  23    0.155    0.009   5.7  0.88  40.6  7.6 55 10.6  0   4.76    79    2.3    0.0     0.0  0  0    0
  216529   529 PP 10  3  0  26    0.156    0.008   7.8  0.67  52.4  8.9 73 14.6  0  14.01   144    6.4    0.0     0.0  0  0    0
  227560   560 PP 10  3  0  28    0.163    0.001  16.7  0.69  72.4  4.7 95 28.7  0  67.31    20   43.4   42.2   297.0  0  0    0
  227572   572 PP 10  3  0  28    0.162    0.001  15.7  0.63  71.3  5.5 95 27.3  0  63.19    35   37.8   36.7   253.0  0  0    0
  227578   578 PP 10  3  0  28    0.162    0.002  19.3  4.24  70.6  5.8 95 32.6  0  77.64     0   57.8   56.5   423.0  0  0    0
  227582   582 PP 10  3  0  28    0.156    0.008   7.9  0.53  53.6  8.9 74 14.8  0  14.92   121    6.8    0.0     0.0  0  0    0
  227585   585 PP 10  3  0  28    0.158    0.006  10.9  0.99  61.6  8.6 89 20.0  0  32.38    71   15.5   13.8    86.0  0  0    0
  247691   691 PP 10  3  0  34    0.162    0.002  15.4  0.38  71.3  5.5 95 26.9  0  61.70    30   36.4   35.2   241.0  0  0    0
  247700   700 PP 10  3  0  34    0.161    0.003  16.8  2.94  69.0  6.7 95 28.8  0  67.88     0   42.0   40.9   292.0  0  0    0
  248724   724 PP 10  3  0  35    0.161    0.003  16.3  3.03  68.1  7.1 95 28.1  0  65.08    68   39.0   38.0   269.0  0  0    0
  251743   743 PP 10  3  0  36    0.161    0.003  14.1  1.11  68.1  7.1 95 24.9  0  54.24     0   28.8   27.7   184.0  0  0    0
  266776   776 PP 10  3  0  38    0.157    0.007   9.4  1.23  55.8  9.0 82 17.4  0  22.52    75   10.2    0.0     0.0  0  0    0
```

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3. FVS-Sn Summary Output File

```
-999    2 FishburnCFI                NONE  0.6100000E+02 SN 1.00 06-09-2007 13:21:55 01.27.06    00000000000
2006   0   215 104  196 176  72  9.4  2474  1413  9411     0     0     0     0 104  196 176  72  9.4      10   93     2     0.0 515 12
2016  10   211 131  234 206  79 10.7  3385  2187 14644     0     0     0     0 131  234 206  79 10.7       0    0     0     0.0 515 12
```

Appendix C. SAS Scripts

1. *DATAIN* Reformatting SAS Script

```
Filename sppIN        'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\spp.dat';
** FIA species codes sorted in ascending order;
Filename DATAIN       'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\DATAIN.dat';
** file contains all the inputs parameters  that are varied using LHS for the lndds equation and
mortality;
Filename parms                'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\parmnames.dat';
** parameter names sorted aphabetically, numbered sequentially in order of DATAIN file;
Filename LHSdata      'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_coefficients.dat';
** LHS values for the lndds equation, 5000 values for each parameter, sorted by order they are
read into FVS-Sn;
Filename SDILHS       'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_SDImax_coeffs.dat';
** LHS values for the SDI max coefficients (one for each species 90), 5000 values for each
species, sorted by run;
Filename MORTLHS      'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_BGmort_coeffs.dat';
** LHS values for the mortality (2 parameters 5000 each, sorted by run, species, and parameter;
Filename SDITHRES
        'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_sdi_thresh_Coeffs.dat';
** LHS values for the SDI threshold percentages, (55 and 85, 5000 values for each), sorted by run
and low and high value;
Filename INTOL
        'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_intolerance_Coeffs.dat';
** LHS values for the intolerance values used in SDI calculations (one for species, 5000 for each
species), sorted by run, species;
Filename HGTDUB
        'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_height_Coeffs.dat';
** LHS values for the height dubbing parameter values;
Filename WCRDUBB      'd:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\LHS_CR_Coeffs.dat';
** LHS values for the Wiebull crown dubbing parameter values;
libname FVS                   'd:\SAS_lib\Vary_all5000';
data sppblank;infile sppIN;input spp;
** add the common variable 1 to the spiecis code dataset so it can be merged to the parmnames
file;
common=1;
run;

data parmnames (index=(common));infile parms;
** add the common variable 1 to the parms dataset so it can be merged to the species dataset;
input parmno parm $;
common=1;
run;

data sppXparms(drop=dummy);
** merges the sppblank (sppIN) and the parmnames (parms) datasets so that each species has all
the parameters associated with it present;

  set sppblank;
  by common;
/* Read an observation from SPPBLANK.  Specify COMMON as the BY variable */
  dummy=0;
/* Set DUMMY to 0 each iteration of the step.  The next DO loop uses the value of DUMMY.
Attempt to read an observation from PARMNAMES, based on the value of the key variable COMMON.
Repeat the process until the value of COMMON from SPPBLANK does not match any value of COMMON
from PARMNAMES. When DUMMY is true (equals 1), set COMMON to a non-existent value.
Changing the value of the KEY= variable forces the pointer to return to the beginning of the
index, so that later observations in SPPBLANK can find matches forthe same value of COMMON in
PARMNAMES.*/

        do until(_iorc_=%sysrc(_dsenom));
        if dummy then common=99999;
        set parmnames key=common;

 /* Use the value of _IORC_ to conditionally process observations.
When the value of COMMON from SPPBLANK matches a COMMON value from PARMNAMES,write an observation
to sppXparms.  When the current observation from SPPBLANK has no matching value for COMMON in
```

```
PARMNAMES, set_ERROR_ to zero. If the current observation from SPPBLANK is not the last in the
current BY-Group and if DUMMY is not true (does not equal 1), then set
the values of DUMMY and _IORC_ accordingly.*/

        select (_iorc_);
      when (%sysrc(_sok)) output;
      when (%sysrc(_dsenom)) do;
        _error_=0;
        if not last.common and not dummy then do;
          dummy=1;
          _iorc_=0;
        end;
      end;

/* In the case of an unexpected _IORC_ condition, write an error message and stop execution.*/
      otherwise do;
        put 'Unexpected ERROR: _IORC_ =  ' _iorc_;
        stop;
      end;
    end;
 /* ends the SELECT group  */
 end;
/* ends the DO UNTIL loop */
drop common;
run;

data FVS.sppXparms;set sppXparms;run;

data BTparms;infile LHSdata;
** read in the lndds LHS values create a new dataset;
input run spp parm $ val;
run;
proc sort data=btparms;by spp parm;run;
proc sort data=sppblank;by spp;run;
proc sort data=sppXparms;by spp parm;run;

data SDILHS;infile SDILHS;
/* Read in the SDImax values from Phil's LHS C program */
input run fortype val;
run;

data MORTLHS;infile MORTLHS ;
/*Read in the big tree mortality values from Phil's LHS C program*/

input run spp parm $ val;
run;

data SDITHRES;infile SDITHRES ;  /*Read in the SDI threshold values from Phil's LHS C program*/
input run num val;

run;

data INTOL;infile INTOL ;
/*Read in the tree intolerance values from Phil's LHS C program*/
input run spp val;
run;

data HGTDUB;infile HGTDUB;
/*Read in the height dubbing values from Phil's LHS C program*/
input run spp parmno $ val;
run;

data WCRDUBB;infile WCRDUBB;
/*Read in the height dubbing values from Phil's LHS C program*/
input run spp parmno $ val;
run;

proc printto log='D:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\logoutput.dat' new;run;

%MACRO LHS;
options cleanup;
```

```
/* macro creates the desired number of DATAIN files needed for the simulation, corresponds to the
number of values sampled from LHS (5000) */
        %DO i=0 %TO 5;

Filename outfile "D:\FVS\TEST_with_mort\Datain_files\DATAIN&i..dat";
* 5000 DATAIN files are created, one for each model run, DATAIN2.dat is the same as the original
DATAIN.dat;

data datatop;infile DATAIN firstobs=1 obs=97 dlm='07'x lrecl=32000;
* The first 97 lines of the DATAIN file are not sampled using LHS, so they are just copied
directly from the original DATAIN file;
                informat line $32000.;
                input line;
                file outfile lrecl=32000;
                put "    " line;
        run;

data hdub;set HGTDUB;if run eq &i;run;
** This section of code reads in the LHS species hdub coefficients generated from the C++ program
and then adds the regression coefficients to the DATAIN&i.dat file;
data hdub;set hdub;if val eq . then val = 0.0;run;
/* replace missing coefficient values with 0.0. The C++ programs arleady sorts the Mortality
coeffecients by run and species number;*/
data hdubtofile;set hdub;obs=_N_;run;


data hdub2;set hdubtofile;
/* Create a data set of only the first column of height dubbing values */
                if obs le 90;
                        drop parmno obs;
                        rename val=p2;
        run;

data hdub3;set hdubtofile;
/* Create a data set of only the second column of height dubbing values */
                if obs gt 90 and obs le 180;
                        drop parmno obs;
                        rename val=p3;
        run;


data hdub4;set hdubtofile;
/* Create a data set of only the third column of height dubbing values */
                if obs gt 180;
                        drop parmno obs;
                        rename val=p4;
        run;

data hdub2datain;merge hdub2 hdub3 hdub4;by run spp;run;
/* Merge the datasets of each column of the height dubbing values */


data hdub2datain;set hdub2datain;
** add the hdub values to each DATAIN&i.dat in the proper format;
        file outfile  lrecl=4096 mod;
                if spp=999 then do;
                put "      " p2 13.7 ','  p3 13.7 ',' p4 13.7 ;
        end;
                else do;
                put "      " p2 13.7 ','  p3 13.7 ',' p4 13.7 ',';
        end;
run;


data datatop;infile DATAIN firstobs=188 obs=331 dlm='07'x lrecl=32000;
* These lines of the DATAIN file are not sampled using LHS, so they are just copied directly from
the original DATAIN file;
        informat line $32000.;
        input line;
        file outfile lrecl=32000 mod;
        put "    " line;
```

```
run;

data test;set BTparms;if run eq &i;run;
** only refers to the model run corresponding to the macro loop;
data test;merge test sppXparms;by spp parm;run;
** expand BTparms to ensure all 90 x 30 spp and parms;
data test;merge test sppblank;by spp;run;
** add species names to BTparms;
data test;set test;if val eq . then val = 0.0;run;
** replace missing coefficient values with 0.0;
proc sort data=test;by parmno spp;run;
data tofile;set test;obs = _N_;run;
** add a counter to the dataset containing lndds LHS values;
data tofile;set tofile;
** add the LHS data corresponding to that model run (&i) and DATAIN&i.dat;
file outfile  lrecl=4096 mod;
sppobs = mod((obs),90);
** each DATAIN&i.dat must be in the same format as the original DATAIN.dat, so the following
formats the values into the appropriate formatted blocks;
parmobs = mod((obs),30);
               if (mod(sppobs,90) eq 0) then do;
               put  "      " val 9.6;
               end;
       else do;
               if(mod(sppobs,5) eq 0) then do;
               put " " val 9.6 ',';
               end;
       else do;
               put "      " val 9.6 ',' @;
       end;
end;
run;

data databot1;infile DATAIN firstobs=872 obs=1069 dlm='07'x;
** add a section of the DATAIN.dat file which is not modified to each DATAIN&i.dat;
informat line $1000.;
input line;
file outfile mod lrecl=10000;
put "       " line;
run;

data wcrdub;set WCRDUBB;if run eq &i;run;
** This section of code reads in the LHS species wcrdub coefficients generated from the C++
program and then adds the regression coefficients to the DATAIN&i.dat file;
data wcrdub;set wcrdub;if val eq . then val = 0.0;run;
/* replace missing coefficient values with 0.0. The C++ programs arleady sorts the Mortality
coeffecients by run and species number;*/
data wcrdubtofile;set wcrdub;obs=_N_;run;

data wcrduba;set wcrdubtofile;
/* Create a data set of only the first column of Wiebull crown dubbing values */
       if obs le 90;
               drop parmno obs;
               rename val=a;
run;

data wcrdubb0;set wcrdubtofile;
/* Create a data set of only the second column of Wiebull crown dubbing values */
       if obs gt 90 and obs le 180;
               drop parmno obs;
               rename val=b0;
run;

data wcrdubb1;set wcrdubtofile;       /
* Create a data set of only the third column of Wiebull crown dubbing values */
       if obs gt 180 and obs le 270;
               drop parmno obs;
               rename val=b1;
run;

data wcrdubc;set wcrdubtofile;
```

```
/* Create a data set of only the third column of Wiebull crown dubbing values */
        if obs gt 270;
                drop parmno obs;
                rename val=c;
run;

data wcrdub2datain;merge wcrduba wcrdubb0 wcrdubb1 wcrdubc;by run spp;run;
/* Merge the datasets of each column of the height dubbing values */


data wcrdub2datain;set wcrdub2datain;
** add the wcrdub values to each DATAIN&i.dat in the proper format;
file outfile  lrecl=4096 mod;
        if spp=999 then do;
        put "      " a 8.4 ','  b0 8.4 ',' b1 8.4 ',' c 8.4;
end;
        else do;
        put "      " a 8.4 ','  b0 8.4 ',' b1 8.4 ',' c 8.4 ',';
end;
run;

data intolerance;set INTOL;if run eq &i;run;
** This section of code reads in the LHS species intolerance coefficients generated from the C++
program and then adds the regression coefficients to the DATAIN&i.dat file;
data intolerance;set intolerance;if val eq . then val = 0.0;run;
** replace missing coefficient values with 0.0;

** the C++ program arleady sorts the Mortality coeffecients by run and species number;
data intol2datain;set intolerance;obs = _N_;run;

data intol2datain;set intol2datain;
** add the intolerance values to each DATAIN&i.dat in the proper format;
file outfile  lrecl=4096 mod;
sppobs = mod((obs),90);
                if (mod(sppobs,90) eq 0) then do;
                put val 10.7;
                end;
        else do;
                if(mod(sppobs,10) eq 0) then do;
                put " " val 10.7 ',';
                end;
        else do;
                put "      " val 10.7 ',' @;
        end;
end;
run;

** This section of code reads in the big tree LHS mortality coefficients generated from the
C++program and then adds the regression coefficients to the DATAIN&i.dat file;
data mort;set MORTLHS ;if run eq &i;run;

data mort;set mort;if val eq . then val = 0.0;run;
/* replace missing coefficient values with 0.0.  The C++ programs arleady sorts the Mortality
coeffecients by species and parameter number. */
data mort2datain;set mort;obs = _N_;run;

data mort2datain;set mort2datain;
file outfile  lrecl=4096 mod;
sppobs = mod((obs),90);
                if (mod(sppobs,90) eq 0) then do;
                put val 10.7;
                end;
        else do;
                if(mod(sppobs,5) eq 0) then do;
                put " " val 10.7 ',';
                end;
        else do;
                put "      " val 10.7 ',' @;
        end;
end;
run;
```

```
data databot2;infile DATAIN firstobs=1205 obs=1219 dlm='07'x;
** add an unchanged section of the DATAIN.dat file;
informat line $1000.;
input line;
file outfile mod lrecl=10000;
put "       " line;
run;

** This section of code reads in the SDImax values generated from the C++ program and then adds
the regression coefficients to the DATAIN&i.dat file;
data SDItest;set SDILHS;if run eq &i;run;

data SDItest;set SDItest;if val eq . then val = 0.0;run;
/*replace missing coefficient values with 0.0.  The C++ programs arleady sorts the Mortality
coeffecients by run and forest type.*/
data SDI2datain;set SDItest;obs = _N_;run;

data SDI2datain;set SDI2datain;
file outfile  lrecl=4096 mod;
fia4type = mod((obs),141);
parmobs = mod((obs),30);
                if (mod(fia4type,141) eq 0) then do;
                put "      " val 9.6;
                end;
        else do;
                if(mod(fia4type,10) eq 0) then do;
                put " " val 9.6 ',';
                end;
        else do;
                put "      " val 9.6 ',' @;
        end;
end;
run;

** This section of code reads in the SDI threshold values generated from the C++ program and then
adds the regression coefficients to the DATAIN&i.dat file;

data threshold2datain;set SDITHRES;if run eq &i;run;

data threshold2datain;set threshold2datain;if val eq . then val = 0.0;run;
/*replace missing coefficient values with 0.0.  The C++ programs arleady sorts the SDI threshold
coeffecients by run and threshold level.*/

data threshold2datain;set threshold2datain;
file outfile  lrecl=4096 mod;
        if num=1 then do;
                put "      " val 9.6;
        end;
        else do;
                put "      " val 9.6;
        end;
run;

data databot3;infile DATAIN firstobs=1237 obs=1267 dlm='07'x;
** adds unchanged section of DATAIN.dat to each DATAIN&i.dat file;
informat line $1000.;
input line;
file outfile mod lrecl=10000;
put "       " line;
run;

%END;
%MEND LHS;

%LHS;

proc printto;run;
```

2. Reformatting and Summarizing the FVS-Sn Model Output Files

```
libname FVS "D:SAS_Lib\Vary_all5000";
** change according to where the resulting datasets are to be saved;
Filename Timeone "D:\FVS_SAS\SA\Time1Random.trl";

data timeone;infile timeone firstobs=2 lrecl=2560 missover;
input sppindx treeindx spp $ sppno treclass sscd Plotnum tpa mort diam1;
tbapa=diam1**2*.005454*tpa;
drop sppindx spp sppno treclass sscd mort tpa;
run;

proc sort data=timeone;by treeindx plotnum;run;


%macro SA;

%DO i=0 %TO 4999 ;

        filename treelist "D:\FVS\TEST_with_mort\Output_1st rep\output&i..tls";

        data TLtemp;
        infile treelist lrecl=2560 missover;
        **informat standID $10. sppcd $2.;
        informat sppcd $2.;
        INPUT rectype @;
        drop treenum;

          IF rectype=-999 THEN DO ;
            **INPUT nrows cycle year standID;
                **INPUT nrows;
                **call symput('m1',nrows);
                **call symput('m2',cycle);    ** the cycle is always 1;
                **call symput('m3',year);     ** the year is 2001 for each record;
                **call symput('m4',standID); ** stand id is always FishburnCFI;
          END ;
          ELSE DO;
                INPUT treeindx sppcd sppno treclass sscd Plotnum tpa mort diam dincr;
                drop treclass sscd;
                treenum = rectype;
                **nrows = symget('m1');
                **cycle = symget('m2');
                **year = symget('m3');
                **standID = symget('m4');
                bapa = .005454*diam**2*tpa;
                **dbhclass = round(diam);            ** drop to shorten run time;
                SArun = &i;
                output;
          END;
        run;

        proc sort data=tltemp;by treeindx plotnum;run;
        data tltemp;merge tltemp timeone;by treeindx plotnum;run;

        data tltemp;set tltemp;
        bapaincr=bapa-tbapa;
        run;

        data tltemp; set tltemp;
                if sppcd='AB' then ccf= .001803*((.868+4.15*diam**.7514)**2)*tpa;
                else if sppcd='AE' then ccf= .001803*((3.36+.776*diam)**2)*tpa;
                else if sppcd='AS' then ccf= .001803*((2.326+2.839*diam)**2)*tpa;
                else if sppcd='BT' then ccf= .001803*((.0754+5.577*diam**.5996)**2)*tpa;
                else if sppcd='BW' then ccf= .001803*((.135+3.703*diam**.7307)**2)*tpa;
                else if sppcd='BN' then ccf= .001803*((4.901+2.48*diam)**2)*tpa;
                else if sppcd='BC' then ccf= .001803*((.621+7.059*diam**.5441)**2)*tpa;
                else if sppcd='BU' then ccf= .001803*((1.0887+2.0769*diam)**2)*tpa;
                else if sppcd='DW' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
```

```
                else if sppcd='HI' then ccf= .001803*((1.0887+2.0769*diam)**2)*tpa;
                else if sppcd='HM' then ccf= .001803*((.523+1.632*diam)**2)*tpa;
                else if sppcd='AH' then ccf= .001803*((3.36+.776*diam)**2)*tpa;
                else if sppcd='OT' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
                else if sppcd='PP' then ccf= .001803*((2.966+1.4038*diam)**2)*tpa;
                else if sppcd='RD' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
                else if sppcd='RM' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
                else if sppcd='SS' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
                else if sppcd='SK' then ccf= .001803*((5.3+1.6*diam)**2)*tpa;
                else if sppcd='SD' then ccf= .001803*((3.36+.776*diam)**2)*tpa;
                else if sppcd='OH' then ccf= .001803*((0+4.776*diam**.7656)**2)*tpa;
                else if sppcd='TM' then ccf= .001803*((2.966+1.4038*diam)**2)*tpa;
                else if sppcd='WN' then ccf= .001803*((4.901+2.48*diam)**2)*tpa;
                else if sppcd='BO' then ccf= .001803*((1.6+1.7*diam)**2)*tpa;
                else if sppcd='CO' then ccf= .001803*((3.5+1.7*diam)**2)*tpa;
                else if sppcd='RO' then ccf= .001803*((5.3+1.6*diam)**2)*tpa;
                else if sppcd='SB' then ccf= .001803*((3.639+1.953*diam)**2)*tpa;
                else if sppcd='SM' then ccf= .001803*((.868+4.15*diam**.7514)**2)*tpa;
                else if sppcd='SO' then ccf= .001803*((3.3+1.8*diam)**2)*tpa;
                else if sppcd='VP' then ccf= .001803*((2.966+1.4038*diam)**2)*tpa;
                else if sppcd='WO' then ccf= .001803*((3.5+1.7*diam)**2)*tpa;
                else if sppcd='WP' then ccf= .001803*((1.62+3.197*diam**.7981)**2)*tpa;
                else if sppcd='YP' then ccf= .001803*((2.9924+1.7122*diam**.7656)**2)*tpa;
                else if sppcd='BG' then ccf= .001803*((3.1+.771*diam)**2)*tpa;
        run;

        proc means data=tltemp noprint;var tpa bapa diam ccf bapaincr mort;
        /*by SArun cycle;id year;*/
        id SArun;
        output out=sumtemp sum(tpa bapa ccf bapaincr mort)=tpa bapa ccf bapaincr mort
mean(diam)=dbh ;
        run;

        data sumtemp;set sumtemp;
        qmd = sqrt(bapa/tpa/.005454);
        drop _Type_;
        run;

        %IF &i eq 0 %THEN %DO;
        data sumlist;set sumtemp;run;
        %END;
        %ELSE %DO;
        data sumlist;set sumlist sumtemp;run;
        %END;

%END;

%MEND SA;

%SA;

data FVS.sumlist;set sumlist;run;
```

3. SAS Script of Regression Analysis to Determine Parameter Sensitivities

```
data COR2.SA_index;set SA_index;run;

proc printto log='D:\FVS_SAS\SAS_LHS_parameters_and_script_1st_rep\regoutput.dat' new;run;


proc reg data=SA_index;
model   bapaincr=             c1-c1144;
model   bapaincr=             c2-c1144;
model   bapaincr = c1      c3-c1144;
model   bapaincr = c1-c2    c4-c1144;
model   bapaincr = c1-c3    c5-c1144;
```

```
model   bapaincr = c1-c4    c6-c1144;
model   bapaincr = c1-c5    c7-c1144;
model   bapaincr = c1-c6    c8-c1144;
model   bapaincr = c1-c7    c9-c1144;
model   bapaincr = c1-c8    c10-c1144;
model   bapaincr = c1-c9    c11-c1144;
model   bapaincr = c1-c10    c12-c1144;
.
.
.
model   bapaincr = c1-c1134    c1136-c1144;
model   bapaincr = c1-c1135    c1137-c1144;
model   bapaincr = c1-c1136    c1138-c1144;
model   bapaincr = c1-c1137    c1139-c1144;
model   bapaincr = c1-c1138    c1140-c1144;
model   bapaincr = c1-c1139    c1141-c1144;
model   bapaincr = c1-c1140    c1142-c1144;
model   bapaincr = c1-c1141    c1143-c1144;
model bapaincr = c1-c1142 c1144;
model bapaincr = c1-c1143;
ods output ANOVA=SAdex;
run;quit;

proc printto;run;

data COR2.sadex;set sadex;run;

data SAdex;set COR2.SAdex;if Source = "Model";run;

data dex;set sadex; drop model source; run;

%macro pout;

        %do i=1 %to 1145;
                data dex;set dex;
                if _n_=&i then parmout=&i-1;
        %END;

%MEND pout;

%pout;

data dex;set dex;
sense=((77411-ss)/107612)*100;run;

data COR2.dex;set dex;run;

data dexsum;set FVS.dex;
if sense gt 0;
keep parmout sense;
run;

data COR2.dexsum;set dexsum;run;
```

Appendix D. FVS-Sn Model Parameters Sampled with LHS

1. Large Tree Diameter Increment Growth Model (lndds) Normal Distribution Sampling Parameters

Species	Intercept		Log of DBH		DBH^2		Log of % crown ratio		Site index		Tangent of slope	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
fir sp.	-2.268	0.2544	1.4425	0.0541	-0.0005	0.0001	0.5685	0.0549	-0.0012	0.0012	-0.2414	0.0902
red cedar	-1.864	0.1109	1.4031	0.0344	-0.0012	0.0002	0.2736	0.0210	-0.0004	0.0008	-0.2320	0.1139
spruce	-2.268	0.2544	1.4425	0.0541	-0.0005	0.0001	0.5685	0.0549	-0.0012	0.0012	-0.2414	0.0902
sand pine	-3.792	0.3497	1.7962	0.0643	-0.0051	0.0007	0.9022	0.0661	-0.0020	0.0033	0.5014	0.7094
shortleaf pine	-0.009	0.0446	1.2382	0.0223	-0.0012	0.0001	0.0531	0.0062	0.0047	0.0003	-0.7047	0.0436
slash pine	-1.642	0.053	1.4611	0.0243	-0.0025	0.0001	0.2659	0.0112	0.0069	0.0004	-0.0185	0.1807
spruce pine	-2.431	0.3282	1.6917	0.0933	-0.0009	0.0002	0.5886	0.0710	0.0001	0.0016	-0.3243	0.2969
longleaf pine	-1.331	0.0675	1.0981	0.0329	-0.0018	0.0001	0.1845	0.0140	0.0088	0.0003	0.2252	0.1103
Table mtn. pine	-2.601	0.0788	1.5254	0.0289	-0.0035	0.0002	0.6157	0.0170	0.0010	0.0006	-0.2178	0.0494
pitch pine	-3.639	0.3744	1.3974	0.1459	-0.0017	0.0005	0.7394	0.0803	0.0087	0.0023	-0.3172	0.1557
pond pine	-2.353	0.1898	1.4256	0.0730	-0.0017	0.0003	0.4558	0.0458	0.0079	0.0016	0.6850	1.6099
e. white pine	-3.498	0.1722	1.3395	0.0441	-0.0010	0.0001	0.7591	0.0348	0.0042	0.0009	-0.3727	0.0798
loblolly pine	0.2222	0.0182	1.163	0.0088	-0.0009	0.0000	0.0285	0.0029	0.0050	0.0001	-0.7593	0.0355
Virginia pine	-2.601	0.0788	1.5254	0.0289	-0.0035	0.0002	0.6157	0.0170	0.0010	0.0006	-0.2178	0.0494
bald cypress	-1.736	0.0985	1.5056	0.0323	-0.0001	0.0000	0.1324	0.0186	0.0040	0.0004	-0.5606	0.8141
pond cypress	-4.225	0.1026	1.8317	0.0339	-0.0006	0.0001	0.4462	0.0252	0.0060	0.0007	2.3567	4.2477
hemlock	-2.268	0.2544	1.4425	0.0541	-0.0005	0.0001	0.5685	0.0549	-0.0012	0.0012	-0.2414	0.0902
Florida maple	-1.686	0.3494	1.4545	0.1050	-0.0008	0.0005	0.2424	0.0551	0.0044	0.0033	-0.3398	0.3292
box elder	-0.871	0.2393	1.2179	0.0689	-0.0001	0.0003	0.2401	0.0421	0.0000	0.0017	-0.6132	0.2254
red maple	-2.261	0.0528	1.4498	0.0133	-0.0009	0.0001	0.3613	0.0108	0.0034	0.0004	-0.0976	0.0456
silver maple	-2.261	0.0528	1.4498	0.0133	-0.0009	0.0001	0.3613	0.0108	0.0034	0.0004	-0.0976	0.0456
sugar maple	-2.313	0.1813	1.3501	0.0413	-0.0008	0.0001	0.3948	0.0386	-0.0005	0.0009	-0.0325	0.0650
buckeye	-1.876	0.5701	1.197	0.1601	-0.0008	0.0003	0.1839	0.1162	0.0103	0.0042	-0.1781	0.2374
birch sp.	-1.092	0.1851	1.0249	0.0531	-0.0007	0.0001	0.2068	0.0318	0.0024	0.0015	-0.1928	0.1174
sweet birch	-1.092	0.1851	1.0249	0.0531	-0.0007	0.0001	0.2068	0.0318	0.0024	0.0015	-0.1928	0.1174
American hornbeam	-1.281	0.1362	1.3356	0.0301			0.1111	0.0229	0.0053	0.0012	-0.2245	0.1801
hickory sp.	-2.728	0.0453	1.5484	0.0144	-0.0008	0.0000	0.2038	0.0088	0.0044	0.0003	-0.2458	0.0331
catalpa	-1.069	0.2407	1.1642	0.0620			0.0843	0.0391	0.0097	0.0017	0.0757	0.7036

Species	Intercept		Log of DBH		DBH^2		Log of % crown ratio		Site index		Tangent of slope	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
hackberry sp.	-0.8332	0.11689	1.1906	0.0332			0.1934	0.0180	-0.0001	0.0009	-0.1790	0.1778
eastern redbud	-1.0625	0.36776	1.1741	0.0856			0.2399	0.0658	-0.0059	0.0032	-0.3918	0.2463
flowering dogwood	-2.5407	0.09457	1.2931	0.0315	-0.0009	0.0013	0.3685	0.0192	0.0043	0.0008	-0.2827	0.0708
common persimmon	-2.5245	0.17699	1.4799	0.0641	-0.0015	0.0005	0.2892	0.0364	0.0034	0.0017	-0.3278	0.2312
American beech	-1.2519	0.10562	1.3493	0.0271	-0.0004	0.0000	0.1931	0.0181	-0.0003	0.0008	-0.3804	0.0571
ash	-2.9545	0.12113	1.4617	0.0313			0.3778	0.0241	0.0071	0.0012	-0.6197	0.1488
white ash	-1.3153	0.16089	1.2163	0.0692	-0.0001	0.0002	0.0879	0.0233	0.0034	0.0010	0.0183	0.0894
black ash	-0.8977	0.11431	1.2431	0.0326			0.0902	0.0172	-0.0005	0.0009	-0.1581	0.1742
green ash	-0.8977	0.11431	1.2431	0.0326			0.0902	0.0172	-0.0005	0.0009	-0.1581	0.1742
honey locust	-0.3149	0.27705	0.9272	0.0758			0.1032	0.0411	0.0030	0.0020	-0.1078	0.5372
loblolly-bay	-2.5146	0.23023	1.4597	0.0682	-0.0013	0.0003	0.6542	0.0484	-0.0036	0.0025	-3.4691	2.6314
silver bell	-2.3523	1.0898	1.7469	0.2998			0.2915	0.2127	0.0032	0.0078	0.3357	0.5379
American holly	-1.9819	0.13746	1.4563	0.0376	-0.0021	0.0005	0.2152	0.0235	0.0042	0.0012	-0.3036	0.1758
butternut	-2.3542	0.29608	1.0502	0.1084	-0.0002	0.0003	0.4253	0.0554	0.0013	0.0020	0.1334	0.1650
black walnut	-2.3542	0.29608	1.0502	0.1084	-0.0002	0.0003	0.4253	0.0554	0.0013	0.0020	0.1334	0.1650
sweetgum	-1.3241	0.03161	1.3959	0.0126	-0.0005	0.0000	0.1455	0.0061	0.0020	0.0002	-0.5030	0.0623
yellow-poplar	-2.5134	0.06629	1.4954	0.0180	-0.0008	0.0000	0.5301	0.0162	0.0007	0.0002	-0.3218	0.0377
magnolia sp.	-2.5168	0.08884	1.4542	0.0275	-0.0009	0.0001	0.2523	0.0206	0.0072	0.0008	-0.0256	0.2963
cucumber ree	-1.2396	0.54755	1.0634	0.1524	-0.0001	0.0005	0.2431	0.1223	-0.0031	0.0028	-0.3085	0.2035
southern	-1.4779	0.23949	1.1265	0.0731	-0.0003	0.0002	0.1343	0.0355	0.0059	0.0022	0.4057	0.2336
sweetbay	-2.5168	0.08884	1.4542	0.0275	-0.0009	0.0001	0.2523	0.0206	0.0072	0.0008	-0.0256	0.2963
big leaf magnolia	-1.4779	0.23949	1.1265	0.0731	-0.0003	0.0002	0.1343	0.0355	0.0059	0.0022	0.4057	0.2336
apple sp.	-1.7462	0.29726	1.2341	0.0830	0.0000	0.0005	0.2855	0.0489	0.0026	0.0024	-0.8729	0.3161
mulberry sp.	-1.7462	0.29726	1.2341	0.0830	0.0000	0.0005	0.2855	0.0489	0.0026	0.0024	-0.8729	0.3161
water tupelo	-2.7218	0.11979	1.5992	0.0286	-0.0002	0.0000	0.3513	0.0237	0.0018	0.0010	-0.0233	0.8408
blackgum	-1.5085	0.06759	1.3064	0.0209	-0.0006	0.0001	0.1124	0.0116	0.0034	0.0006	-0.2966	0.0624
swamp tupelo	-2.5557	0.06883	1.303	0.0166			0.3193	0.0151	0.0065	0.0006	-0.1301	0.3018
e. hophornbeam	-1.432	0.26188	1.4523	0.0811	-0.0015	0.0010	0.0611	0.0355	0.0049	0.0024	-0.4227	0.2337
sourwood	-3.18	0.109	1.3558	0.0290	-0.0008	0.0004	0.5322	0.0245	0.0052	0.0008	-0.2927	0.0679
redbay	-2.0966	0.17253	1.2547	0.0441			0.3441	0.0356	0.0027	0.0017	-1.7622	1.0002
sycamore	-1.013	0.19749	1.2729	0.0604	-0.0002	0.0001	0.2345	0.0364	0.0004	0.0008	-0.0925	0.2131

Species	Intercept		Log of DBH		DBH^2		Log of % crown ratio		Site index		Tangent of slope	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
cottonwood	-1.069	0.24072	1.1642	0.0620			0.0843	0.0391	0.0097	0.0017	0.0757	0.7036
big tooth aspen	-1.069	0.24072	1.1642	0.0620			0.0843	0.0391	-1.0690	0.0017	0.0757	0.7036
black cherry	-2.61	0.15488	1.2203	0.0406	-0.0002	0.0002	0.5207	0.0322	0.0039	0.0013	-0.0717	0.1486
white oak	-1.6083	0.04223	1.4686	0.0139	-0.0008	0.0000	0.1395	0.0080	0.0045	0.0003	-0.2233	0.0278
scarlet oak	-2.2843	0.09143	1.5699	0.0273	-0.0006	0.0001	0.2724	0.0201	0.0051	0.0005	-0.2043	0.0438
southern red oak	-0.7836	0.04903	1.4325	0.0177	-0.0004	0.0000	0.0445	0.0071	0.0030	0.0004	-0.3121	0.0637
cherry bark oak	-0.2955	0.08964	1.2399	0.0353	-0.0002	0.0000	0.0206	0.0107	0.0038	0.0006	-0.1059	0.1263
turkey oak	-2.6981	0.13501	1.6221	0.0396	-0.0017	0.0005	0.3549	0.0276	0.0007	0.0014	-1.0848	0.3364
laurel oak	-1.5613	0.07965	1.3355	0.0248	-0.0004	0.0000	0.2462	0.0142	0.0047	0.0007	-0.7045	0.1838
overcup oak	-0.9472	0.12572	1.3764	0.0481	-0.0005	0.0001	0.0997	0.0166	0.0013	0.0009	-0.6669	0.6704
blackjack oak	-1.9489	0.09215	1.6114	0.0326	-0.0008	0.0002	0.1357	0.0167	0.0027	0.0009	-0.0718	0.1306
swamp chestnut oak	-1.3217	0.16025	1.6405	0.0590	-0.0003	0.0001	0.0382	0.0245	0.0058	0.0013	-1.2511	0.3194
chinkapin oak	-2.2235	0.31548	0.9374	0.1113	0.0002	0.0002	0.2863	0.0672	0.0086	0.0019	-0.0653	0.1371
water oak	-0.8455	0.03501	1.4884	0.0121	-0.0003	0.0000	0.0533	0.0057	0.0053	0.0003	-0.1511	0.0820
chestnut oak	-2.9007	0.07745	1.3474	0.0215	-0.0005	0.0000	0.3001	0.0181	0.0084	0.0003	-0.1339	0.0303
northern red oak	-2.7326	0.08666	1.4995	0.0223	-0.0007	0.0000	0.3448	0.0191	0.0046	0.0005	-0.1749	0.0360
Shumard oak	-0.3287	0.23565	1.2825	0.0927	-0.0004	0.0002	0.0716	0.0407	-0.0012	0.0011	-0.6926	0.2269
post oak	-1.4303	0.05388	1.2937	0.0211	-0.0005	0.0001	0.0479	0.0071	0.0055	0.0004	-0.4089	0.0602
black oak	-2.3458	0.07561	1.4503	0.0214	-0.0007	0.0001	0.2514	0.0141	0.0059	0.0005	-0.3078	0.0409
live oak	-3.6407	0.19001	1.4485	0.0468	-0.0002	0.0000	0.5492	0.0415	0.0094	0.0017	-0.0997	0.5740
black locust	-1.3079	0.14544	0.9633	0.0436			0.2686	0.0269	0.0037	0.0013	-0.3354	0.1115
willow	-1.1094	0.16504	1.1871	0.0311			0.2021	0.0269	0.0063	0.0014	-0.1355	0.6726
sassafras	-1.7451	0.1621	1.3133	0.0436	-0.0002	0.0003	0.2010	0.0313	0.0042	0.0013	-0.0133	0.1039
basswood	-1.8481	0.3134	1.4242	0.0967	-0.0015	0.0002	0.2892	0.0689	0.0035	0.0022	-0.5801	0.1445
elm	-2.3562	0.17818	1.4794	0.0453	-0.0005	0.0002	0.4254	0.0339	0.0028	0.0015	-1.0010	0.2335
winged elm	-0.7901	0.14166	0.9497	0.0551			0.1003	0.0169	0.0044	0.0013	-0.4394	0.1805
American elm	-0.5107	0.17778	1.1648	0.0525			0.1279	0.0239	0.0005	0.0013	-0.4465	0.1873
slippery elm	-0.2292	0.26333	1.0603	0.0879			0.1168	0.0358	-0.0018	0.0021	0.1588	0.2549
misc. softwoods	-1.8644	0.11088	1.4031	0.0344	-0.0012	0.0002	0.2736	0.0210	-0.0004	0.0008	-0.2320	0.1139
misc. hardwoods	-1.432	0.26188	1.4523	0.0811	-0.0015	0.0010	0.0611	0.0355	0.0049	0.0024	-0.4227	0.2337
unknown	-1.646	0.29806	1.4477	0.0768	-0.0022	0.0008	0.2410	0.0582	-0.0033	0.0023	-1.0800	0.1943

Species	F(x) ofslope and cosine of aspect		F(X) of slope and sine of aspect		Relative height		Plot basal area per acre		Plot basal area in trees larger than subject tree		PVM221	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
fir sp.	0.0665	0.0641	0.0870	0.0588	-0.4038	0.1549	-0.0008	0.0006	-0.0025	0.0004		
red cedar	0.0775	0.0991	-0.0258	0.1059	0.1774	0.0831	-0.0036	0.0003	-0.0019	0.0003	0.1318	0.0834
spruce	0.0665	0.0641	0.0870	0.0588	-0.4038	0.1549	-0.0008	0.0006	-0.0025	0.0004		
sand pine	-1.7881	0.7849	-1.2315	0.7610			-0.0053	0.0011	-0.0032	0.0009		
shortleaf pine	0.1277	0.0358	0.0284	0.0382	0.0403	0.0358	-0.0044	0.0001	-0.0033	0.0001	-0.5694	0.0327
slash pine	-0.1932	0.2089	-0.2510	0.2273	0.0691	0.0441	-0.0029	0.0002	-0.0049	0.0002		
spruce pine	0.5269	0.3020	0.0099	0.3717	-0.3262	0.1629	-0.0018	0.0007	-0.0014	0.0005		
longleaf pine	0.0869	0.0990	0.1074	0.1078	0.3880	0.0584	-0.0022	0.0002	-0.0029	0.0002		
Table mtn. pine	0.0188	0.0398	-0.0521	0.0394	0.0596	0.0519	-0.0023	0.0002	-0.0027	0.0002	-0.1575	0.0195
pitch pine	0.0835	0.1004	0.1507	0.0982	-0.1932	0.2385	-0.0023	0.0011	-0.0022	0.0009		
pond pine	-2.9079	2.5077	1.6834	2.5707	-0.1982	0.1425	-0.0030	0.0005	-0.0045	0.0005		
e. white pine	-0.0852	0.0599	-0.0356	0.0557	0.6052	0.1158	-0.0009	0.0004	-0.0041	0.0003		
loblolly pine	0.1854	0.0347	-0.0728	0.0381	0.0069	0.0169	-0.0034	0.0001	-0.0042	0.0001	-0.0697	0.0738
Virginia pine	0.0188	0.0398	-0.0521	0.0394	0.0596	0.0519	-0.0023	0.0002	-0.0027	0.0002	-0.1575	0.0195
bald cypress	-0.4281	1.1884	-0.7395	1.0405	-0.1196	0.0652	-0.0005	0.0002	-0.0008	0.0002		
pond cypress	-8.6391	6.3160	5.6155	5.7559	-0.1258	0.0877	-0.0002	0.0002	-0.0006	0.0002		
hemlock	0.0665	0.0641	0.0870	0.0588	-0.4038	0.1549	-0.0008	0.0006	-0.0025	0.0004		
Florida maple	-0.2049	0.2801	-0.1471	0.3177	-0.1408	0.3316	-0.0033	0.0014	-0.0019	0.0009		
box elder	0.3159	0.2039	-0.2371	0.1925	0.0712	0.1419	-0.0012	0.0007	-0.0008	0.0004	-0.2029	0.1198
red maple	-0.0698	0.0358	0.0942	0.0353	0.2824	0.0386	-0.0021	0.0001	-0.0014	0.0001	-0.0100	0.0229
silver maple	-0.0698	0.0358	0.0942	0.0353	0.2824	0.0386	-0.0021	0.0001	-0.0014	0.0001	-0.0100	0.0229
sugar maple	-0.0095	0.0451	0.0056	0.0489	0.6318	0.0959	-0.0014	0.0005	-0.0015	0.0003	-0.0749	0.0355
buckeye	0.1872	0.1916	-0.1085	0.1704	0.5477	0.3578	-0.0042	0.0018	-0.0006	0.0012		
birch sp.	-0.1124	0.0836	0.1133	0.0793	0.4894	0.1440	-0.0020	0.0006	-0.0018	0.0004		
sweet birch	-0.1124	0.0836	0.1133	0.0793	0.4894	0.1440	-0.0020	0.0006	-0.0018	0.0004		
American hornbeam	0.0320	0.1947	-0.1607	0.1703	-0.2446	0.1280	-0.0039	0.0005	-0.0006	0.0003	-0.2607	0.1317
hickory sp.	0.0558	0.0260	0.0806	0.0284	0.5700	0.0322	-0.0033	0.0002	-0.0010	0.0001	0.0341	0.0189
catalpa	-0.6011	1.0384	-0.7571	1.0974	0.5013	0.1484	-0.0010	0.0005	-0.0013	0.0005		

Species	F(x) ofslope and cosine of aspect		F(X) of slope and sine of aspect		Relative height		Plot basal area per acre		Plot basal area in trees larger than subject tree		PVM221	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
hackberry sp.	0.0397	0.1702	-0.0716	0.1882	0.5087	0.0708	-0.0018	0.0004	-0.0018	0.0003	-0.4352	0.1447
eastern redbud	0.0391	0.1726	-0.0384	0.2000	0.4119	0.2553	-0.0011	0.0014	-0.0028	0.0009	0.1474	0.1028
flowering dogwood	-0.0840	0.0516	0.1047	0.0486	-0.6112	0.0961	-0.0031	0.0003	-0.0012	0.0002	0.1012	0.0274
common persimmon	-0.2007	0.2015	-0.1459	0.2195	0.2436	0.1557	-0.0013	0.0007	-0.0028	0.0005	0.1119	0.1209
American beech	0.1604	0.0469	-0.0884	0.0486	0.2793	0.0702	-0.0025	0.0003	-0.0012	0.0003	-0.1914	0.0391
ash	0.0201	0.1239	-0.0208	0.1138	0.1854	0.0999	-0.0020	0.0002	-0.0008	0.0002	0.4248	0.0728
white ash	-0.0011	0.0721	-0.0216	0.0830	0.4872	0.0847	-0.0008	0.0005	-0.0013	0.0003	-0.0825	0.0646
black ash	-0.1382	0.1750	-0.0812	0.2027	0.4966	0.0647	0.0000	0.0004	-0.0015	0.0002	0.1469	0.1404
green ash	-0.1382	0.1750	-0.0812	0.2027	0.4966	0.0647	0.0000	0.0004	-0.0015	0.0002	0.1469	0.1404
honey locust	0.9588	0.4697	0.8231	0.6756	0.5384	0.1570	-0.0012	0.0008	-0.0025	0.0006	-0.2566	0.4092
loblolly-bay	-10.1495	4.0198	1.4044	3.4366	0.1068	0.1780	-0.0003	0.0005	-0.0022	0.0004		
silver bell	-0.6578	0.3653	0.5858	0.2821	-1.7716	1.0337			-0.0008	0.0018		
American holly	0.2105	0.1915	-0.1594	0.1703	-0.4141	0.1499	-0.0031	0.0004	-0.0004	0.0003	-0.1262	0.1310
butternut	-0.2097	0.1281	0.0149	0.1382	0.6163	0.1716	-0.0006	0.0010	-0.0006	0.0008	-0.0711	0.0786
black walnut	-0.2097	0.1281	0.0149	0.1382	0.6163	0.1716	-0.0006	0.0010	-0.0006	0.0008	-0.0711	0.0786
sweetgum	0.1415	0.0655	0.0035	0.0662	0.2568	0.0287	-0.0030	0.0001	-0.0019	0.0001	0.2148	0.1057
yellow-poplar	-0.0016	0.0292	0.0648	0.0294	0.1617	0.0420	-0.0018	0.0002	-0.0022	0.0001	-0.0350	0.0171
magnolia sp.	0.1496	0.3238	0.0324	0.3841	0.2437	0.0741	-0.0013	0.0002	-0.0011	0.0002	-1.7212	0.5759
cucumber tree	-0.0715	0.1341	0.2657	0.1388	0.5332	0.3214	0.0007	0.0014	-0.0016	0.0010		
southern	-0.0636	0.1800	0.0171	0.1716	0.5390	0.2031	-0.0027	0.0010	-0.0009	0.0006	-0.1840	0.1378
sweetbay	0.1496	0.3238	0.0324	0.3841	0.2437	0.0741	-0.0013	0.0002	-0.0011	0.0002	-1.7212	0.5759
big leaf magnolia	-0.0636	0.1800	0.0171	0.1716	0.5390	0.2031	-0.0027	0.0010	-0.0009	0.0006	-0.1840	0.1378
apple sp.	-0.0789	0.2573	-0.0236	0.2825	0.1806	0.2246	-0.0017	0.0012	-0.0001	0.0007	0.3526	0.1754
mulberry sp.	-0.0789	0.2573	-0.0236	0.2825	0.1806	0.2246	-0.0017	0.0012	-0.0001	0.0007	0.3526	0.1754
water tupelo	2.0736	0.9898	-2.2132	0.9423	0.1339	0.0696	-0.0004	0.0002	-0.0003	0.0001		
blackgum	-0.1320	0.0486	-0.0316	0.0514	0.1212	0.0530	-0.0025	0.0002	-0.0010	0.0002	-0.0149	0.0335
swamp tupelo	-0.0537	0.4145	0.1495	0.3975	-0.1091	0.0507	-0.0011	0.0001	-0.0012	0.0001		
e. hophornbeam	-0.2365	0.2049	0.2011	0.1941	-0.2089	0.2172	-0.0031	0.0008			-0.0415	0.1527
sourwood	0.0505	0.0494	-0.0087	0.0481	0.0770	0.0867	-0.0024	0.0004	-0.0008	0.0002	0.0124	0.0269
redbay	1.2026	1.3409	0.3839	1.1082	0.1768	0.1504	-0.0026	0.0005	-0.0008	0.0004		
sycamore	0.4946	0.2188	0.1768	0.2359	0.3325	0.1100	-0.0003	0.0006	-0.0016	0.0005	-0.3084	0.0945

Species	F(x) ofslope and cosine of aspect		F(X) of slope and sine of aspect		Relative height		Plot basal area per acre		Plot basal area in trees larger than subject tree		PVM221	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
cottonwood	-0.6011	1.0384	-0.7571	1.0974	-0.3677	0.1484	-0.0010	0.0005	-0.0013	0.0005		
big tooth aspen	-0.6011	1.0384	-0.7571	1.0974	-0.3677	0.1484	-0.0010	0.0005	-0.0013	0.0005		
black cherry	-0.0282	0.1221	-0.1807	0.1294	0.1814	0.1028	-0.0025	0.0005	-0.0019	0.0004	0.2906	0.0624
white oak	0.0085	0.0231	-0.0329	0.0244	0.3584	0.0302	-0.0028	0.0001	-0.0023	0.0001	-0.1912	0.0150
scarlet oak	-0.0049	0.0325	0.0488	0.0353	0.2069	0.0585	-0.0012	0.0003	-0.0013	0.0002	-0.2588	0.0195
southern red oak	0.0512	0.0575	0.1094	0.0596	0.2414	0.0399	-0.0033	0.0002	-0.0019	0.0001	-0.2945	0.0475
cherry bark oak	0.1913	0.1412	-0.3243	0.1563	0.4315	0.0661	-0.0023	0.0003	-0.0018	0.0002	-0.3030	0.1601
turkey oak	-0.1969	0.3250	0.5146	0.3214	-0.0339	0.1005	-0.0028	0.0007	-0.0029	0.0004		
laurel oak	0.4218	0.2264	0.2965	0.2054	0.3818	0.0715	-0.0015	0.0002	-0.0023	0.0002		
overcup oak	-0.9779	0.8289	-0.3113	0.8976	0.4279	0.0879	-0.0014	0.0003	-0.0026	0.0003		
blackjack oak	-0.1474	0.1013	0.2419	0.1140	0.0567	0.0755	-0.0036	0.0004	-0.0018	0.0003	-0.1726	0.1131
swamp chestnut oak	-0.3422	0.3821	0.0778	0.3881	0.0865	0.1462	-0.0042	0.0006	-0.0020	0.0005	-0.2524	0.3320
chinkapin oak	-0.0088	0.0913	0.4719	0.1356	0.7333	0.1578	-0.0003	0.0011	-0.0017	0.0007	-0.0399	0.1039
water oak	0.0735	0.0921	-0.1657	0.0992	0.1309	0.0313	-0.0035	0.0001	-0.0016	0.0001	0.1971	0.1164
chestnut oak	-0.0561	0.0192	0.0039	0.0198	0.5970	0.0454	-0.0011	0.0002	-0.0015	0.0002		
northern red oak	-0.0425	0.0241	0.1103	0.0261	0.4661	0.0496	-0.0009	0.0002	-0.0011	0.0002		
Shumard oak	0.1764	0.2314	0.0692	0.2366	0.4556	0.1925	-0.0005	0.0010	-0.0021	0.0007	-0.8546	0.3987
post oak	0.0092	0.0533	0.0545	0.0596	0.5146	0.0403	-0.0033	0.0002	-0.0014	0.0002	-0.0426	0.0817
black oak	-0.0336	0.0309	0.0548	0.0327	0.5275	0.0447	-0.0022	0.0002	-0.0009	0.0002	-0.1223	0.0203
live oak	-0.1742	0.7337	-0.1028	0.7218	0.0737	0.1398	-0.0032	0.0006	-0.0008	0.0005		
black locust	-0.0848	0.0728	0.1279	0.0727	0.3967	0.1023	-0.0019	0.0005	-0.0017	0.0004		
willow	-0.0830	0.7854	0.0595	0.7357	0.0940	0.0700			-0.0011	0.0003	-0.3162	0.4797
sassafras	-0.0217	0.0721	-0.0700	0.0831	0.5427	0.1149	-0.0026	0.0006	-0.0003	0.0003	-0.1096	0.0548
basswood	0.2357	0.1061	-0.0559	0.0991	0.2535	0.2185	-0.0012	0.0011	-0.0029	0.0007		
elm	-0.0645	0.2123	-0.1466	0.1989	-0.0834	0.1354	-0.0031	0.0005	-0.0014	0.0003	0.3402	0.1139
winged elm	0.2722	0.1670	0.2483	0.2016	0.3481	0.0981	-0.0030	0.0006	-0.0010	0.0004	0.1178	0.2121
American elm	0.2287	0.1750	0.0698	0.2111	0.5165	0.1057	-0.0031	0.0006	-0.0015	0.0004	-0.3127	0.1705
slippery elm	-0.2161	0.2227	0.0378	0.2313	0.4304	0.1661	-0.0013	0.0010	-0.0021	0.0006	-0.1671	0.2654
misc. softwoods	0.0775	0.0991	-0.0258	0.1059	0.1774	0.0831	-0.0036	0.0003	-0.0019	0.0003	0.1318	0.0834
misc. hardwoods	-0.2365	0.2049	0.2011	0.1941	-0.2089	0.2172	-0.0031	0.0008			-0.0415	0.1527
unknown	0.1129	0.2025	0.1584	0.1836	0.7197	0.1780			-0.0025	0.0006		

Species	PVS222		PVM231		PVP221		PVP222		PVP231A		PVP231B	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
fir sp.					-0.1211	0.0568			0.0225	0.0930	-0.0977	0.3650
red cedar	0.2179	0.0603	0.4370	0.0830	0.0839	0.0668	-0.0055	0.0388			0.4907	0.0415
spruce					-0.1211	0.0568			0.0225	0.0930	-0.0977	0.3650
sand pine												
shortleaf pine	-0.2527	0.0234	-0.2657	0.0133	-0.6945	0.0268	-0.2851	0.0259	-0.5046	0.0133		
slash pine									0.3241	0.0890	0.3241	0.0470
spruce pine											-0.1558	0.0548
longleaf pine									-0.1751	0.0337	-0.0678	0.0309
Table mtn. pine					-0.1076	0.0188	-0.0346	0.0425			0.0251	0.0428
pitch pine					0.0201	0.0938	-0.2980	0.2859	0.2367	0.1151		
pond pine												
e. white pine					-0.0656	0.0567	-0.4507	0.1652	0.1020	0.0354		
loblolly pine	0.5820	0.0511	0.7901	0.0132	-0.5848	0.0272	-0.3641	0.0270	-0.1833	0.0063	0.2563	0.0049
Virginia pine					-0.1076	0.0188	-0.0346	0.0425			0.0251	0.0428
bald cypress							0.2302	0.1086	0.4578	0.2376	0.1545	0.0375
pond cypress												
hemlock					-0.1211	0.0568			0.0225	0.0930	-0.0977	0.3650
Florida maple	0.0450	0.2731	-0.1217	0.4448			0.2900	0.3607			0.4169	0.1342
box elder	-0.3544	0.2076	0.3712	0.2238	-0.2829	0.2206	-0.2508	0.0698	-0.3512	0.0712	-0.1566	0.0692
red maple	-0.1578	0.0795	-0.0468	0.0759	0.1717	0.0300	0.1704	0.0313	-0.0317	0.0139	0.1116	0.0238
silver maple	-0.1578	0.0795	-0.0468	0.0759	0.1717	0.0300	0.1704	0.0313	-0.0317	0.0139	0.1116	0.0238
sugar maple	-0.2163	0.0541			0.0648	0.0389			-0.2072	0.0732	-0.1459	0.1089
buckeye					0.1682	0.1408	0.0249	0.1334	0.0298	0.2766		
birch sp.	0.3799	0.2685	-0.5284	0.2762	0.3068	0.1288	0.1676	0.1091	0.1790	0.0632	0.3654	0.0814
sweet birch	0.3799	0.2685	-0.5284	0.2762	0.3068	0.1288	0.1676	0.1091	0.1790	0.0632	0.3654	0.0814
American hornbeam	-0.1704	0.5698	-0.3148	0.2342	-0.1147	0.4062	0.0436	0.1116	-0.0909	0.0384	0.0879	0.0466
hickory sp.	-0.2217	0.0216	-0.1727	0.0238	0.0425	0.0201	-0.0127	0.0148			0.1168	0.0150
catalpa							-0.0106	0.1078	-0.3803	0.1062	-0.0913	0.0626

Species	PVS222		PVM231		PVP221		PVP222		PVP231A		PVP231B	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
hackberry sp.	-0.1180	0.1158	-0.4953	0.1108	-0.3478	0.1438	-0.3365	0.0465	-0.3258	0.0569	-0.1304	0.0333
eastern redbud	0.1844	0.2273	-0.0703	0.5329	0.2811	0.1948	0.3227	0.1551			0.4521	0.1788
flowering dogwood	0.3529	0.1584	0.1663	0.2402	0.2338	0.0882	0.1046	0.0653			0.3597	0.0531
common persimmon	-0.0233	0.1521	0.2895	0.3126	0.4809	0.1406	0.2151	0.0913	-0.0497	0.0549	0.2494	0.0791
American beech	-0.3702	0.0842	-0.1816	0.2285	-0.1057	0.0403	0.0932	0.0331	0.0069	0.0304	-0.0036	0.0334
ash					-0.1818	0.2684			0.0732	0.0354		
white ash	-0.1491	0.0533	-0.2417	0.0873	-0.1467	0.0463			-0.2086	0.0486	-0.0156	0.0409
black ash	-0.4434	0.1835	-0.4484	0.0954	-0.1330	0.1205	-0.0791	0.0442	-0.1198	0.0720	-0.1170	0.0301
green ash	-0.4434	0.1835	-0.4484	0.0954	-0.1330	0.1205	-0.0791	0.0442	-0.1198	0.0720	-0.1170	0.0301
honey locust	-0.1495	0.1946	0.0474	0.2099	-0.3417	0.4193	-0.2152	0.1115	-0.3970	0.1416	0.0959	0.0921
loblolly-bay												
silver bell									-0.2117	0.6184		
American holly					-0.2781	0.2663	-0.1798	0.4235	0.0196	0.0354	0.1632	0.0631
butternut	0.3744	0.1262	-0.0588	0.4430	-0.0726	0.0925			-0.0157	0.0849	0.3496	0.1166
black walnut	0.3744	0.1262	-0.0588	0.4430	-0.0726	0.0925			-0.0157	0.0849	0.3496	0.1166
sweetgum	-0.0271	0.0478	-0.0987	0.0410	0.3114	0.0675	0.2035	0.0253	-0.0348	0.0111	0.1154	0.0108
yellow-poplar					0.1148	0.0204	0.2553	0.0199			0.0954	0.0228
magnolia sp.					-0.4387	0.3241			-0.3169	0.0900	0.0149	0.0427
cucumber tree	-0.3340	0.2680			0.3262	0.0990	-0.1580	0.2106	-0.0890	0.1426	0.5875	0.2490
southern	-0.7080	0.4045			-0.9474	0.5687			-0.2563	0.1268	-0.1816	0.1043
sweetbay					-0.4387	0.3241			-0.3169	0.0900	0.0149	0.0427
big leaf magnolia	-0.7080	0.4045			-0.9474	0.5687			-0.2563	0.1268	-0.1816	0.1043
apple sp.	0.1290	0.2268	0.2436	0.1975	0.2691	0.1848	0.0002	0.1296	-0.2535	0.1051		
mulberry sp.	0.1290	0.2268	0.2436	0.1975	0.2691	0.1848	0.0002	0.1296	-0.2535	0.1051		
water tupelo							0.1862	0.1275	-1.0484	0.4735	0.0318	0.0433
blackgum	-0.2668	0.0454	-0.2516	0.0520	-0.0005	0.0447	0.0588	0.0342	-0.1168	0.0242	0.1389	0.0220
swamp tupelo									0.0182	0.0682	0.6882	0.0494
e. hophornbeam	0.1304	0.3934	0.2129	0.2678	0.1107	0.3054	-0.1305	0.1287	-0.0259	0.0900	0.0875	0.0751
sourwood					0.1604	0.0454	0.0795	0.0563			0.2953	0.0433
redbay											0.7121	0.2757
sycamore	-0.4689	0.1207	-0.5736	0.1755	-0.1640	0.1210	-0.2919	0.0619	-0.3128	0.0639	-0.2044	0.0576

Species	PVS222		PVM231		PVP221		PVP222		PVP231A		PVP231B	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
cottonwood							-0.0106	0.1078	-0.3803	0.1062	-0.0913	0.0626
big tooth aspen							-0.0106	0.1078	-0.3803	0.1062	-0.0913	0.0626
black cherry	0.1635	0.1102	-0.1114	0.1104	0.0602	0.0891	0.0893	0.0615			0.2399	0.0577
white oak	-0.1551	0.0155	-0.1550	0.0164	-0.0633	0.0157	-0.0319	0.0119			0.1647	0.0127
scarlet oak					-0.0634	0.0215	-0.0236	0.0221			0.0676	0.0365
southern red oak	-0.2678	0.0469	-0.1135	0.0348	-0.1462	0.0350	-0.0787	0.0199	-0.1429	0.0156		
cherry bark oak	-0.5682	0.2403	-0.0018	0.0852	-0.3014	0.1292	-0.1064	0.0363	-0.1392	0.0450		
turkey oak									-0.1415	0.1312	0.9875	0.1178
laurel oak									-0.1847	0.0546	0.1833	0.0442
overcup oak			-0.5068	0.4406			0.0749	0.1374	-0.0835	0.1414	0.0453	0.0305
blackjack oak	0.1074	0.0614	-0.0848	0.0484	0.1272	0.1225	-0.0667	0.0455	-0.0525	0.0442	0.1785	0.0402
swamp chestnut oak			-0.2785	0.3353	-0.2016	0.2108	0.2224	0.0914	-0.0534	0.0921	0.0066	0.0444
chinkapin oak	-0.1104	0.0875	-0.1702	0.1925	0.0246	0.0868			0.1269	0.0646	-0.0106	0.1417
water oak	0.1081	0.2201	-0.0614	0.0474	-0.3432	0.2389	-0.0563	0.0400	-0.1135	0.0155	0.0761	0.0105
chestnut oak					0.1514	0.0169	0.2000	0.0192	0.2043	0.0141	0.2951	0.0356
northern red oak	0.0238	0.0209	0.0583	0.0264	0.0434	0.0266	0.0362	0.0210	0.1321	0.0209	0.1632	0.0343
Shumard oak	-0.5904	0.1887	-0.1603	0.1157	-0.1907	0.2586	-0.3291	0.1151	-0.2371	0.0983		
post oak	-0.2526	0.0244	-0.2437	0.0192	-0.1630	0.0390	-0.1605	0.0190	-0.0485	0.0194		
black oak	-0.1449	0.0219	-0.1631	0.0322	0.0219	0.0203			-0.0486	0.0174	0.1514	0.0223
live oak												
black locust	-0.1744	0.0902	0.1705	0.2061	0.0167	0.0817	0.0358	0.0528	0.0479	0.0566	0.3719	0.0789
willow					-0.3606	0.2314	0.0314	0.0962	0.1510	0.0943	-0.1203	0.0476
sassafras	0.0687	0.1544	-0.9819	0.3035	-0.0664	0.0584			-0.1532	0.0633	0.0756	0.0688
basswood	0.0223	0.1842	0.3788	0.3111	0.1953	0.0941	0.1065	0.1108	-0.1458	0.1086	-0.1550	0.1368
elm	-0.3306	0.3279	0.2617	0.6111	0.4314	0.2927	-0.1072	0.1689			0.0453	0.0932
winged elm	-0.2358	0.0823	-0.4359	0.0597	-0.0362	0.1202	-0.2291	0.0564	0.1257	0.0827		
American elm	-0.0970	0.1320	-0.3616	0.1168	-0.1274	0.1264	-0.2937	0.0580	-0.4137	0.1405	-0.1275	0.0453
slippery elm	-0.2930	0.2044	0.0848	0.3008	-0.2293	0.1785	-0.2872	0.0953	-0.0147	0.1688		
misc. softwoods	0.2179	0.0603	0.4370	0.0830	0.0839	0.0668	-0.0055	0.0388			0.4907	0.0415
misc. hardwoods	0.1304	0.3934	0.2129	0.2678	0.1107	0.3054	-0.1305	0.1287	-0.0259	0.0900	0.0875	0.0751
unknown												

Species	PVP232		PVP234		PVP255		PVP411		FTLOHD		FTNOHD	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
fir sp.											-0.0233	0.0465
red cedar	0.3995	0.0408	0.9385	0.3558	1.0882	0.1135			0.1288	0.0399	-0.0202	0.1431
spruce											-0.0233	0.0465
sand pine									1.2140	0.2503		
shortleaf pine	-0.1133	0.0135	0.1141	0.0422	0.0925	0.0788			0.1064	0.0290	0.4550	0.2010
slash pine			0.3068	0.0958			-0.3423	0.0627	0.3259	0.0256		
spruce pine			-0.1122	0.1020								
longleaf pine			0.1233	0.1207					0.0482	0.0601		
Table mtn. pine	-0.1509	0.0293							-0.0590	0.0767	0.3258	0.1224
pitch pine											-0.1102	0.2448
pond pine							-0.2056	0.5594	0.1877	0.0704	-0.0622	0.0834
e. white pine									-0.5852	0.2244	-0.1222	0.0844
loblolly pine			0.2818	0.0133	0.2746	0.0252			0.1264	0.0111		
Virginia pine	-0.1509	0.0293							-0.0590	0.0767	0.3258	0.1224
bald cypress			0.0219	0.0216	0.2882	0.1703	-0.0330	0.1347			-0.0508	0.4248
pond cypress							0.1566	0.0427				
hemlock											-0.0233	0.0465
Florida maple	0.1631	0.0929	0.4518	0.3049							-0.5811	0.5409
box elder	-0.2335	0.0769			-0.0117	0.1623					0.1973	0.1186
red maple			0.2839	0.0322			-0.3401	0.1135			-0.0086	0.0350
silver maple			0.2839	0.0322			-0.3401	0.1135			-0.0086	0.0350
sugar maple	0.7079	0.2712	0.2898	0.1581					0.1777	0.0769	0.0811	0.0290
buckeye									0.2765	0.3043		
birch sp.	0.2370	0.0727	0.4176	0.2775	1.1518	0.2217					-0.0901	0.0563
sweet birch	0.2370	0.0727	0.4176	0.2775	1.1518	0.2217					-0.0901	0.0563
American hornbeam			0.2154	0.1057							0.1071	0.0870
hickory sp.	0.1138	0.0153	0.1839	0.0225	0.4417	0.0444			0.3071	0.0168	0.1271	0.0350
catalpa	-0.1460	0.0640			-0.2272	0.2433						

Species	PVP232		PVP234		PVP255		PVP411		FTLOHD		FTNOHD	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
hackberry sp.	-0.2121	0.0340			-0.2090	0.0838					-0.0209	0.1381
eastern redbud	0.5523	0.1503	0.2560	0.5293	0.5764	0.5662			-0.1318	0.1322	-0.1591	0.1721
flowering dogwood	0.0936	0.0221	0.4882	0.1872					0.1937	0.0320	0.0802	0.0733
common persimmon			0.3638	0.0804	0.3179	0.3166			0.1403	0.0699	0.0082	0.2577
American beech			-0.0313	0.0597					0.1399	0.0305	0.0950	0.0308
ash							-0.7956	0.1791			0.0651	0.0687
white ash	-0.0042	0.0621	0.1514	0.0781	-0.0563	0.0873			0.1121	0.0433	0.2441	0.0534
black ash	-0.0757	0.0341			-0.0035	0.0642					0.0035	0.1132
green ash	-0.0757	0.0341			-0.0035	0.0642					0.0035	0.1132
honey locust	-0.0788	0.0846			0.1153	0.1435						
loblolly-bay												
silverbell											-0.0632	0.2661
American holly			-0.2838	0.4237	0.9415	0.3335					-0.0031	0.1419
butternut	0.2551	0.1229	0.2592	0.3472	0.3525	0.3224			0.1637	0.0920	-0.1769	0.1223
black walnut	0.2551	0.1229	0.2592	0.3472	0.3525	0.3224			0.1637	0.0920	-0.1769	0.1223
sweetgum			0.1294	0.0191	0.4924	0.0661					0.0576	0.0491
yellow-poplar	0.1131	0.0146	0.1115	0.0702					0.0839	0.0156	0.0574	0.0253
magnolia sp.			0.1616	0.1868							-0.3268	0.5905
cucumber tree	0.5759	0.2343	0.5730	0.3350					-0.2958	0.2264	0.0496	0.0955
southern			0.4935	0.1792							-0.1533	0.1570
sweetbay			0.1616	0.1868							-0.3268	0.5905
big leaf magnolia			0.4935	0.1792							-0.1533	0.1570
apple sp.	-0.1194	0.0854	0.0324	0.1299	0.4986	0.2291					-0.3575	0.2433
mulberry sp.	-0.1194	0.0854	0.0324	0.1299	0.4986	0.2291					-0.3575	0.2433
water tupelo			-0.0546	0.0248								
blackgum			-0.0314	0.0595	0.3758	0.1548			0.1147	0.0248	0.0631	0.0747
swamp tupelo			0.2029	0.0986							0.5808	0.4535
e. hophornbeam			0.0184	0.1679	0.2551	0.5489					-0.1546	0.1764
sourwood	0.0573	0.0285	0.4248	0.3023					0.0767	0.0412	0.3524	0.0760
redbay			0.4893	0.5385			-0.1476	0.2049			-1.1994	0.5413
sycamore	-0.1674	0.0594			0.1230	0.2177					-0.0197	0.1090

Species	PVP232		PVP234		PVP255		PVP411		FTLOHD		FTNOHD	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
cottonwood	-0.1460	0.0640			-0.2272	0.2433						
big tooth aspen	-0.1460	0.0640			-0.2272	0.2433						
black cherry	0.1259	0.0387	0.2648	0.1538	1.9013	0.5488			0.1816	0.0504	0.3034	0.0974
white oak	0.0319	0.0123	0.0900	0.0301	0.4487	0.2636			0.2149	0.0210	0.1962	0.0408
scarlet oak	0.0871	0.0341							0.0820	0.0568	0.1741	0.0770
southern red oak	-0.1371	0.0140	0.0445	0.0309	0.1894	0.0420			0.1490	0.0245	0.2015	0.2876
cherry bark oak	0.0001	0.0197	-0.0357	0.0270	-0.1984	0.0915					0.1300	0.1558
turkey oak			1.1097	0.4739	1.4460	0.1740			-0.0496	0.3844		
laurel oak			0.2382	0.0748	0.7681	0.2849	-1.3285	0.1563			-0.1277	0.2640
overcup oak	0.0630	0.0300			-0.0659	0.1052					-0.9243	0.4618
blackjack oak			-0.0372	0.1497	0.3803	0.0700	-0.7419	0.2547	-0.1232	0.0985		
swamp chestnut oak			0.0076	0.0737							-0.2863	0.2765
chinkapin oak	0.7554	0.2792	0.4719	0.4316	0.6063	0.3425			0.0861	0.1556	0.0354	0.1211
water oak			0.1229	0.0143	0.2497	0.0348	-0.2618	0.3593			0.0445	0.1526
chestnut oak	0.0856	0.0542	0.0809	0.1965	0.5851	0.2359			0.2372	0.1290	0.1360	0.0443
northern red oak	0.2054	0.0424	0.4333	0.1060					0.1037	0.0525	0.2080	0.0258
Shumard oak	-0.0891	0.0694	-0.1909	0.1030	-0.0368	0.1629			0.1400	0.0639	0.2076	0.2523
post oak	-0.0812	0.0192	0.1596	0.0331	0.1714	0.0247			0.2690	0.0332	0.4827	0.2649
black oak	0.0848	0.0306	0.3698	0.0570	-0.0520	0.0626			0.0497	0.0567	0.2720	0.0675
live oak			0.2684	0.1444			-0.6395	0.2567				
black locust	0.1711	0.0904	0.2405	0.0826	0.4446	0.1450			0.1382	0.0594	0.1174	0.0678
willow	-0.0597	0.0466			-0.2031	0.0974						
sassafras	-0.0404	0.0618	0.3340	0.1146	0.3935	0.2042			-0.0585	0.0686	0.0140	0.0890
basswood	-0.0720	0.1212	0.9203	0.3072	0.6449	0.3156			0.0672	0.1253		
elm	0.0361	0.0408	-0.3189	0.0882	0.2710	0.1187					-0.0055	0.1076
winged elm	0.0701	0.0529	-0.0225	0.0613	0.2354	0.0647			0.2119	0.0445	0.1126	0.2551
American elm	-0.0431	0.0552			0.1199	0.1207					-0.2211	0.1482
slippery elm	-0.0299	0.0858	0.2100	0.0781	-0.3603	0.2622					-0.2324	0.1537
misc. softwoods	0.3995	0.0408	0.9385	0.3558	1.0882	0.1135			0.1288	0.0399	-0.0202	0.1431
misc. hardwoods			0.0184	0.1679	0.2551	0.5489					-0.1546	0.1764
unknown												

Species	FTOKPN		FTSFHP		FTUPHD		FTUPOK		FTYLPN		PLANT	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
fir sp.	0.2349	0.1430	-0.2717	0.0581	-0.0043	0.0565			0.0390	0.1569		
red cedar	0.0544	0.0407			0.0792	0.0388			0.1443	0.0336		
spruce	0.2949	0.1430	-0.2717	0.0581	-0.0043	0.0565			0.0390	0.1569		
sand pine	0.7512	0.1466			1.1400	0.5271	0.2395	0.5215			0.1738	0.0626
shortleaf pine	0.0175	0.0096			0.0668	0.0249	-0.0402	0.0132				
slash pine	0.1162	0.0161			0.1620	0.0634	0.4107	0.1087			0.2276	0.0120
spruce pine	-0.0990	0.0474			0.0723	0.0606	-0.0551	0.0861	-0.2369	0.0940		
longleaf pine	0.0889	0.0177			0.0867	0.0494	0.1061	0.0327			0.1108	0.0205
Table mtn. pine	0.0454	0.0165	0.0920	0.2374	-0.0043	0.0312	-0.0678	0.0227				
pitch pine	-0.0104	0.0715	0.0437	0.5287			-0.3159	0.0723	0.1168	0.1199		
pond pine	0.0444	0.0508			0.4822	0.3031	0.2965	0.4910				
e. white pine	-0.0737	0.0623	-0.1990	0.0831			0.0220	0.0334	0.0461	0.0682	0.0981	0.0475
loblolly pine	0.0508	0.0054			0.0637	0.0125	-0.0169	0.0121			0.2457	0.0052
Virginia pine	0.0454	0.0165	0.0920	0.2374	-0.0043	0.0312	-0.0678	0.0227				
bald cypress	-0.2015	0.0936			0.1949	0.0974	0.0816	0.1436	-0.3243	0.1166		
pond cypress	-0.1968	0.0405							-0.2418	0.0475		
hemlock	0.2949	0.1430	-0.2717	0.0581	-0.0043	0.0565			0.0390	0.1569		
Florida maple	-0.0494	0.1291			-0.0219	0.1181	-0.3235	0.1027	0.3042	0.1468		
box elder	-0.0023	0.2074	-0.3615	0.4482	0.2133	0.0837	-0.0034	0.0918	-0.2522	0.2695		
red maple	-0.0917	0.0170	-0.2265	0.1825	-0.1157	0.0166	-0.2339	0.0172	0.0000	0.0160		
silver maple	-0.0917	0.0170	-0.2265	0.1825	-0.1157	0.0166	-0.2339	0.0172	0.0000	0.0160		
sugar maple	-0.0078	0.1524	0.2683	0.4509	0.0181	0.0396			-0.9691	0.3249		
buckeye					-0.1584	0.1498	-0.0660	0.1165				
birch sp.	-0.2115	0.1093	-0.1129	0.1855	-0.1503	0.0600	-0.2296	0.0625	-0.1222	0.1682		
sweet birch	-0.2115	0.1093	-0.1129	0.1855	-0.1503	0.0600	-0.2296	0.0625	-0.1222	0.1682		
American hornbeam	-0.1848	0.0633			-0.1450	0.0378	-0.1259	0.0489	-0.0240	0.0791		
hickory sp.	0.0751	0.0166	0.1637	0.2983	0.1458	0.0154			0.0910	0.0234		
catalpa	-0.1226	0.3460			-0.2272	0.1159	0.4284	0.1804	-0.1277	0.2715		

Species	FTOKPN		FTSFHP		FTUPHD		FTUPOK		FTYLPN		PLANT	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
hackberry sp.	-0.2270	0.1025			-0.0466	0.0393	-0.1422	0.0502	-0.3732	0.1201		
eastern redbud	0.0815	0.1788					-0.0913	0.0841	0.0053	0.1490		
flowering dogwood	0.2278	0.0270	-0.2073	0.3609	0.1234	0.0230			0.3957	0.0261		
common persimmon	-0.0301	0.0772			0.0647	0.0665	-0.0637	0.0681				
American beech	0.1124	0.0432	0.1915	0.4542	0.0985	0.0262			0.3019	0.0625		
ash	-0.0062	0.0883	0.2434	0.4632	0.0098	0.0464	-0.0418	0.0496	-0.0491	0.0824		
white ash	-0.0425	0.0633			0.1993	0.0378			0.2562	0.0854		
black ash	-0.1088	0.0680			-0.0186	0.0379	-0.0855	0.0437	-0.2794	0.1027		
green ash	-0.1088	0.0680			-0.0186	0.0379	-0.0855	0.0437	-0.2794	0.1027		
honey locust	-0.2283	0.1874			-0.1705	0.0711	-0.1787	0.1211	-0.3432	0.1814		
loblolly-bay	-0.0632	0.0650			-0.2973	0.2557			0.0650	0.0587		
silverbell					-0.1116	0.2583						
American holly	-0.0077	0.0398			-0.0822	0.0365	-0.1877	0.0415	-0.0083	0.0461		
butternut	-0.1647	0.1541	-0.5573	0.5484			-0.1565	0.0613	-0.2326	0.2062		
black walnut	-0.1647	0.1541	-0.5573	0.5484			-0.1565	0.0613	-0.2326	0.2062		
sweetgum	-0.0908	0.0121	0.4912	0.4574	-0.1559	0.0137	-0.1683	0.0143	0.0585	0.0121		
yellow-poplar	-0.0552	0.0191	-0.5000	0.1391			-0.0907	0.0136	0.0539	0.0223		
magnolia sp.	-0.0177	0.0275			-0.0295	0.0469	-0.0970	0.0885	-0.0310	0.0340		
cucumber tree	-0.3532	0.4312			0.0084	0.0994			-0.6272	0.5360		
southern	0.1837	0.0860	-0.0247	0.5502	0.0559	0.0708	0.1096	0.0817	0.0524	0.1244		
sweetbay	-0.0177	0.0275			-0.0970	0.0469	-0.0970	0.0885	-0.0310	0.0340		
big leaf magnolia	0.1837	0.0860	-0.0247	0.5502	0.0559	0.0708	0.1096	0.0817	0.0524	0.1244		
apple sp.	0.0100	0.1342			-0.0240	0.0854	-0.0250	0.0829	0.2725	0.1694		
mulberry sp.	0.0100	0.1342			-0.0240	0.0854	-0.0250	0.0829	0.2725	0.1694		
water tupelo	-0.2036	0.1122			0.0670	0.1784	0.6968	0.2655	0.0455	0.3816		
blackgum	0.0767	0.0245	-0.4480	0.3583	0.1115	0.0228			0.2292	0.0275		
swamp tupelo	-0.1107	0.0216			0.0062	0.0537	-0.1953	0.0790	0.0062	0.0217		
e. hophornbeam	-0.0871	0.0997			-0.0711	0.0785	-0.2042	0.0771	0.1205	0.1508		
sourwood	0.0799	0.0281	-0.1315	0.2253	-0.0230	0.0259			0.3004	0.0296		
redbay	-0.0228	0.0486			0.0602	0.1363	0.3909	0.2486	-0.0458	0.0463		
sycamore	-0.2625	0.0989			-0.1506	0.0572	-0.1616	0.0624	-0.2394	0.1220		

Species	FTOKPN		FTSFHP		FTUPHD		FTUPOK		FTYLPN		PLANT	
	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
cottonwood	-0.1226	0.3460			-0.2272	0.1159	0.4284	0.1804	-0.1277	0.2715		
big tooth aspen	-0.1226	0.3460			-0.2272	0.1159	0.4284	0.1804	-0.1277	0.2715		
black cherry	0.1625	0.0504			0.1461	0.0456			0.2035	0.0465		
white oak	0.1070	0.0122	0.2101	0.1701	0.1001	0.0115			0.1549	0.0184		
scarlet oak	0.0738	0.0237	-0.1269	0.1934	0.0891	0.0244			0.0157	0.0398		
southern red oak	0.0557	0.0134			0.0685	0.0164			0.0480	0.0166		
cherry bark oak	-0.0659	0.0273			-0.0660	0.0269	-0.1143	0.0231	-0.0231	0.0382		
turkey oak	0.1674	0.0334			0.0993	0.0832			0.1846	0.0332		
laurel oak	0.0295	0.0289			-0.0531	0.0233	0.0122	0.0503	0.0307	0.0317		
overcup oak	-0.1835	0.1042			-0.0832	0.0597	-0.0578	0.0853	-0.0766	0.2555		
blackjack oak	0.0003	0.0314			0.1703	0.0771			-0.0962	0.0320		
swamp chestnut oak	0.0768	0.0787			0.0375	0.0675	0.0101	0.0678	0.0882	0.1390		
chinkapin oak	0.0213	0.2456			0.1115	0.1026			-0.5189	0.4204		
water oak	-0.0429	0.0130			-0.0880	0.0103	-0.0859	0.0180	-0.0686	0.0148		
chestnut oak	0.0308	0.0238	-0.2382	0.1254	0.0968	0.0217			0.0536	0.0411		
northern red oak	0.0107	0.0287	-0.0240	0.1452	0.1381	0.0197			0.0523	0.0443		
Shumard oak	0.0093	0.0896			0.1325	0.0971			0.2198	0.1390		
post oak	0.0428	0.0158			0.0906	0.0237			0.0566	0.0205		
black oak	0.0342	0.0224	-0.1046	0.3254	0.0718	0.0267			-0.0444	0.0351		
live oak	0.0741	0.0577			0.0617	0.0486	0.2298	0.0675	-0.0430	0.0588		
black locust	-0.0976	0.1029					-0.0830	0.0421	-0.0465	0.1133		
willow	0.0015	0.1022			0.0196	0.0691	0.1650	0.1489	-0.0014	0.1413		
sassafras	-0.1395	0.0613	0.4142	0.3051			-0.1670	0.0379	-0.0182	0.0632		
basswood	0.0082	0.2174			-0.0335	0.0883	0.0122	0.0729	0.1485	0.2709		
elm	-0.2638	0.0696			-0.0546	0.0483	-0.2020	0.0550	0.0720	0.0533		
winged elm	0.1741	0.0493			0.1685	0.0463			0.3640	0.0562		
American elm	-0.0196	0.0939			-0.2106	0.0455	-0.2372	0.0513	0.1372	0.1449		
slippery elm	-0.0861	0.1444			-0.0736	0.0810	-0.2423	0.0889	0.1776	0.2574		
misc. softwoods	0.0544	0.0407			0.0792	0.0388			0.1443	0.0336		
misc. hardwoods	-0.0871	0.0997			-0.0711	0.0785	-0.2042	0.0771	0.1205	0.1508		
unknown												

2. Shade Intolerance Beta Distribution Parameters

Species	Mode	Variance	alpha	beta
fir sp.	0.1	0.01	2.039	10.388
red cedar	0.7	0.01	13.451	6.341
spruce	0.3	0.01	7.191	15.443
sand pine	0.7	0.01	7.191	15.443
shortleaf pine	0.7	0.01	13.451	6.341
slash pine	0.7	0.01	13.451	6.341
spruce pine	0.1	0.01	2.039	10.388
longleaf pine	0.7	0.01	13.451	6.341
Table mountain pine	0.7	0.01	13.451	6.341
pitch pine	0.7	0.01	13.451	6.341
pond pine	0.7	0.01	13.451	6.341
eastern white pine	0.5	0.01	11.316	11.317
loblolly pine	0.7	0.01	13.451	6.341
Virginia pine	0.7	0.01	13.451	6.341
bald cypress	0.5	0.01	11.316	11.317
pond cypress	0.5	0.01	11.316	11.317
hemlock	0.1	0.01	2.039	10.388
Florida maple	0.3	0.01	7.191	15.443
box elder	0.3	0.01	7.191	15.443
red maple	0.3	0.01	7.191	15.443
silver maple	0.3	0.01	7.191	15.443
sugar maple	0.1	0.01	2.039	10.388
buckeye	0.3	0.01	7.191	15.443
birch sp.	0.7	0.01	13.451	6.341
sweet birch	0.7	0.01	13.451	6.341
American hornbeam	0.1	0.01	2.039	10.388
hickory sp.	0.5	0.01	11.316	11.317
catalpa	0.7	0.01	13.451	6.341
hackberry sp.	0.5	0.01	11.316	11.317
eastern redbud	0.3	0.01	7.191	15.443
flowering dogwood	0.1	0.01	2.039	10.388
common persimmon	0.1	0.01	2.039	10.388
American beech	0.1	0.01	2.039	10.388
ash	0.3	0.01	7.191	15.443
white ash	0.7	0.01	13.451	6.341
black ash	0.7	0.01	13.451	6.341
green ash	0.3	0.01	7.191	15.443
honey locust	0.7	0.01	13.451	6.341

Species	Mode	Variance	alpha	beta
loblolly-bay	0.3	0.01	7.191	15.443
silverbell	0.3	0.01	7.191	15.443
American holly	0.1	0.01	2.039	10.388
butternut	0.7	0.01	13.451	6.341
black walnut	0.7	0.01	13.451	6.341
sweetgum	0.7	0.01	13.451	6.341
yellow-poplar	0.7	0.01	13.451	6.341
magnolia sp.	0.3	0.01	7.191	15.443
cucumber tree	0.5	0.01	11.316	11.317
southern	0.3	0.01	7.191	15.443
sweetbay	0.5	0.01	11.316	11.317
bigleaf magnolia	0.3	0.01	7.191	15.443
apple sp.	0.7	0.01	13.451	6.341
mulberry sp.	0.3	0.01	7.191	15.443
water tupelo	0.7	0.01	13.451	6.341
blackgum	0.3	0.01	7.191	15.443
swamp tupelo	0.7	0.01	13.451	6.341
eastern hophornbeam	0.3	0.01	7.191	15.443
sourwood	0.3	0.01	7.191	15.443
redbay	0.3	0.01	7.191	15.443
sycamore	0.5	0.01	11.316	11.317
cottonwood	0.9	0.01	9.884	1.983
bigtooth aspen	0.9	0.01	9.884	1.983
black cherry	0.7	0.01	13.451	6.341
white oak	0.5	0.01	11.316	11.317
scarlet oak	0.9	0.01	9.884	1.983
southern red oak	0.5	0.01	11.316	11.317
cherrybark oak	0.7	0.01	13.451	6.341
turkey oak	0.7	0.01	13.451	6.341
laurel oak	0.3	0.01	7.191	15.443
overcup oak	0.5	0.01	11.316	11.317
blackjack oak	0.7	0.01	13.451	6.341
swamp chestnut oak	0.7	0.01	13.451	6.341
chinkapin oak	0.7	0.01	13.451	6.341
water oak	0.7	0.01	13.451	6.341
chestnut oak	0.5	0.01	11.316	11.317
northern red oak	0.5	0.01	11.316	11.317
Shumard oak	0.7	0.01	13.451	6.341
post oak	0.7	0.01	13.451	6.341

Species	Mode	Variance	alpha	beta
black oak	0.5	0.01	11.316	11.317
live oak	0.5	0.01	11.316	11.317
black locust	0.9	0.01	9.884	1.983
willow	0.9	0.01	9.884	1.983
sassafras	0.7	0.01	13.451	6.341
basswood	0.3	0.01	7.191	15.443
elm	0.5	0.01	11.316	11.317
winged elm	0.3	0.01	7.191	15.443
American elm	0.5	0.01	11.316	11.317
slippery elm	0.3	0.01	7.191	15.443
misc. softwoods	0.5	0.01	11.316	11.317
misc. hardwoods	0.5	0.01	11.316	11.317
unknown	0.5	0.01	11.316	11.317

3. Uniform Distribution Sampling Parameters of SDI$_{max}$ Parameters

Forest type	SDI low threshold	SDI high threshold	Distribution range
101	390	520	130
102	390	520	130
103	390	520	130
104	401	535	133.75
105	345	460	115
121	345	460	115
122	345	460	115
123	345	460	115
124	345	460	115
125	345	460	115
126	345	460	115
127	345	460	115
141	293	390	97.5
142	326	435	108.75
161	379	505	126.25
162	379	505	126.25
163	371	495	123.75
164	274	365	91.25
165	311	415	103.75
166	356	475	118.75
167	349	465	116.25
168	263	350	87.5
181	225	300	75
182	311	415	103.75
183	311	415	103.75
184	311	415	103.75
185	311	415	103.75
201	420	560	140
202	518	690	172.5
221	398	530	132.5
222	518	690	172.5
223	345	460	115
224	345	460	115
241	435	580	145
261	551	735	183.75
262	574	765	191.25
263	551	735	183.75
264	551	735	183.75
265	551	735	183.75
266	551	735	183.75
267	551	735	183.75
268	551	735	183.75
269	551	735	183.75
270	551	735	183.75
271	578	770	192.5
281	506	675	168.75
301	551	735	183.75
304	578	770	192.5
305	551	735	183.75
321	488	650	162.5
341	548	730	182.5
342	548	730	182.5
361	345	460	115
362	484	645	161.25
363	345	460	115
364	345	460	115
365	353	470	117.5
366	353	470	117.5
367	353	470	117.5
368	353	470	117.5
371	435	580	145
381	390	520	130
383	390	520	130
401	345	460	115
402	225	300	75
403	270	360	90
404	356	475	118.75
405	360	480	120
406	356	475	118.75
407	416	555	138.75

Forest type	SDI low threshold	SDI high threshold	Distribution range
409	371	495	123.75
501	285	380	95
502	285	380	95
503	311	415	103.75
504	323	430	107.5
505	300	400	100
506	330	440	110
507	375	500	125
508	330	440	110
509	353	470	117.5
510	270	360	90
511	341	455	113.75
512	304	405	101.25
513	221	295	73.75
514	225	300	75
515	315	420	105
519	356	475	118.75
520	330	440	110
601	296	395	98.75
602	345	460	115
605	319	425	106.25
606	225	300	75
607	589	785	196.25
608	469	625	156.25
701	311	415	103.75
702	315	420	105
703	338	450	112.5
704	371	495	123.75
705	353	470	117.5
706	311	415	103.75
707	334	445	111.25
708	334	445	111.25
709	334	445	111.25
722	413	550	137.5
801	345	460	115
802	244	325	81.25
803	341	455	113.75
805	364	485	121.25
807	311	415	103.75
809	416	555	138.75
901	544	725	181.25
902	413	550	137.5
904	544	725	181.25
911	413	550	137.5
912	413	550	137.5
921	345	460	115
922	300	400	100
923	413	550	137.5
924	413	550	137.5
925	353	470	117.5
926	413	550	137.5
931	413	550	137.5
932	413	550	137.5
941	413	550	137.5
942	413	550	137.5
943	394	525	131.25
951	394	525	131.25
952	394	525	131.25
953	394	525	131.25
954	394	525	131.25
955	413	550	137.5
981	413	550	137.5
982	413	550	137.5
991	394	525	131.25
992	394	525	131.25
993	394	525	131.25
995	394	525	131.25
996	353	470	117.5
997	353	470	117.5
998	353	470	117.5
999	285	380	95

Vita

Nathan D. Herring was born in 1982 in Pottsville, Pennsylvania to parents David M. and Jean M. Herring. He attended Pine Grove Area School District, Pine Grove, Pennsylvania, graduating in 2001. In 2005 he earned a Bachelor of Science degree in Forest Management from the Pennsylvania State University, University Park, Pennsylvania. Upon graduation, he entered graduate school at the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, where he earned a Master of Science degree in Forest Biometrics in 2007.