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Data Quality Assessment of Continuous Forest Inventory on State Forest Lands in Tennessee

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I am submitting herewith a thesis written by Matthew Wade Holt entitled "Data Quality Assessment of Continuous Forest Inventory on State Forest Lands in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Donald Hodges, Major Professor

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Vice Provost and Dean of the Graduate School

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Data Quality Assessment of Continuous Forest Inventory on State Forest Lands in Tennessee

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ABSTRACT

The Tennessee Division of Forestry (TDF) implemented a Continuous Forest Inventory (CFI) system in 2009 for the 15 state forests, encompassing multiple physiographic land types and forest types. The initial design contained plans to measure the plots on five-year intervals. The objectives of the CFI system include: determining the growth by species and forest types for all state forest land, estimating growth models for individual trees in mixed hardwood stands, developing a harvest schedule, and assessing the impact of different silvicultural treatments over time. Following the implementation, the University of Tennessee Department of Forestry, Wildlife and Fisheries was asked to assess the study. The objectives for this assessment were to: assess the data quality of the initial plot measurements and identify inconsistencies; determine the usefulness of the Forest Vegetation Simulator (FVS) in producing accurate estimates of current volume per acre (VPA); and evaluate the current inventory design. In order to produce future growth estimates, an accurate estimate of the current inventory is needed. Known relationships in forestry were used to establish metrics for assessing the quality of the plot measurements. Two estimates of volume were used in this study: Lasher's equation contained in FVS and the d^2H (diameter and height) equation used by FIA. The FVS equation consistently over estimated volume at the acre level and individual tree level. The overall design was determined to be inadequate for providing information by forest type within each state forest. This can be remedied by utilizing stratified samples by delineating each forest by its forest type. The results of this investigation will provide a starting point for improving the work already conducted by the Division in regards to quantifying the current inventory of the Tennessee State Forest system.

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Introduction and Literature Review

The State of Tennessee owns and manages 166,897 acres of state forests, which are managed by the Tennessee Department of Agriculture, Forestry Division (TDF). These acres are spread across the entire state and cover multiple geographic and physiographic regions. As stated in Plan 2020 circulated by the Tennessee Department of Agriculture: "following decades of restoration, conservation, and careful management Tennessee's state forest system now contains an abundant supply of high-quality timber and other forest products." From the same document an independent audit report from the Rainforest Alliance, Smartwood Program, in 2006 stated

"Many stands on the state forests are mature and beginning to senesce. Regeneration efforts need to be increased on these areas but personnel limitations have prevented handling of needed sales." (TDF 2007)

In 2007 TDF implemented a plan to measure forest growth across all 15 state forests. Measurements of growth for individual forests as well as total state forest land will be used to determine harvest limits, make policy decisions, and study management practices. Prior to measuring or quantifying growth, an inventory must be completed. Lacking an adequate understanding of the current inventory will prohibit any progress on future growth calculations. TDF designed a Continuous Forest Inventory (CFI) methodology that would be used to establish the sampling design for all 15 state forests.

The objectives of the TDF study were to: determine the growth by species and forest types for all state forest land, develop growth models for individual trees in mixed hardwood stands in Tennessee, develop a harvest schedule, and assess the impact of different silvicultural treatments over time. Forest management depends heavily on the understanding of the quantity and quality of the current growing stock (Davis et al. 1960). Following the implementation of the inventory, TDF requested an in depth analysis of their study by The University of Tennessee Department of Forestry, Wildlife and Fisheries. In order to determine the effectiveness of the current inventory in answering the questions TDF was asking, the decision was made to address three key objectives:

1. Assess the quality of the plot level measurements
2. Determine the usefulness of the outputs produced by the Forest Vegetation Simulator (FVS) (USDA 2002)
3. Identify changes that should be made to the current design

Inventory

Chapman and Meyer (1949) state "the forest is an enterprise in which volume is produced and the time required for production is essential in understanding the forest's ability." Forest lands being held for long term objectives such as development and or investments need to be inventoried for quantity and quality (Meteer 1965). Inventories are a direct responsibility of forester managers and have become the major source of information on which to base management decisions (Hall 1965). Crossley (1960) argues an inventory should be capable of measuring change that happens in forest conditions through time. Predictions of change require a starting point, commonly referred to as current volume or inventory; a projection of existing conditions into the future or growth; and an adjustment of projected values for mortality and ingrowth or growing stock (Lynch 1962, Davis 1960). The concept of a continuously productive or regulated forest is rooted in the understanding of site, quality, growth, and yield (Davis 1954).

The importance of an inventory in forest management is well documented. The primary questions then are what type of information should be collected, how should it be quantified, and how often should it be measured? Avery and Burkhart (2002) state that an inventory should contain knowledge of current volume in the form of numerical data that can be used to make management decisions. Volume is the most common unit of numerical data used to quantify an inventory, this being the amount of wood that could be harvested and sold (Baker 1953, Chapman and Meyer 1949). A forest inventory most commonly requires an inventory that is drawn from a sample rather than a census due to the size of populations needing to be represented (Husch et al. 1972). Sampling in forestry generally consists of an aggregation of points, plots, or strips that can be permanent or temporary. These samples are then used to make an inference regarding the entire population. Historically these samples have been related to sales, purchases, tax appraisals, or accounting practices and in some instances may be referred to as a cruise. Sampling provides a snapshot of a population at one point in time, commonly referred to as non-recurring temporary sample (Putnam et al. 1960). Non-recurring inventories will continue to have a place in forest management. Organizations and or managers attempting to quantify long term sustained yield, growth, or impacts of certain management practices require an inventory that can be periodically re-measured to capture changes in time (Crossley 1960).

Continuous Forest Inventory

Continuous Forest Inventory (CFI) is the repeated measurement of a permanent plot at a set interval in time. This practice has been implemented throughout the United States and most of the developed world. Continuous measurement or repeated measurement of forest stands was developed in France in 1878, and first applied in Switzerland by Biolley in the 1890s. The method was developed in the forest of Covet and became known as the *methode du controle.* This method was introduced to American forest management in the 1930s by Kirkland, Meyer, and Stevenson (Spur 1952). CFI in the US has evolved from European models since its introduction in the 1930s. The *methode du controle* used grouped data focusing on one parameter, diameter. American CFI identifies individual trees and focuses on multiple parameters. While both methods can use permanent plots, American CFI requires exact locations with precise measurement (Spur 1952). The most direct way of measuring growth is the repeated measurement of the same location, often referred to as a permanent plot. The value of permanent plots was recognized early and has become essential in management and research (Spur 1952). Repeated measurements of permanent plots constitute a record of growth and changes of various parameters associated with the plot. Growth and stocking estimates could be measured from two successive inventories not using permanent plots; however, the precision and accuracy of growth will be less than when using permanent plots (Husch et al. 1972). Hall (1959) describes CFI as a way to use past performance to make future predictions. CFI provides a clinical study of the individual trees and their relationship to the environment. Changes or patterns can easily be translated from research into forest management (Bourdo 1965). CFI can be used to identify appropriate silvicultural practices on individual trees and stands. This numerical assessment can be used to bring the ratio of growth to removal closer, quantify management practices, and provide valuable insight into policy decisions. Empirical models can be developed using this assessment and provide estimates prior to implementation of management decisions (Avery and Burkhart 2002).

Determining the optimal sampling intensity in CFI is more difficult than a temporary sample. The acceptable or desired level of sampling error is unique to each CFI implementation. Most CFI implementations seek to achieve a sampling error based on the outcomes desired; however, designs generally are created based on financial limitations. As in all samples, variance within the forest and the area of the forest demand different levels of intensity, but most samples range from 0.03 to 0.1 percent of a given area. Variability tends to increase as the size of the forest increases but not at the same rate, implying a larger forest requires a lower intensity for a desired level of precision (Husch et al. 1972).

Inaccurate measurements can have substantial effects when CFI plots represent a small fraction of the population. Scott (1965) emphasizes all initial plot work needs to be done with the anticipation of direct comparison of subsequent repeated measurements. Methodologies for CFI need to contain specific procedures and work to remove all subjective measurements. The notion that mensuration is an imprecise science should not be an excuse or encouragement for careless field procedures. Two concepts considered to be the most important in CFI measurements are careful and accurate measurement and truly comparable data, ensuring that the change in a forest can be captured with the data (Meteer 1965).

Growth and Yield

The basic components of growth calculations are: current inventory growth, ingrowth, mortality, and removals (Husch et al. 1972). While individual tree diameter or basal area growth can be quantified with single measurements, stand growth is a more complex issue (Spur 1952). Forest managers often must forecast stand dynamics many years into the future due to long rotation lengths. Managers working with mixed species stands and forests that are constantly changing face several complex issues. Two types of methods, direct and indirect, are used to forecast stand dynamics. Direct methods consist of using past data trends to predict future growth and mortality, such as stand table projections. Limitations occur when forecasts are needed in areas not included in past data, management practices have not been measured, or long periods of time need to be forecast. Indirect methods use other stands to make inferences about the stand in question. This method consists of equations, tables, and computer simulators that are collectively referred to as growth and yield models. (Avery and Burkhart 2002)

Growth and yield models were first developed in the 1850s, starting in Europe and contain graphs of documented yields through time for important species. Early American models started in the 1920s followed guide curve assumptions and continued to be the standard until advancements in computer technology (Peng 2000). Growth models can be classified into two main categories - whole stand and individual tree models.

Whole stand models contain parameters associated with a stand, such as basal area, density, or known underlying diameter distributions. Whole stand models provide adequate growth and development numbers for the stand as a whole, but lack information regarding individual tree development (Peng 2000). Guide curve models historically contained two variables due to the complexity of graphing three. Normal yield and empirical tables are two types of graphical models. Normal yield tables are based on an ideal (commonly referred to as "fully" stocked) stand. Points from plots are collected from stands of various site qualities and ages, graphed, then connected to create a normal yield table (Husch at al. 1971). To apply normal yield tables, a manager must assume that the stand is fully stocked and that the curve was derived from a stand that has always been fully stocked. Empirical yield tables are based on the concept of average stocking. Normal and empirical tables both are based on indirect measurements being applied to the stand in question and provide some estimate of volume per acre. Normal and empirical tables both have limitations due to the absence of a density measure, and hence are unable to accommodate stands that have been managed. (Avery and Burkhart 2002)

Variable density models were introduced in 1939 by MacKinney and Chaiken in the form of multiple regression equations and addressed the issue of requiring a measure to address specific stand dynamics such as trees per acre, age, or basal area. This technique has since been applied to stands to predict aggregate numbers such as total stand volume (Avery and Burkhart 2002).

Individual tree models were first developed in the 1960s for even-aged Douglas-fir (Newham 1964). Individual tree models progressed beyond even-aged, single species to multiple species and uneven-aged stands. Yield tables do not allow for estimating the diameter distribution of growth, a common need for forest managers. Individual tree models contain a distribution of diameter, stand dynamics, and information about the structure of the stand. Individual tree models grow individual trees then aggregate this growth to provide estimates at the stand level (Avery and Burkhart 2002). Individual tree models can be classified into two main categories, distance dependent and distance independent. Distance independent models do not require the known location of the trees. Avery and Burkhart (2002) list three main components of a distance independent model - diameter growth, height growth, and mortality - in which they claim mortality can either be generated stochastically or be a function of a growth rate. The data required to use independent models are generally available and the outputs are capable of estimating growth (Peng 2000). Distance dependent models are similar in components, but contain the actual coordinates of the individual trees. Distance dependent models are often expensive to develop due to the labor involved in collecting the required data. This method does allow for the competition indexes and other interactions of individual trees to be based on size and distance to neighbors.

FVS

The U.S. Forest Service (USFS) developed the Forest Vegetation Simulator (FVS) as a distance independent individual tree growth and yield model, comprised of 22 regions of the US. The growth equations for FVS are derived from plot data collected by the USFS Forest Inventory and Analysis group (FIA) (Donnelley et al. 2001). The Southern Variant was developed in 1998 and released in 2001 with updated growth equations (Donnelley et al. 2001).   Input variables for the model include: species, dbh, height, site quality, and plot design. FVS predicts diameter growth, height growth, and mortality, making this a robust model in the sense it takes very little data to predict future results. Outputs include stand and stock tables that can forecast multiple rotations into the future. FVS employs two types of mortality models: background and density related. Background mortality is a function of stand density being below a specified level, while density is based on the individual tree's density relative to the stand's maximum density (Radtke et al. 2012).

Data Quality

CFI measurements are subject to highly erratic results compared to the amount of growth for the often short period between measurements (Spur 1952). While computers assist in the calculations, data quality is often overlooked. Data quality control for the initial assessment of the plot data most often will be focused on distinguishing points that appear to be outliers. Outliers according to Anscombe (1960) arise from two main sources, variation within the data and errors among the data. Outliers have been described as observations that deviate so much from others that they appear to come from other processes (Hawkins 1980), observations that appear to be inconsistent with the other data (Johnson 1992) and as being odd in the eyes of the researcher (Dixon 1950, Wainer 1976). In most instances outliers are associated with extreme values. It is important to note that not all outliers are illegitimate points, and not all illegitimate points are extreme (Barnett and Lewis 1994). Aggarwal and Yu (2001) describe that often outlier points contain information about abnormal behavior in a system. This assumes the value associated with the outlier is a product of the same noise or variation associated with the mean of the variable in which the outlier is contained. Terminology also often discussed in the outlier conversation is “fringeliers” or points “on the fence”. Wainer (1976) introduced the concept of “unusual events that happen more often than seldom”. Osborn (2004) describes these points as having a wide dispersion and a stronger influence with less ability to be easily identified. The impacts that outliers can have not only on analysis but also models can at times be costly. With an increased dispersion of data the error associated is generally inflated.

Chapter II
Overview of the State Forests

The purpose of this section is not to provide an in-depth examination of the history of the state forests, but rather to highlight a few key points related to the purposes of this study. As in all measures of prediction, the past must reflect the future. While it may be assumed that ownership plays little role in biological functions, the management that the owners choose to implement does. The state of Tennessee, through the Division of Forestry, has decided to manage the forests on an 80-year rotation for hardwoods and a 60-year rotation for pine (TDF 2007). These are important numbers to remember when determining the sampling frame used in making predictions. The current state of each individual state forest is unique in the time that it has been under state management. The question becomes how will the change in management affect the growth rates through time? This section is intended to highlight that some state forests have been under the management regime of the state longer than others. Therefore the ability to make direct comparisons may not be appropriate in all instances. This will likely play out after multiple rotations, but for now the past is crucial in understanding the future. Historical information that is presented was chosen based on its potential to affect the results presented in subsequent chapters. The results were not analyzed in terms of understanding these impacts but rather that they may have some influence.

The mission of TDF is to manage the 15 state forests for a mix of natural resources. This includes game and nongame wildlife and high-quality timber. The 15 state forests are spread across 4 regions of the state (Figure 1): East, Cumberland, Highland Rim, and West. (TDF)

The East region contains Martha Sundquist, Chuck Swan, Scott, and Lone Mountain State Forests. Martha Sundquist was acquired in 2001 from International Paper. It has been

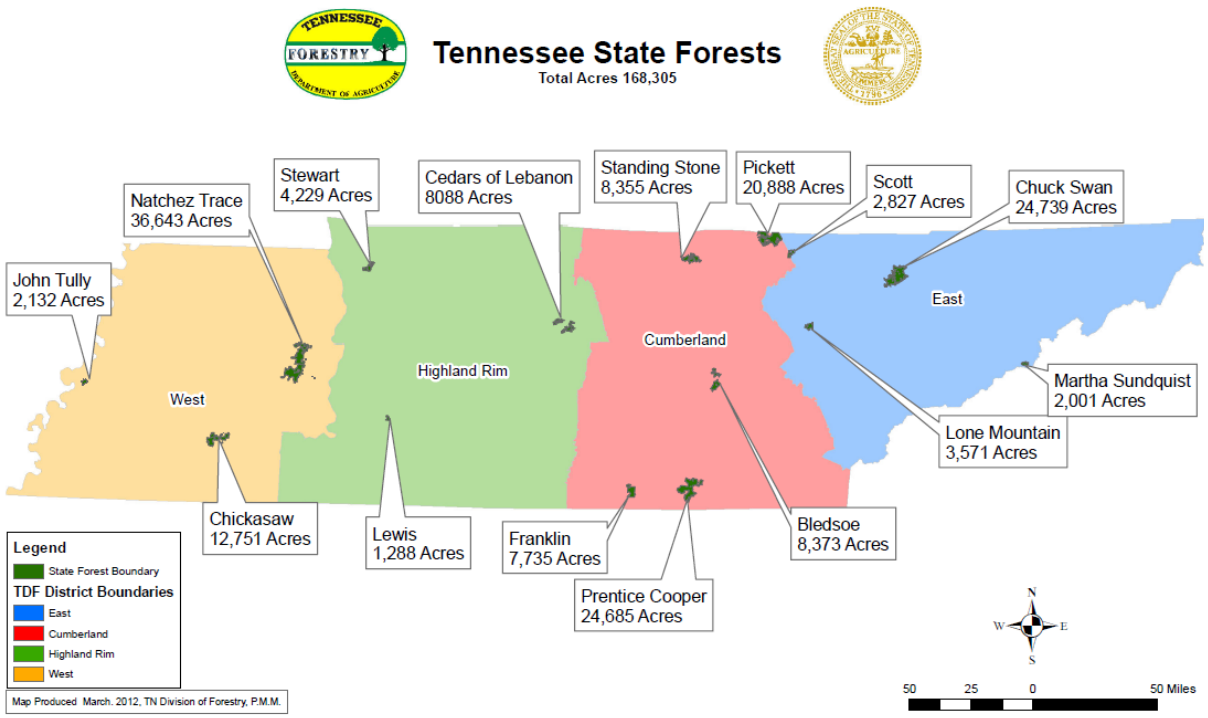

Figure 1. State Forests locations and acreage, map generated by the Tennessee Division of Forestry.

owned and managed by wood industry companies since the 1930s. It lies in the Blue Ridge region of the state and is the only forest located in this unique physiographic land type. Chuck Swan was acquired from TVA is 1952, under an agreement that the land would be managed. Prior to the acquisition of the land by TVA the area was comprised of small farms which succession has reverted back to forest. Chuck Swan is in the Ridge and Valley physiographic land type. Scott State Forest was acquired by the state in 1938 at a tax delinquent sale, and is on the Cumberland Plateau. Lone Mountain was acquired partially through a tax sale in 1929 and through a deed transfer in 1938 by the Lone Mountain Land Company. Under the ownership of the Lone Mountain Land Company the land was heavily logged and mismanaged preventing any harvest from taking place aside from a few salvage harvests. Lone Mountain lies on the Cumberland Plateau. (TDF)

The Cumberland region of the state contains Pickett, Standing Stone, Bledsoe, Prentice Cooper, and Franklin State Forests. Pickett was acquired through a donation to the state by Stearns Coal and Lumber Company in 1933, becoming a state forest in 1935. Standing Stone was deeded to the state in 1955 under the Resettlement Administration. The previous tenants used the land for agriculture and as a result erosion can be seen across the landscape. Standing Stone sits on the Eastern Highland Rim. Bledsoe was acquired by the state in 1907 and became a state forest in 1933. Standing Stone sits on the Cumberland Plateau. Prentice Cooper was acquired between 1938 and 1944 then deemed a state forest in 1945. Prentice Cooper lies along the scenic Tennessee River Gorge. Franklin State Forest was acquired in 1936 from the Cross Creek Coal Company and became a state forest in 1940. As a result of the previous land use Franklin was highly degraded and has since returned to mature forest. (TDF)

The Cedars of Lebanon, Lewis, and Stewart State Forests are located in the Highland Rim region of the state. Cedars of Lebanon was purchased by the Resettlement Administration in 1935 and turned over to the Division in 1955. The landscape was mostly small farms prior to acquisition and suffered from heavy grazing, erosion, and indiscriminant burning. Cedars of Lebanon is unique to the state, containing the largest continuous cedar glade-barren in Tennessee. Lewis was acquired though a delinquent tax sale in 1933 and deeded to the Division of Forestry in 1936. Stewart State Forest was once part of the Leech Estate and became a state forest in 1935. (TDF)

The Western region of the state contains Natchez Trace, Chickasaw, and John Tully State Forests. Natchez Trace was acquired in 1949 through the Resettlement Administration. The land was once highly eroded, and as a result deep gullies are still present. Management since the time of acquisition has been focused on fire prevention and erosion reduction. This can be seen by the quantity of loblolly pine (*Pinus taeda*) present on the state forest. Chickasaw became state property in 1938 and a state forest in 1955. Similar to Natchez Trace, the land was highly eroded and degraded due to land use practices. John Tully was acquired in 2002 from the Anderson Tully Land and Timber Company. Prior to the acquisition most of the merchantable timber was harvested. John Tully is the only state forest found in the Mississippi River alluvial valley, containing unique forest types not found on other state forests. (TDF)

Chapter III
Methods

Data

Division personnel began establishing the original CFI plots on the 15 state forests in 2007 and completed the initial sample in 2009. The extended time was due to several factors, but primarily the multiple responsibilities and priorities of the personnel within this time period. Inventories began in the spring and were conducted across growing seasons, ultimately requiring a more complex growth analysis following multiple measurements.

The following information was derived from the methodology used by the Division during the initiation of plots (Morrissey et al. 2007). A systematic approach was taken for each state forest and a ratio of 250 acres represented by one plot was established, with a minimum of 20 plots per state forest. This number was derived from previous experience, literature, and the cost per plot. Spacing was calculated based on the acreage of the state forest being measured and then mapped using GIS technology.

Plot centers were identified on aerial photos and then located using GPS. Crew members were given coordinates and allowed a 25-foot error from the exact location. To avoid plots with multiple conditions each plot was required to be classified as forested or non-forested. Plot type or condition was determined by the condition at plot center. Plots that had multiple conditions were moved 60 feet perpendicular to the forested/non-forested boundary, to maintain a single condition within the plot.

Plot Layout

Plots consisted of four subplots (Figure 2), three concentric circular subplots and one offset circular subplot located 10 feet east (90˚) of the center pin. Table 1 describes the size and radius used for each subplot listed. Two witness trees were established for the location of plot center; criteria for tree selection included common species, proximity to plot center, and position in relation to plot center (perpendicular to each other). Aluminum tags were attached to each tree less than six inches from the ground and another at least 6 inches above DBH, both facing plot center. Diameter, azimuth, distance from plot center, and species were recorded to aid in the location of plot center for the next measurement.

Site index was recorded at each plot location using suitable trees off plot that represented plot conditions. Species, age, and height were recorded and an average plot age was assigned to each plot. Sawtimber was defined as twelve inches in diameter and larger at breast height for hardwoods and ten inches in diameter and larger at breast height for softwoods. All trees were mapped by collecting azimuth and distance measurements from plot center. Trees were then assigned a numerical value to assist in the measurement process. The following attributes were collected for all trees that fell within the plot boundary.

- Species
- Diameter at Breast Height (DBH) to the nearest 0.1”
- Status “alive or dead”
- Total Height (feet)
- Merchantable Height
- Percent cull of the merchantable portion
- Percent live crown ratio

Figure 2. Plot design used by TDF. Figure prepared by TDF.

Table 1. Plot sizes (Acre) by product type

Type	Size	Radius(feet)
Sawtimber	0.20	52.7
Poletimber	0.05	26.3
Sapling	0.01	11.8
Regeneration	0.001	3.7

Data Quality

The first process was to determine any species code errors associated with the plots. This was mostly found through the implementation of the USFS species groups. The plot boundary was checked by adding a filter to the raw data sheet and by sorting the distances from greatest to least. This process was conducted for total height, DBH, merchantable height, and percent cull. A large portion of the plots had no value for percent cull. It was assumed that this was the result of no cull being present. Individual trees were compared to trends of each state forest using known relationships in forestry. A DBH vs. Height relationship was used to identify trees that contained an extreme value either due to transcription or measurement. A XY scatter plot was used with both variables being continuous. To verify the results the function plot(x, y) was conducted in R (www.jmp.com). No inconsistencies were found between the two programs. Errors in the tree data that could be identified from revisiting the original data sheets were corrected, while errors that could not be resolved were left, but noted as being potentially odd. Merchantable height was compared to total height for individual trees on each state forest to determine if there was a relationship in the two variables. This was conducted in JMP and R to verify the plots. Volume per acre (VPA) estimates were checked using non-parametric techniques (e.g., box-plots) to establish potential outliers. Box plots of each individual state forest identified VPA estimates that appeared large or small relative to the estimates for the individual state forest. JMP analysis of distributions with boxplots was used, while boxplots (x, data=) were used in R. Outlier plots that had a large amount of volume relative to the other plots on the state forest were checked by examining basal area. Individual tree basal area was added to the original data set by generating a new column and multiplying the diameter squared by 0.005454.

Calculations

Volume estimates were produced using regression equations developed from the USFS Southern Research Station (SRS) Forest Inventory Analysis (FIA) program. First, the raw data were checked for consistencies between plot id and forest id. To verify this, all plots were classified by state forest with identification number checked to confirm the assignment. No inconsistencies were found. Species-specific inside bark equations from the general form of a linear regression model were used from trees felled on public land (Oswalt et al. 2011). The FIA equations will be referred to as Traditional going forward in this report.

$$V = \alpha + \beta\,(dbh^2 Ht) + \varepsilon$$

Where:

dbh = bole diameter at breast height

Ht = Total tree height

α & β are species specific coefficients

V = Volume

Prior to assigning the coefficients, the species identification numbers were grouped based on the grouping used to develop the equations. All changes can be found in Table 15 (Appendix A).

Cubic-foot volume was calculated for all trees using the Equation Form CU000067 (CV4), which calculated cubic-foot volume from a 1-foot stump to a 4-inch top (Oswalt et al. 2011). A function in Microsoft Excel was employed to match and lookup coefficient values from a table. Checks were conducted to verify that the function was working properly by species and that no inconsistencies were found.

$$CV4_{Sawtimber} = D1 + D2 * (dbh^2 * HT)$$

Where:

D1 & D2 = Species specific coefficients

Table 16 (Appendix A) contains the coefficients by species groups for both D1 & D2 used in the CV4 equation.

The saw-log portion of the tree measured in cubic-feet was determined using equation CU000069 (CUSAW). The same function in Excel was used but referenced the array containing the coefficients for CU000069. This process created a ratio containing the merchantable portion of the tree dependent on species group (hardwood to a 10” top and softwood to a 8” top). The same grouping of USFS species codes was used throughout all of the calculations. This ratio was then multiplied by the total cubic feet estimate from CV4 to produce an estimate of total merchantable cubic feet volume.(Oswalt et al. 2011)

$$R = H1 + H2 * \left(\frac{1}{DBH - 5}\right)^2$$

$$CUSAW = R * CV4$$

Where:

H1 & H2 = Species specific coefficients

The saw-log portion of the tree measured in board feet was calculated using equation BD000049 (BD). This equation calculates a ratio of the merchantable portion of the tree in terms of board feet. An Excel function was used to match and lookup the corresponding coefficients from a table. Coefficients can be found in Table 17 (Appendix A)

$$R = I1 + I2 * (1 - \left(\frac{1}{DBH}\right)$$

Where:

I1 & I2 = Species specific coefficients

Gross board feet were then derived using the following equation by multiplying the ratio of board feet to the total cubic feet estimate. This is cited as being log rule International ¼, however how this was derived has not been documented. This log rule will be used for estimating board foot volume in this study.

$$BD = R * CV4$$

Net saw-log volume for individual trees was calculated by extracting the percent cull from the original plot data and reducing the gross board feet volume estimate by this percentage. The process of determining percent cull required the field crew to estimate a merchantable height. This height, however, could be different from the predicted heights contained in the estimate. The variation of quality found in hardwoods and the subjective nature of cull reduction could influence both the accuracy and precision of this reduction. The use of this percent cull reduction was used to indicate the need for more precise estimates of cull reduction and not to show the accuracy of the reduction. Given that 1/5 acre plots were used, an expansion factor of 5 was applied to each tree to produces estimates at the per acre level.

$$BD - (BD*(\%\ cull)) = \text{Net Volume (board feet)}$$

Implementation of FVS

The USFS provides a template for an Access database available to the public on the USFS website and it was accessed on 5/10/2013. The template contained two tables, StandInit and TreeInt. StandInt contains attributes used at the plot level (i.e., Plot Number, Stand ID, Variant (Southern), SI, Age, Plot Size (used for expansion factor), location (Lat., Long), Region, District, and Forest). TreeInt contains the attributes of each individual tree including Plot Number, Tree Number, Species, DBH, Total Height, and Crown Ratio.

The SUPPOSE GUI for FVS provided by the USFS website and accessed on 5/15/2013 was used to input and calculate per plot estimates. A Treelist file (stand and stock table) was generated and used to reference individual trees. The outputs were put into an Access database that could be extracted and loaded into JMP to allow for statistical calculations. TDF provided an Excel file containing the estimates produced from FVS. These estimates were verified by comparing them to this study.

Statistics

The following statistics were calculated for each state forest for the volume estimated from the USFS SRS FIA equations and for the FVS plot estimates: mean VPA, standard deviation of VPA, standard error of the mean, and confidence intervals at the 95% level of confidence. Confidence intervals were calculated for each state forest. Finite population corrections were not used due to the small sampling fraction. A coefficient of variation and sampling error as a percent of the mean were calculated for each state forest for comparison purposes. Data were compiled using code written in VBA in Microsoft's VBA developer. This process combined the individual trees volume estimates by plot id for both total cubic feet (CV4) and merchantable board feet (BD). Pivot tables were used to verify that no inconsistencies were found. There were no inconsistencies found between the pivot table results and the macro compiled results. Results for each state forest were then loaded into JMP, a program used for statistical analysis and part of the SAS Institute, Inc. (www. jmp.com). JMP was selected due to the user friendly nature of the GUI, track record for accuracy, ability to quickly analyze results, and save script for repetition. All summary statistics were calculated in JMP, R, and Excel to verify that the correct estimates were being produced. Distributions were calculated in R version 3. 0. 2 to compare with distributions produced in JMP. R was used due to the ease of producing multiple figures quickly with consistent formatting. To prevent the possibility of errors occurring during the creation of new files all procedures were run from the original data set and verified against a saved copy of the original.

Stratified Sampling

Once volume per acre (FIA equations) was estimated, stratified sampling statistics were calculated for the overall population mean. It was assumed that averages differ by strata and that the associated variance is small in comparison to overall variance. This should produce a more precise estimate of the total population mean (Avery and Burkhart 2002). The sample mean was calculated for each stratum and combined in a weighted overall mean. The calculations were carried out in Excel due to the ease of manipulation as well as the ability to visually verify reference. Columns were generated for each attribute of the equation and area estimates were derived from TDF.

$$\bar{y}_{st} = \frac{\sum_{h=1}^{L} N_h \bar{y}_h}{N}$$

Where:

L = number of strata

N_h = total number of units in stratum h (h = 1,….,L)

N = total number of units in all strata

To calculate standard error it is first necessary to compute the variance for each individual strata s_h^2. Variance is calculated using the equation from simple random sampling. From the individual strata variances the standard error of the mean is computed as (this equation ignores the finite population correction factor - see Avery and Burkhart (2002)).

$$s_{\bar{y}_{st}} = \sqrt{\frac{1}{N^2}\sum_{h=1}^{L}\frac{N_h^2 s_h^2}{n_h}}$$

Confidence intervals for the mean are computed as

$$\bar{y} \pm t s_{\bar{y}_{st}}$$

Where:

degrees of freedom for the t value can be computed by

$$(n1 - 1) + (n2 - 1) + \cdots + (\mathrm{n}L - 1), [i.e., \text{by} \sum_{h=1}^{L}(n_h - 1)]$$

To calculate the optimum allocation of field plots

$$n_h = \left[\frac{N_h s_h}{\sum_{h=1}^{L} N_h s_h}\right] n$$

Forest Type Classification

Forest type classification was derived using the algorithm contained in FVS. Arner et al. (2001) describe the process tree used to obtain stocking, stand size, and forest type. The process of plot delineation was not used in this classification; therefore the entire plot was classified as one forest type. As detailed in Arner et al. (2001), the origin of the forest types derived from the algorithm is Eyre (1980), which has been used by FIA units for plot classification for some time.

Chapter IV
Results

The results are presented in three separate components: data quality, volume comparison, and design. Data quality refers to the individual tree attributes as well as the plot level estimates. The volume comparison presents the differences between the two methods of calculating board feet estimates and cubic feet estimates (traditional and FVS), and the differences found between the equations/models. The design topic describes the current quality based on sampling error, and the multiple options for improving the precision, based on altering the overall design both for the overall estimates as well as within forest estimates. Prior to presenting these topics an overview of the key results for the state forests is reported to provide a context of what species types, age, and species groups are being discussed in the subsequent sections.

Forest Overview

White oak (*Quercus alba* L.) was the most common species reported on the state forests, followed by loblolly pine (*Pinus taeda* L.) (Table 1). The distribution of plot age can be seen in Figure 1, with reported ages ranging from 0 to 195 years. The average age was 65 years. The distribution of each state forest can be found in Appendix E. The most common forest type was Oak-hickory, which comprised more than 70 percent of all forest groups (Table 2).

Data Quality

Tree data

The initial assessment of plot data began with checking the measurements with known values. Distance of trees from plot center was to be equal to or less than 52.7 feet. Nineteen trees fell outside the plot boundary or were recorded incorrectly, 228 trees contained no percent cull value, and 2 trees contained species codes not listed in the Southern Variant. The errors due to transcription were corrected by reviewing the data sheets and were not included. The assessment of individual trees began at the state forest level looking at known relationships. Scatter plots were used to depict overall trends among the individual forest as well as individual trees that were separated from the surrounding data. A plot containing no odd data points or patterns (Figure 2) was included for reference. Rounding of total height measurements (Figure 3) was noted on two state forests (Bledsoe and Franklin). To magnify this result Figure 4 illustrates the rounded values of loblolly pine on Natchez Trace. There is no increase recorded in height as DBH increases. Individual trees that stood out (Highlighted) (Figure 5) were investigated for having incorrect data.

Height measurements that were identified as being taller or shorter than the surrounding data were further investigated for the units of the measurements in the data sheets. The most common type of data error was the total height being recorded in logs (16 feet) or the values in the merchantable column being switched with total height. Two state forests reported total height measurements that stood out as potential taller errors (Natchez Trace and Pickett); these two points also were the two tallest trees recorded on all state forests at 180 and 200 feet. Appendix C contains all of the relationships of DBH to height not presented in this section.

Table 2. Frequency of species for all plots on all 15 State Forests. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design.

Common Name	Frequency		
Yellow buckeye	1	Birch spp.	12
Bitternut hickory	1	Southern magnolia	12
Shellbark hickory	1	Elm spp.	13
Nutmeg hickory	1	Black cherry	14
Hackberry spp.	1	Green ash	16
Cottonwood	1	Yellow birch	19
Oak deciduous	1	Sycamore	19
Blackjack oak	1	Pin oak	19
Shumard oak	1	Cherrybark oak	27
Slash pine	2	Ash spp.	33
Eastern hemlock	2	unknown hardwood	37
Boxelder	2	Sugar maple	40
Buckeye	2	American beech	45
Overcup oak	2	Shagbark hickory	47
Basswood spp.	2	Hemlock spp	71
American elm	2	Blackgum	74
Slippery elm	2	Eastern redcedar	83
Silver maple	3	Pignut hickory	84
Honeylocust	3	Eastern white pine	91
Red hickory	4	Mockernut hickory	96
Common persimmon	4	Northern red oak	109
Sourwood	4	Hickory spp.	142
Paulownia	4	Post oak	149
Pecan	5	Sweetgum	162
Hackberry	5	Shortleaf pine	174
Swamp tupelo	5	Virginia pine	198
Water oak	5	Black oak	230
Willow oak	7	Red maple	254
Black locust	8	Southern red oak	269
Black walnut	9	Scarlet oak	435
White ash	10	Chestnut oak	493
Cucumbertree	10	Yellow-poplar	537
Chinkapin oak	11	Loblolly pine	617
		White oak	766
		Total	5509

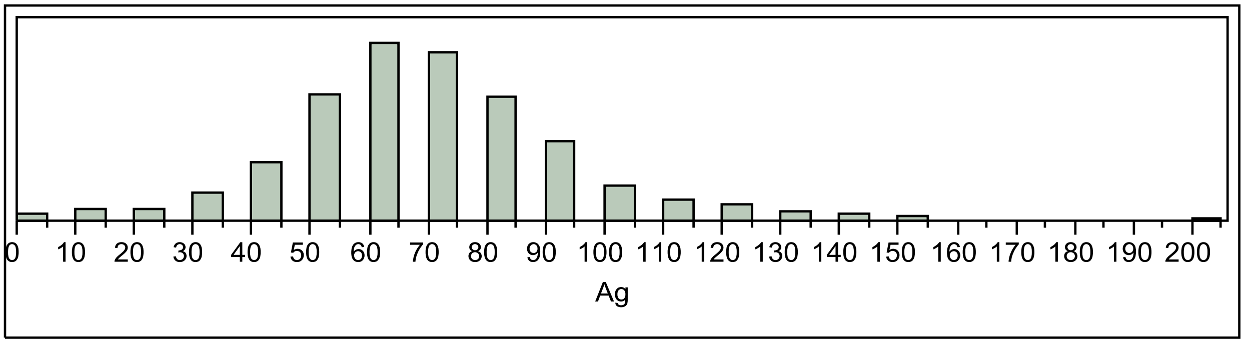

Figure 3. Distribution of age of all plots on all 15 State Forests. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design.

Table 3. **Distribution of Forest Types of all plots on all 15 State Forests. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design.**

Forest Group	Frequency
Oak-gum-cypress	8
White-red-jack pine	9
Elm-ash-cottonwood	14
Maple-beech-birch	22
Other-nonstocked	25
Loblolly-shortleaf pine	64
Pine	67
Oak -hickory	502
Total	711

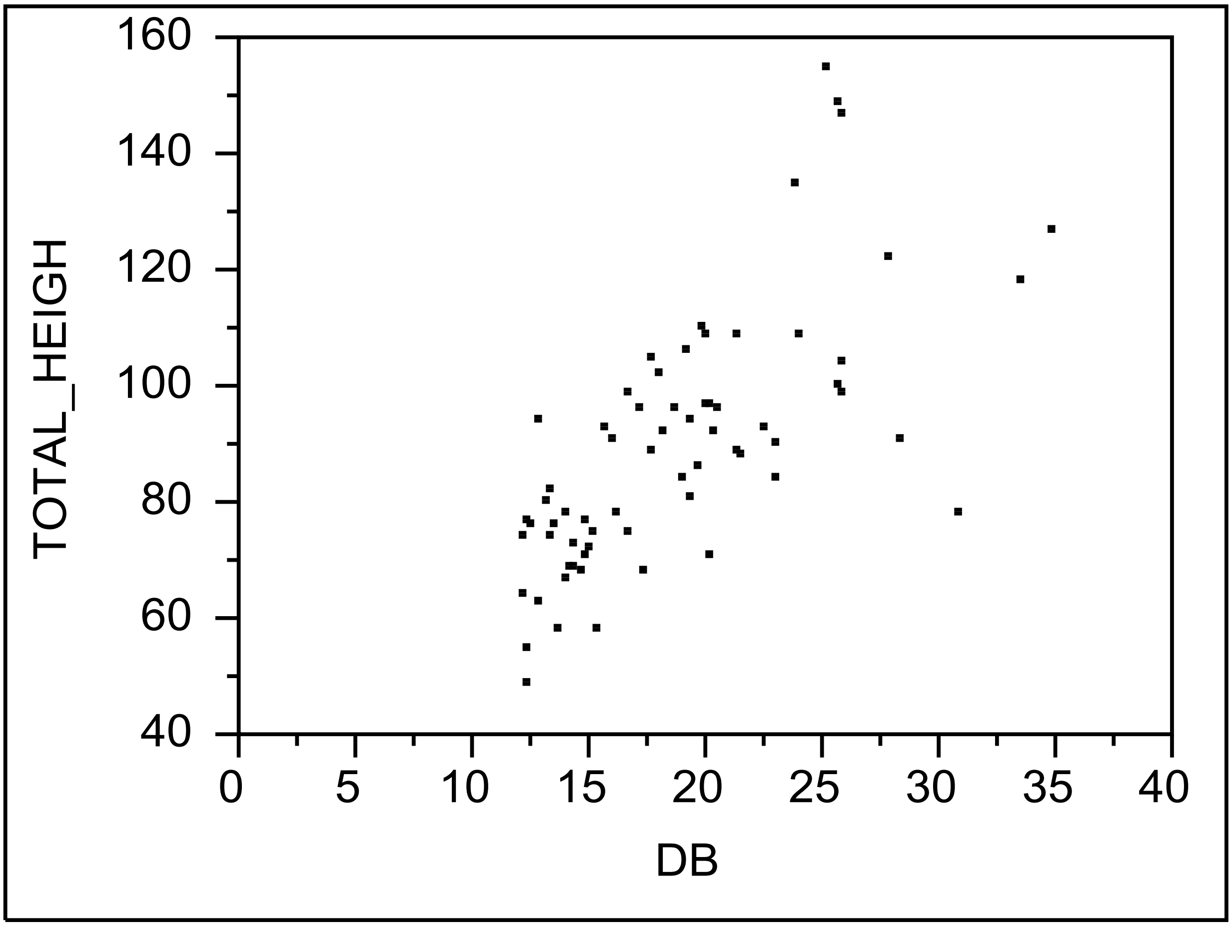

Figure 4. **X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet for John Tully State Forest. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.**

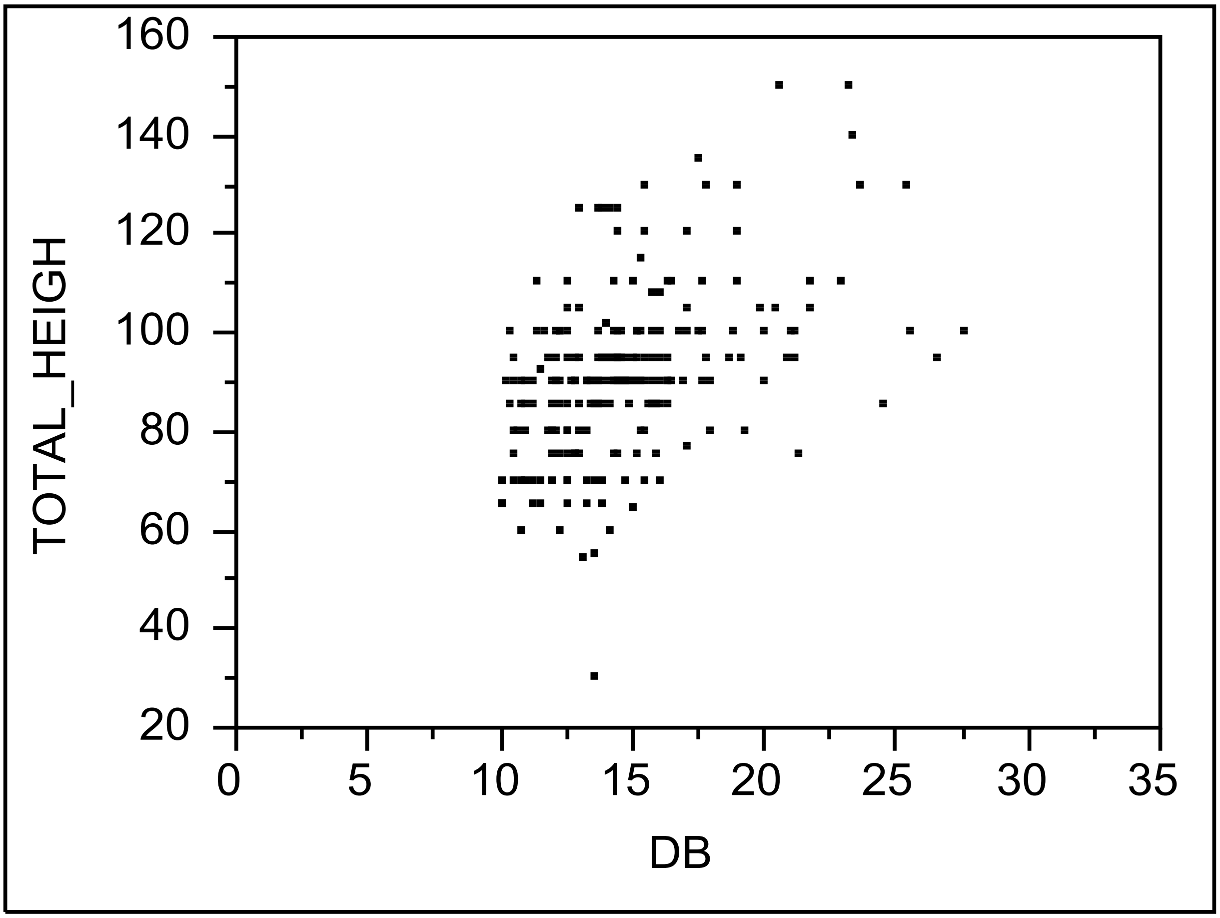

Figure 5. **X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet for Bledsoe State Forest. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.**

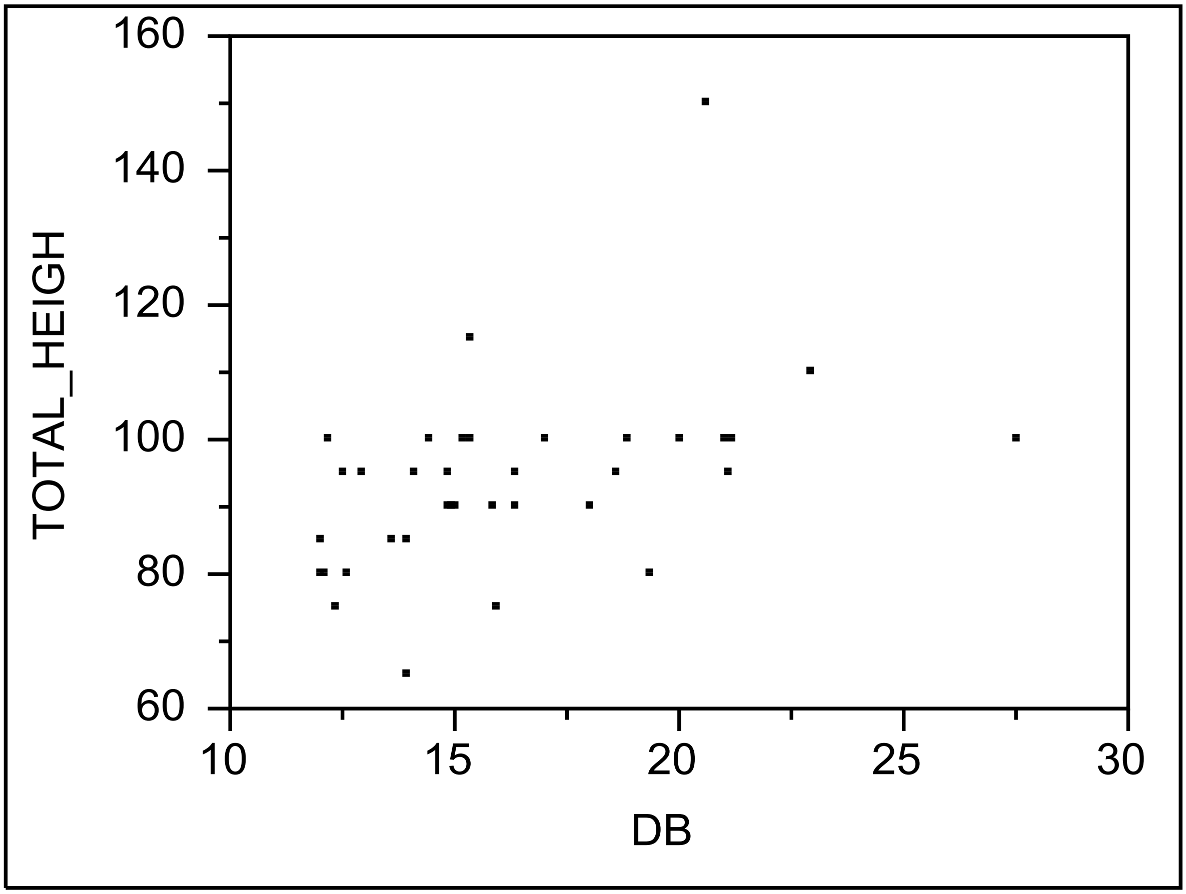

Figure 6. Relationship of DBH vs. Total height for loblolly pine on Bledsoe SF.

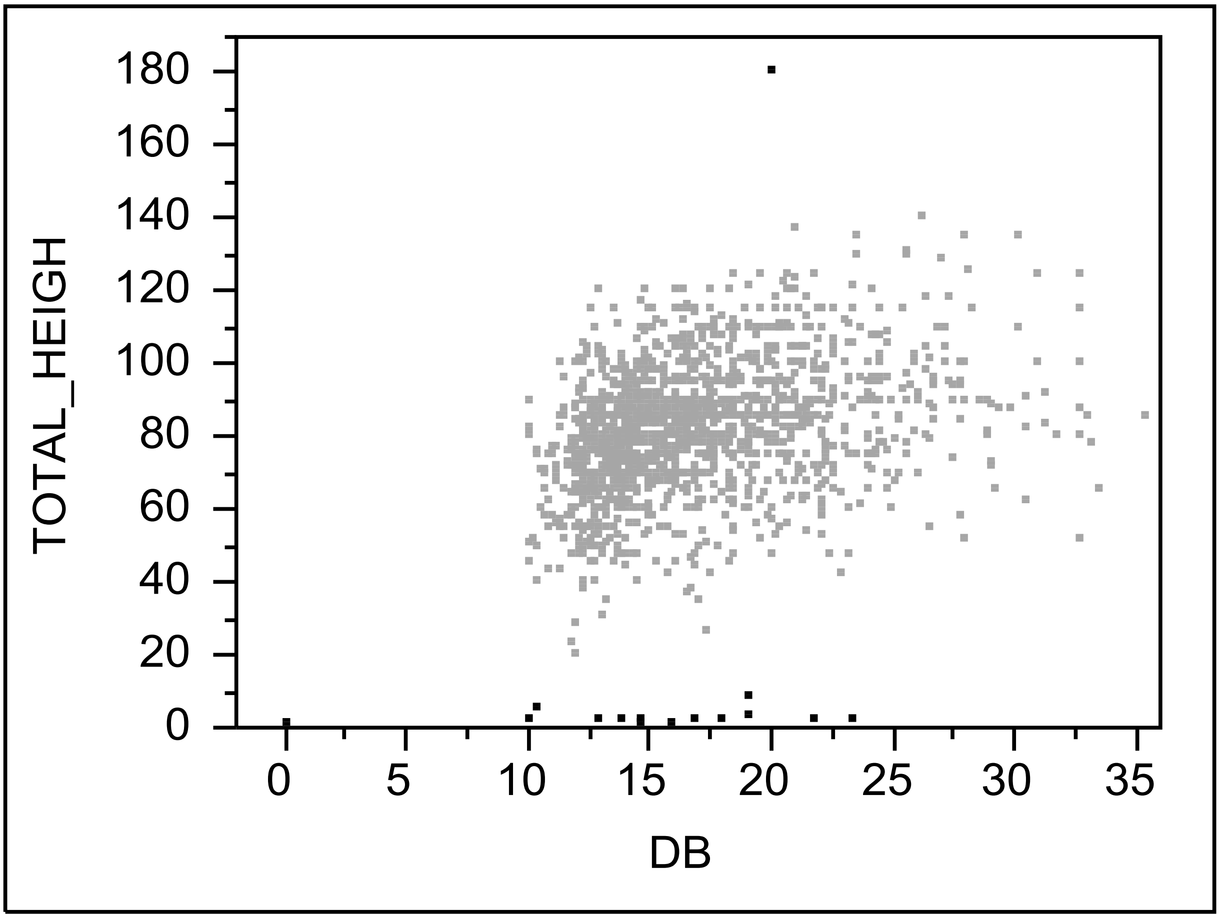

Figure 7. Scatter plot of DBH vs Total Height for all sawtimber trees measured on Natchez Trace State Forest with 15 points highlighted

Merchantable height is the measurement describing the portion of the tree that can be used for a specific product type. One-way plots were used to view the distribution across different x values or levels (horizontal axis). DBH was used as the x value due to the merchantable limits being based on a diameter at breast height and an upper stem diameter specified based on hardwood or softwood. Figure 6 shows the expected trend on Martha Sundquist; Figure 7 illustrates the distribution on Chickasaw and no trend can be seen indicating that merchantable increases with DBH.

Age was compared to volume, assuming that an increase of volume could be seen as age increased (Figure 8). Franklin State Forest exhibited no obvious increase or change across age. To investigate the impacts of multiple forest types masking patterns, Natchez Trace's Oak-Hickory forest type displayed no increase in volume as age increased (Figure 9). The distribution of volume by age indicated two points that seemed extreme, a 0 year old plot with an estimate of 7,000 board feet per acre as well as a 24 year old plot with an estimate around 27,000 board feet per acre.

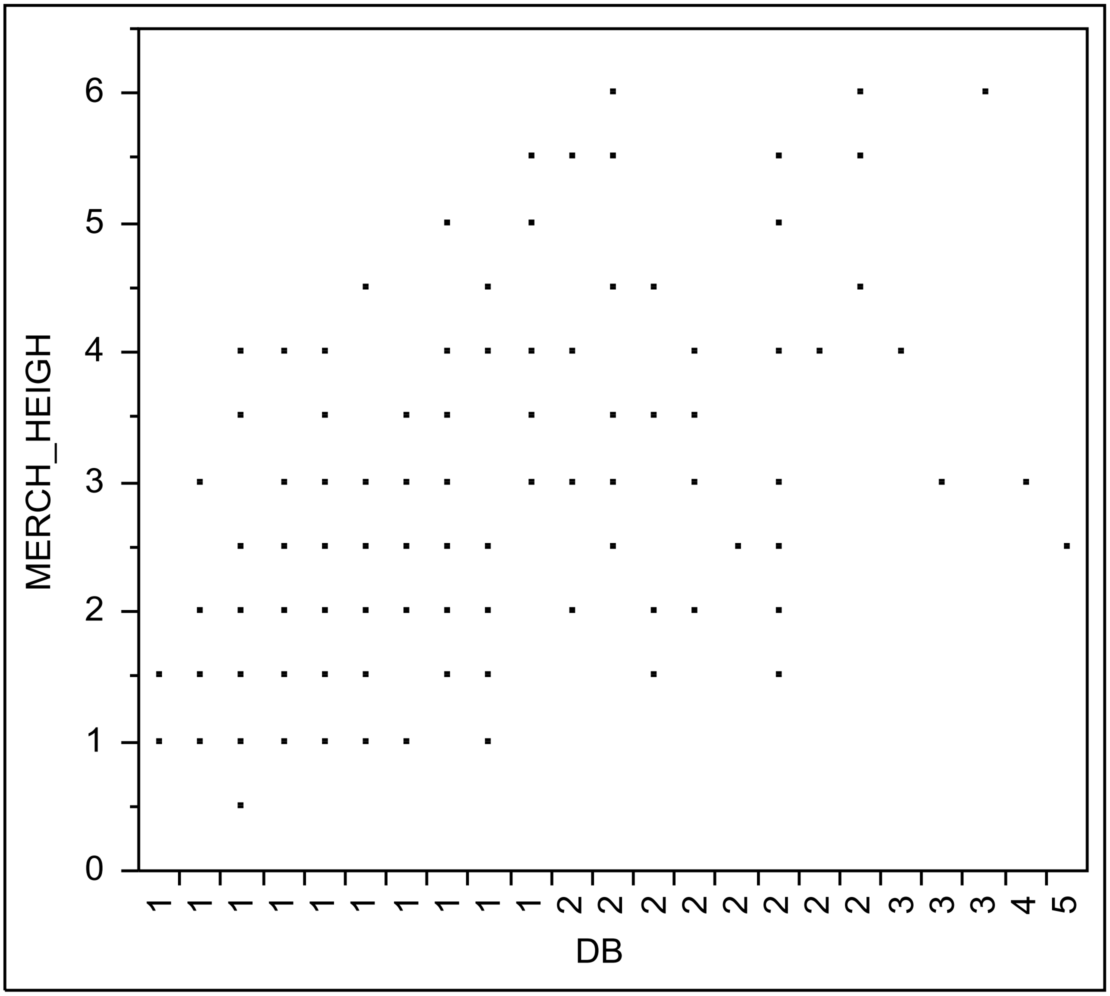

Figure 8. Distribution of Merchantable Height (MERCH_HEIGHT) (logs) by DBH for Martha Sundquist State Forest of all measured sawtimber trees.

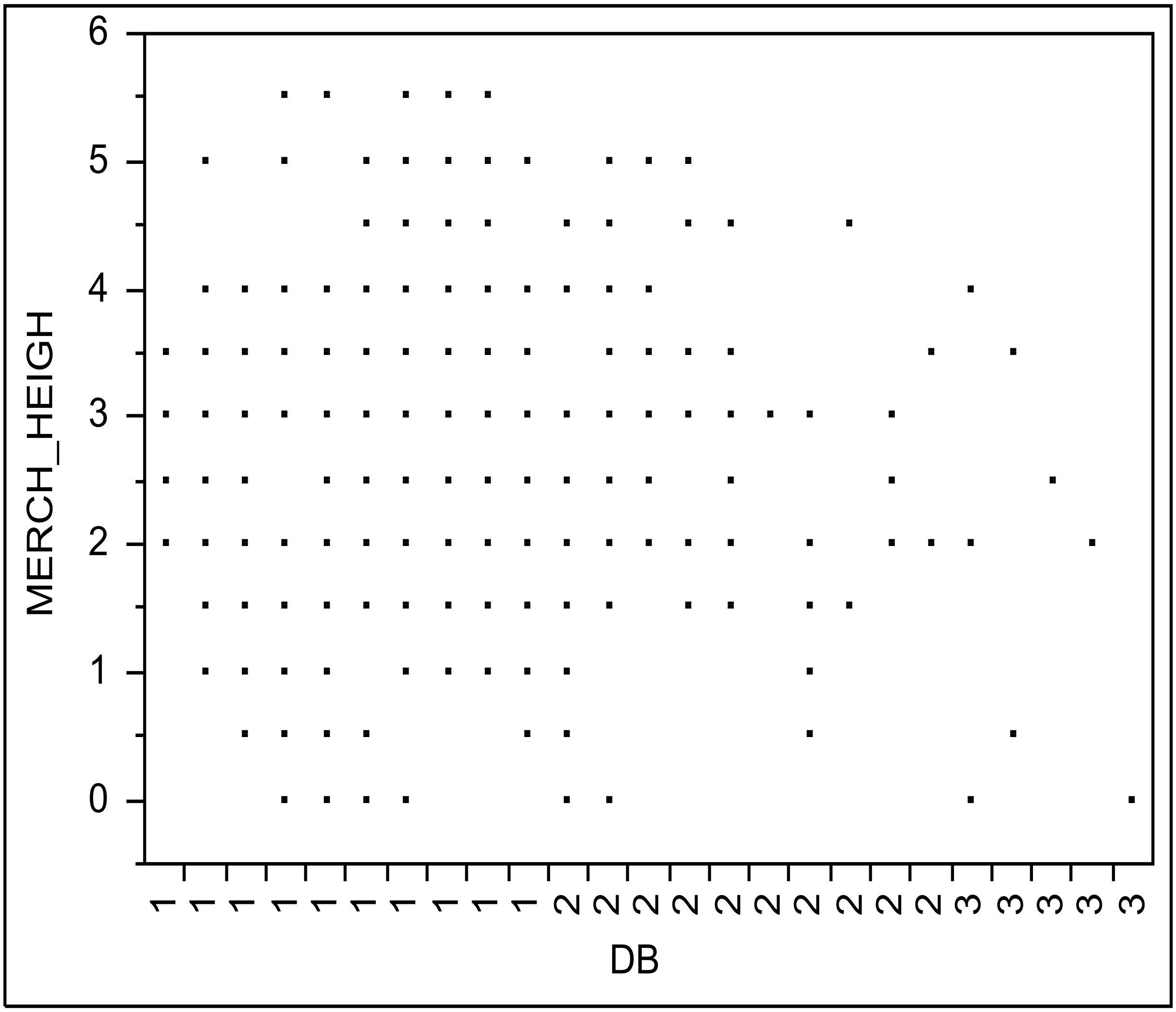

Figure 9. Distribution of Merchantable Height (MERCH_HEIGHT) in (logs) by DBH for Chickasaw State Forest of all measured sawtimber trees.

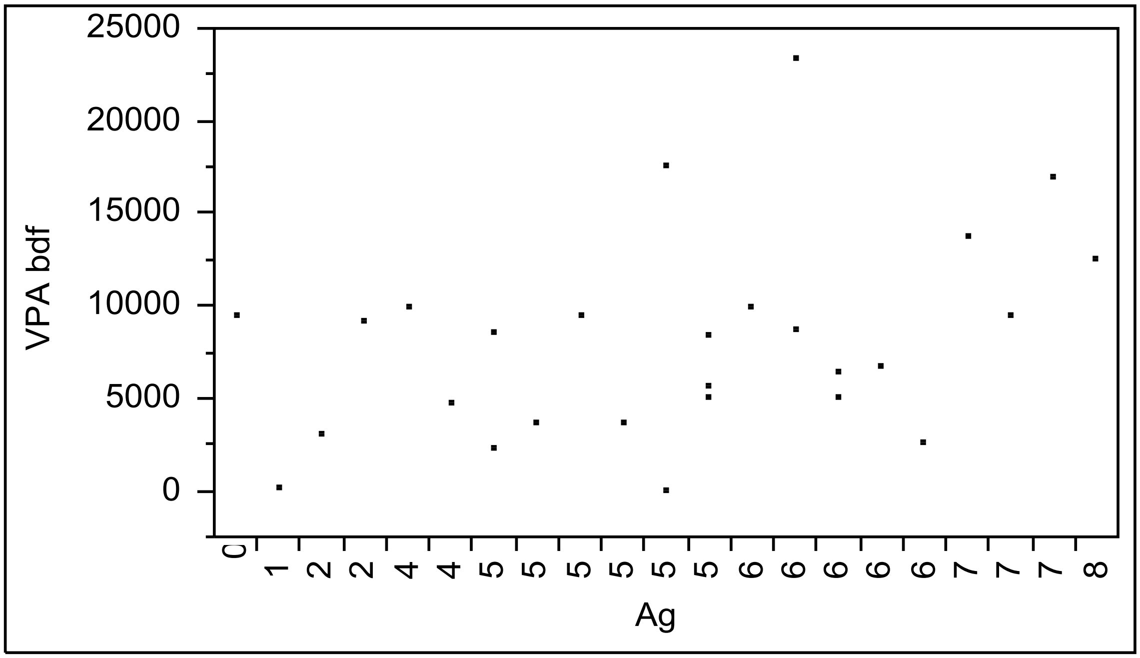

Figure 10. Distribution of Traditional Volume per acre (VPA) board feet (bdft) estimates by age Franklin State Forest.

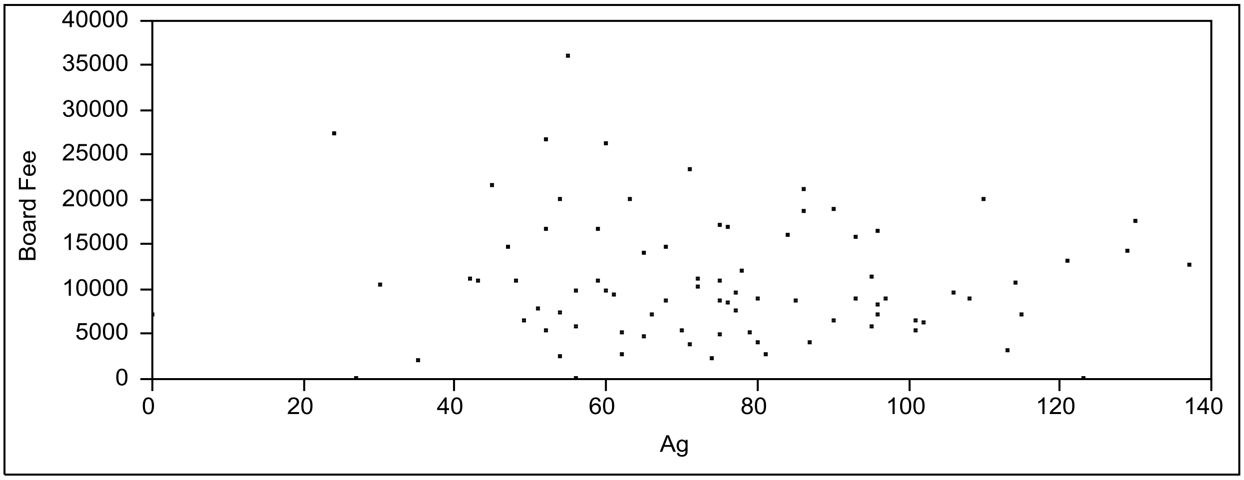

Figure 11. Distribution of VPA (board feet) by age for Oak-Hickory forest type on Natchez Trace State Forest.

Volume Assessment

VPA estimates were compiled for each state forest and box plots were used to distinguish outliers. Histograms were included for distributions and to display the spread of an individual or group of outliers. State forests that contained outliers (figure 12) were reevaluated with the outliers removed (figure 13). Seven state forests contained outliers relative to other plot estimates. In the West region Chickasaw and Natchez Trace contained 1 outlier. In the Central region Cedars of Lebanon contained 4 outliers, the most outliers across all 15 state forests. In the East region Franklin, Standing Stone, Pickett, and Scott all contained 1 outlier. Prentice Cooper and Pickett both contained 3 outliers. All state forests box plots with distribution not presented in this section are in Appendix D.

Traditional vs FVS

The Forest Vegetation Simulator (FVS) was used to compile the initial plot estimates by TDF. Confidence intervals at the 95 % level were used to distinguish a difference of means between the three estimates: traditional calculation (All Plots), traditional calculations with outliers removed, and FVS. It is assumed that the populations within each state forest are normally distributed therefore standard formulas for calculating the mean, standard error, and confidence intervals were used (Avery and Burkhart 2002)

If either tail of the confidence interval overlapped the tail of the other methods, no difference of the mean was assumed. The 15 state forests were divided into three regions West, Central, and East for comparison purposes. The West region (Table 3) contained one forest, Natchez Trace, with a mean that differed from the other estimates. Outliers removed differed from the FVS estimate but not from the traditional estimate. The Central region (Table 4) contained two state forests that did not contain any outliers, Stewart and Lewis. Cedars of Lebanon's All Plots and Outliers Removed both differed from the FVS estimate.

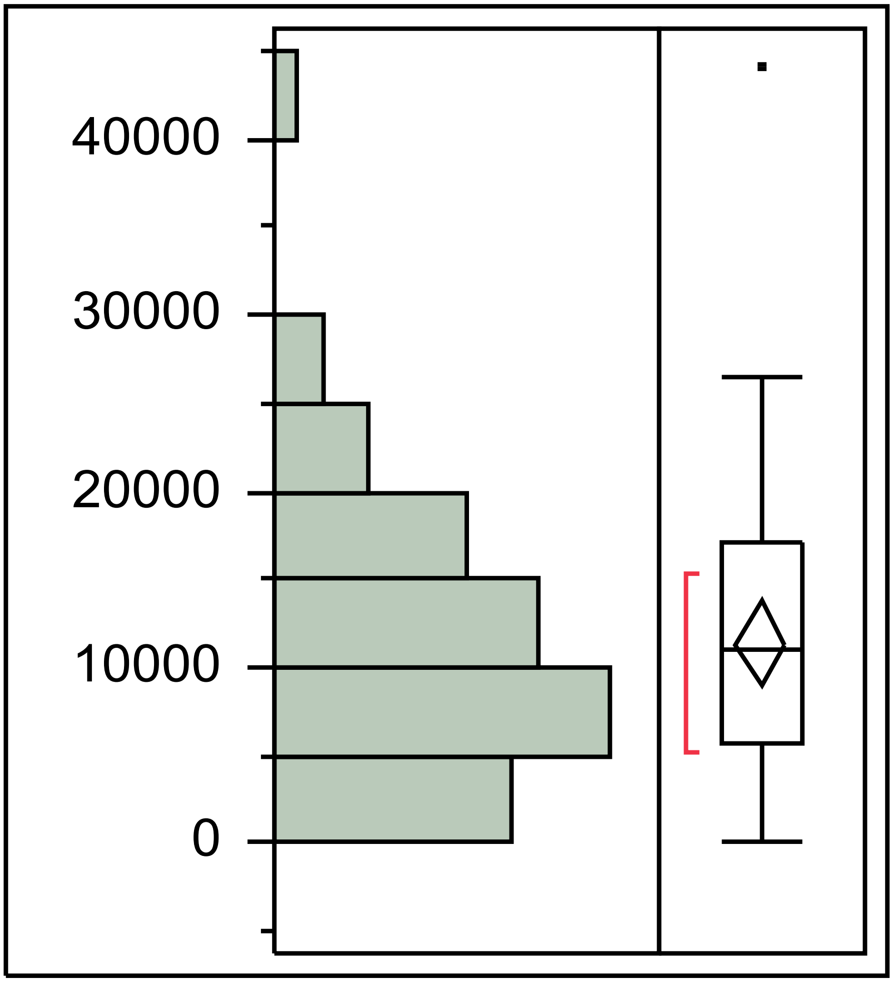

Figure 12. Distribution of volume per ace (Board Feet) for all plots on Chickasaw State Forest box plot with whiskers included for outlier detection.

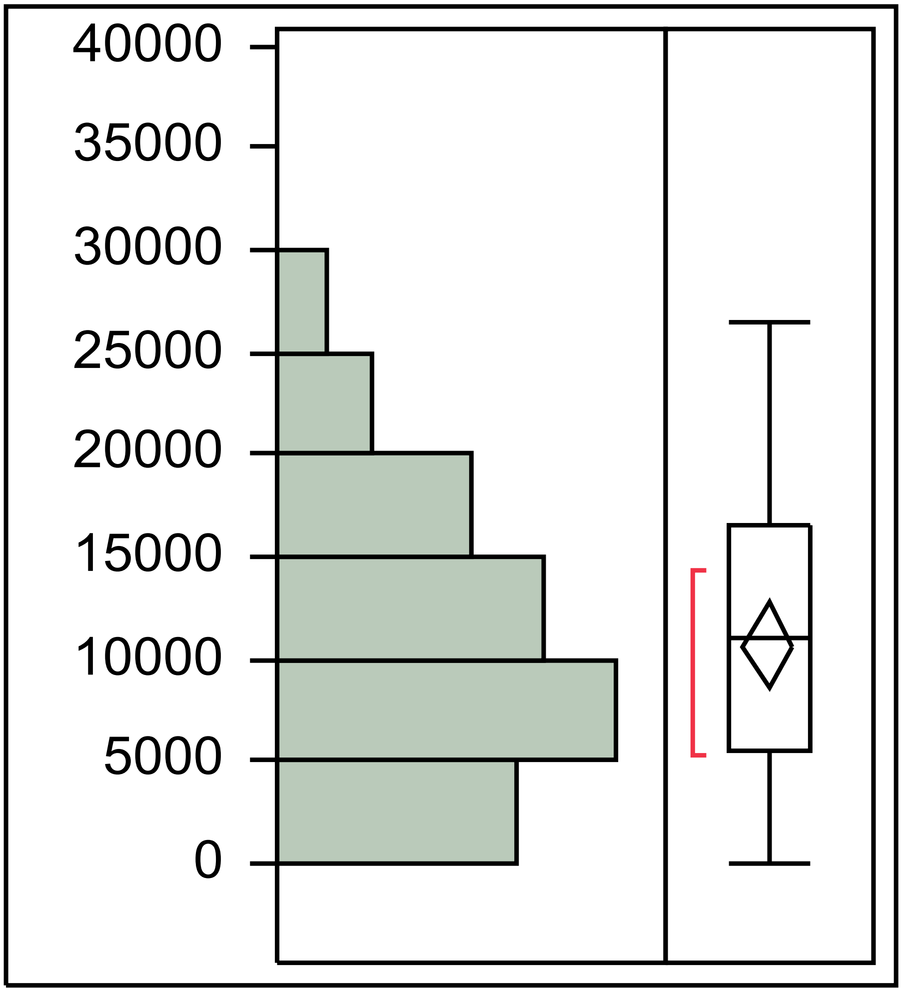

Figure 13 distribution of volume per acre (Board Feet) for 49 plots on Chickasaw State Forest 1 outlier removed from figure 8

Table 4. Board feet per acre estimates for the central region separated by state forests. LCL (Lower Confidence Limit) and UCL (Upper Confidence Limit) calculated using a 95% confidence limit. State Forests containing (*) in the Outliers Removed rows did not contain any outliers.

WEST REGION				
John Tully	n	Mean	LCL*	UCL*
All Plots	20	5672	2555	8789
Outliers Removed	19	4501	2463	6540
FVS	20	5517	2677	8358
Chickasaw				
All Plots	50	11341	8915	13767
Outliers Removed	49	10674	8609	12739
FVS	50	13258	10793	15723
Natchez Trace				
All Plots	144	12070	10672	13468
Outliers Removed	143	11903	10535	13271
FVS	144	14962	13434	16491

Table 5. Board feet per acre estimates for the central region separated by state forests. LCL (Lower Confidence Limit) and UCL (Upper Confidence Limit) calculated using a 95% confidence limit. State Forests containing (*) in the Outliers Removed rows did not contain any outliers.

CENTRAL REGION				
Stewart	n	Mean	LCL*	UCL*
All Plots	20	6557	4342	8772
Outliers Removed	*	*	*	*
FVS	20	8875	6012	11738
Lewis				
All Plots	20	7745	5582	9908
Outliers Removed	*	*	*	*
FVS	20	11660	8708	14611
Cedars				
All Plots	31	2640	1622	3659
Outliers Removed	27	1740	1265	2215
FVS	31	4982	3676	6288

The East region (Table 5) contained four state forests that did not contain any outliers (Bledsoe, Lone Mountain, Chuck Swan, and Martha Sundquist). Prentice Cooper's All Plots and Outliers Removed differed from FVS. Outliers Removed differed from FVS for both Franklin and Pickett while Chuck Swan's All Plots was different from the FVS estimate. While only six state forests had statistically different means, there was a consistent pattern of higher estimation from FVS. To better understand the difference in the two estimates FVS and traditional, individual tree comparisons were calculated. The FVS estimates were compared to traditional (Figure 12) for 27 trees spread across multiple state forest and species groups. Using FVS, 26 of the 27 trees were overestimated. To assess the potential of FVS not having a similar cull percent used, Figure 13 depicts the same 27 trees with a reduction in cull that was used in the traditional calculations. The distance between the two methods was reduced, but there was still an overriding trend of over estimating volume. In order to determine the location of the difference, both methods produce an estimate of cubic feet (Figure 14). To identify the potential extreme cases of difference, the species that showed the greatest difference in Figure 14 was 832 (Chestnut Oak) and was used for further investigation (Figure 15). There appears to be a more precise estimate of cubic feet between the two methods than of board feet (Figure 14).

FIA estimates were calculated using the Evalidator tool on the USFS data mart website on February 22, 2014 (Table 6). The numerator was set to net volume of the sawtimber portion of the tree for timberland. The denominator was set to the area of timberland in acres. A row variable was included to classify TN based on the five units: West, West Central, Central, Plateau, and East. A filter (and cond.owngrpcd<40) was applied to both the numerator and denominator to only calculate public ownership estimates. The report shows the number of non-zero plots and is not clear if zeros were included in the calculations.

Table 6. Board feet per acre estimates for the east region separated by state forests. LCL (Lower Confidence Limit) and UCL (Upper Confidence Limit) calculated using a 95% confidence limit. State Forests containing (*) in the Outliers Removed rows did not contain any outliers.

EAST REGION				
Franklin	n	Mean	LCL	UCL
All Plots	27	7962	5822	10101
Outliers Removed	26	7372	5536	9209
FVS	27	12624	10037	15211
Prentice Cooper				
All Plots	96	5730	4869	6591
Outliers Removed	93	5308	4570	6046
FVS	96	10805	9468	12143
Standing Stone				
All Plots	33	8798	6431	11165
Outliers Removed	32	8241	6137	10345
FVS	33	12458	9265	15651
Bledsoe				
All Plots	30	5701	3848	7553
Outliers Removed	*	*	*	*
FVS	144	9554	7051	12058
Pickett				
All Plots	82	6165	5009	7322
Outliers Removed	79	5450	4648	6252
FVS	82	8901	7234	10568
Scott				
All Plots	23	2970	1876	4064
Outliers Removed	22	2633	1750	3517
FVS	23	4440	2948	5931
Lone Mountain				
All Plots	20	5299	3368	7229
Outliers Removed	*	*	*	*
FVS	20	10239	6982	13497
Chuck Swan				
All Plots	95	7281	5879	8682
Outliers Removed	*	*	*	*
FVS	95	11046	9346	12746
Martha Sundquist				
All Plots	20	11638	9161	14114
Outliers Removed	*	*	*	*
FVS	20	15159	11860	18459

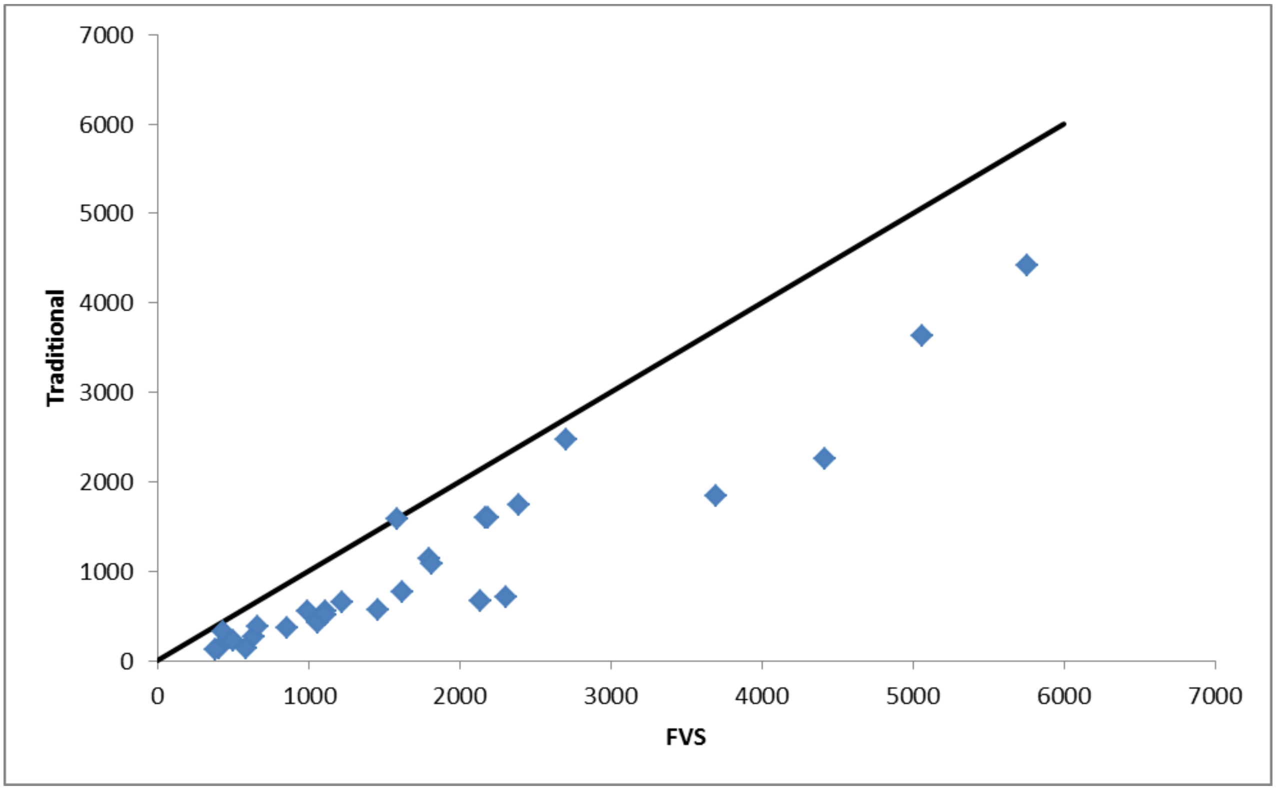

Figure 14. FVS vs. Traditional of individual trees board feet estimates. 1:1 line included for reference.

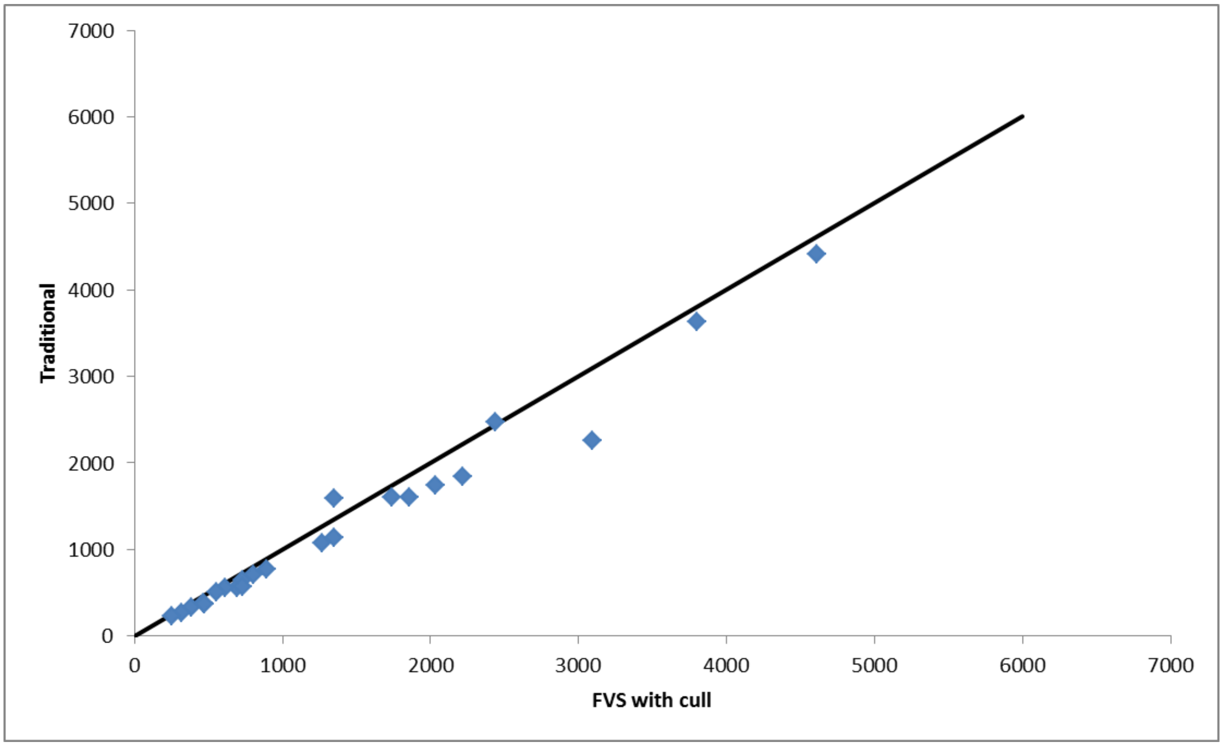

Figure 15. FVS with cull vs. Traditional Calculations estimates are of individual trees 1:1 line included for reference

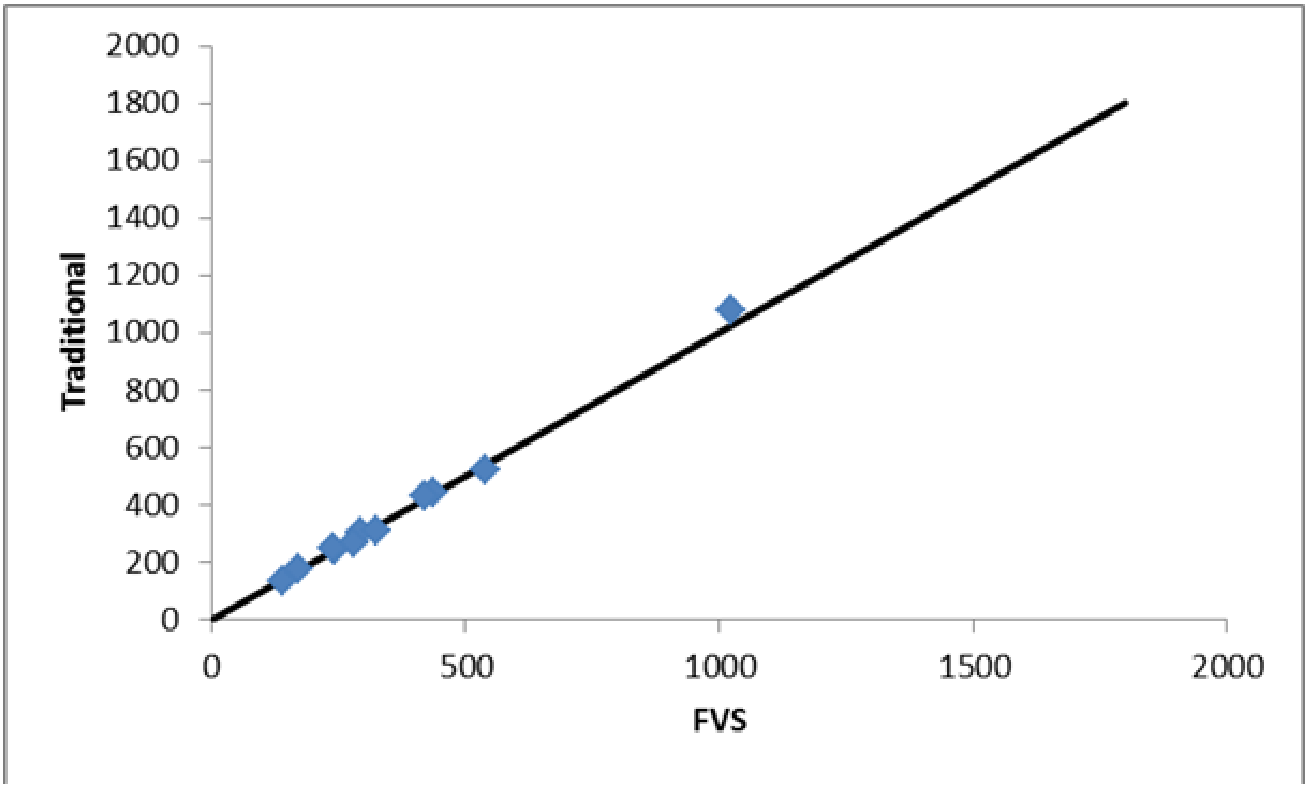

Figure 16. FVS vs. Traditional of Cubic feet for individual trees. The estimate is for the portion of the tree from a 1' stump to a 4" top for both methods. 1:1 line included for reference

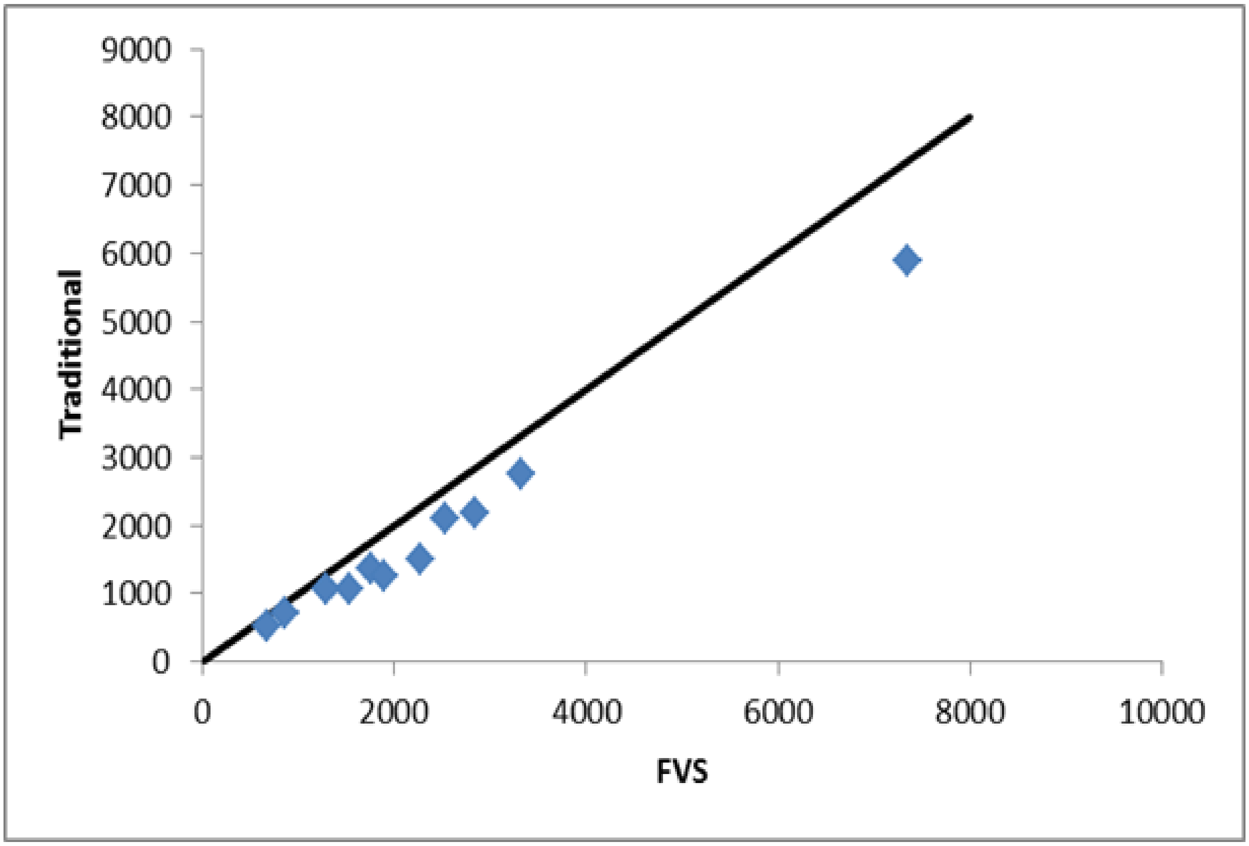

Figure 17. FVS vs. Traditional of board feet for individual trees. The estimate is for the portion of the tree from a 1' stump to a 7" top for softwood species and a 9" top for hardwood species. 1:1 line included for reference

Table 7. FIA region estimates of volume per acre (board feet) of Public Timberland using Evalidatior accessed on February 11, 2014 for TN

Region	Mean	Sampling Error
Total	9,612.36	10%
West	14,380.70	22%
West Central	10,401.13	24%
Central	7,193.80	40%
Plateau	8,299.17	19%
East	9,195.23	18%

The sampling error reported by FIA is at the 68% level of confidence and was converted to a 95% by dividing by the z score for the 68% level then multiplying by the z score for the 95% level. In the west region, John Tully was the only state forest with estimates that stood out from the estimates of FIA. All of the other state forests were not distinguishably different from FIA's estimates of public timberland volume per acre.

Overall Design

Sampling error with all plots was calculated for each state forest (Table 7) for comparison purposes. John Tully State Forest contained the highest sampling error at 55% while Natchez Trace was the lowest at 12%. In order to provide a more precise estimate of the total population average (Table 6) stratified sampling formulas were used to calculate an overall per acre mean, standard error, and confidence interval. Individual state forests were considered subpopulations. Total estimate of volume for the 15 state forests (Table 8) was included to provide a total estimate for the current inventory. The mean per acre board feet (Int. ¼) was 8,159.10 with a sampling error of 509.38 or 6.24%. Plot allocation (Table 9) was calculated using a proportional method in which the larger the area the more plots it received and the optimum allocation method, which takes variability into consideration (Avery and Burkhart 2002). The results of using a proportional allocation would result in 6 state forests receiving a more intense sample (Bledsoe, Chickasaw, Chuck Swan, Franklin, Natchez Trace, and Pickett). Nine state forests could use inventories with a decreased intensity (Cedars, John Tully, Lewis, Lone Mountain, Martha Sundquist, Prentice Cooper, Scott, Stewart, and Standing Stone). Natchez Trace would receive the largest number of new plots at 24. Optimum allocation allows for the smallest possible standard error to be calculated for the overall mean. The overall number of plots was not adjusted from the original sample design. While the proportional is solely based on area, the optimal is based on the overall

Table 8. Overall sampling error at the 95 % level expressed as a percent of the mean for all 15 State Forests

State Forest	Sampling Error(%)
John Tully	55%
Cedar	39%
Scott	37%
Lone Mountain	36%
Stewart	34%
Bledsoe	32%
Lewis	28%
Standing Stone	27%
Franklin	27%
Chickasaw	21%
Martha Sundquist	21%
Chuck Swan	19%
Pickett	19%
Prentice Cooper	15%
Natchez Trace	12%

Table 9. Estimates of overall board feet per acre using stratified sampling formulas. Mean and Confidence Interval (95% level) reported in board feet, Total Area in acres, and Total Board Feet reported in MMBF

Mean	8159.10
Confidence Interval	8159.1+/-509.38
(LCL , UCL)	(7649.72 , 8668)
Total Area	145922
Total Board Feet	1190.59+/-74.33
(LCL , UCL)	(1116 , 1265)

Table 10. Allocation of 711 plots using proportional and optimal allocation methods contained in stratified sampling design.

State Forest	Current Plots	Proportinal Allocation	Optimum Allocation
Bledsoe	30	38	30
Cedars	31	25	11
Chickasaw	50	59	80
Chuck Swan	95	112	122
Franklin	27	28	24
John Tully	20	10	10
Lewis	20	6	4
Lone Mountain	20	17	11
Martha Saunquist	20	9	8
Natchez Trace	144	168	225
Pickett	82	86	71
Prentice Cooper	96	87	59
Scott	23	14	6
Standing Stone	33	34	35
Stewart	20	19	15
Sum	711	711	711

variance as well as the area of each stratum. Under the optimum allocation Natchez Trace would receive the most plots at 225 while Lewis would receive the least at 4.

To assess the task of reallocating plots, two state forests were investigated, Natchez Trace and Chickasaw. Natchez Trace was chosen due to the results of the proportional and optimum allocation, while Chickasaw was chosen due to the similarities it shares with Natchez Trace geographically and from a comparison stand point. The results of the inventory were compiled for these two state forests based on forest types (Tables 10 and 12). Natchez Trace has 4 forest types, Loblolly/Shortleaf, Oak-Pine, Oak-Hickory, and Upland Hardwoods. Oak-Hickory makes up the majority of the forest at 60%, while Upland Hardwoods is the least common at 2%. Table 10 shows the estimates of board feet per acre for the different forest types. Ten plots did not contain enough information for the algorithm to calculate a forest type, due to the lack of information; therefore it was listed as no stocking. The current sampling error by forest type is highest for Upland Hardwoods and least for Oak-Hickory. In order to achieve an allowable error of 20% of the mean chosen as an arbitrary point, but often used in forestry the results can be seen in Table 11. Loblolly/Shortleaf would see a decrease in plots from 24 to 19, Oak-Pine would increase from 19 to 44, Oak-Hickory would decrease from 87 to 41, and Upland Hardwoods would increase from 4 to 51. Applying the percentage increase from the results of the desired sampling error of 20% we can allocate the proportional number of 168 and the optimum of 225 accordingly. Under the proportional method, Loblolly/Shortleaf would receive 20, Oak-Pine 48, Oak-Hickory 44, and Upland Hardwoods 55. The optimum allocation would result in Loblolly receiving 26, Oak-Pine 64, Oak-Hickory 59, and Upland Hardwoods 74. Chickasaw State Forest had 4 forest types, Loblolly/ Shortleaf, Oak-Pine, Oak-Hickory, and Bottomland Hardwoods (Table 12). The distribution of Chickasaw is described in Table 13.

Table 11. Forest type estimates of VPA (board feet) of Natchez Trace State Forest. Confidence interval and sampling error calculated at the 95% level.

Forest Type	Loblolly/Shortleaf	Oak-Pine	Oak-Hickory	Upland Hardwoods	No Stocking
Mean	19,259	14,633	10,985	10,537	*
n	24	19	87	4	10
±	3,311	4,674	1,471	11,829	*
SE%	17%	32%	13%	112%	*
CV	41%	66%	63%	71%	*

Table 12. Sampling intensity to reach a desired sampling error of 20% of the mean at the 95% confidence level

Forest Type	n
Loblolly/Shortleaf	19
Oak-Pine	44
Oak-Hickory	41
Upland Hardwoods	51

Table 13. Forest type estimates of VPA (board feet) of Chickasaw State Forest. Confidence interval and sampling error calculated at the 95% level.

Forest Type	Loblolly/Shortleaf	Oak-Pine	Oak-Hickory	Bottomland Hardwoods
Mean	9,399	9,893	12,290	472
n	9	4	37	1
±	7,493	13,821	2,670	*
SE %	80%	140%	22%	*
CV	104%	88%	67%	*

Table 14. Sampling Intensity to reach a sampling error of 20% of the mean at the 95% confidence level on Chickasaw State Forest

Forest Type	n
Loblolly/Shortleaf	106
Oak-Pine	77
Oak-Hickory	46

To compare the variability of the forest types between Natchez Trace and Chickasaw, Coefficient of Variation (CV) was calculated. Where Natchez Trace has a mean of 19,259 board feet per acre for Loblolly and Chickasaw has a mean of 9,399, little can be concluded regarding variation. The CV is a ratio of the standard deviation to the mean which makes it insensitive to size, allowing for a comparison of relative variability. The variability for Chickasaw was 104% while Natchez had a variability of 41% for Loblolly/Shortleaf. Tables 10 and 12 contain the measures of variability for all forest types of both state forests. This analysis could be conducted for each state forest and region; however, this is beyond this investigation.

Chapter V
Discussion

This section will discuss the results, draw conclusions for those results requiring further explanation, and provide recommendations based on the information presented. The discussion will explore and describe the implications of the results; however, it will not try to infer the exact impacts on management. Variance and quality are assumed to be cumulative, implying that a loss of precision or accuracy at the tree level will impact the plot, state forest, and overall estimates.

Tree level Quality

Data quality can affect population as well as future growth estimates substantially. As described previously, an estimate of current inventory is crucial for calculating growth. Trees that fell outside of the plot but were included would overestimate the VPA. Trees containing no value for percent cull that were assumed correct must be verified and recorded as zero, rather than “blank” for cull percent. Species code errors need to be verified and compared following each measurement cycle. It is possible to infer the likelihood of potential errors for certain species from the initial inventory, e.g., species that are outside of native or known ranges, but this is not definitive. The second measurement of the CFI plot will provide more insight into corrections that need to be made to species codes.

Total height was collected in order to implement the volume model and equation contained in FVS and to serve as a measure of growth. Figure 2 was included to provide an example of the trend and pattern expected between DBH and total height. To be more descriptive, the relationship between DBH and total height is often linear for small ranges of DBH and curvilinear for a wider range of DBH of a given species (Avery and Burkhart 2002). The slope or gradient of a curve should be positive and steeper near the origin, then decrease further from the origin. All 15 state forests showed some indication of a curvilinear relationship across the full range of DBH recorded. Rounding total height was detected on two state forests (Natchez Trace and Bledsoe) (Figure 3). The presence of straight lines parallel with the x-axis implies the height estimate was rounded, while straight lines parallel with the y-axis implies the diameter estimates were grouped. Rounding will result in an inability to produce precise measures of growth following the second measurement. A loss of precision when predicting volume of the current inventory can be expected for these two state forests (where total height rounding was detected) as well (Figure 4). The implications of rounding are likely small in terms of volume calculations, due to the taper of this section of the tree. However, the actual difference is unknown. Height errors due to transcription, if not identified, could result in an over or underestimation of volume (Figure 5). The use of an equation when calculating volume will likely not result in a recognizable error when a positive number is present; hence there is a need to distinguish these points prior to running any calculations.

The use of subjective attributes such as merchantable height to calculate volume proved to be inconsistent in terms of upper stem limits (Figure 7). Figure 6 was included for reference of an ideal distribution, an increasing upper limit, and increased height variability as diameter increases. Species vary in terms of taper, the percent change between the upper stem diameter inside bark and the DBH inside bark. Several state forests contained estimates of taper that appeared extreme, however. It is unclear if there is a lack of understanding in regards to the limits of merchantability or if the methodology did not specify clearly the upper stem diameter. The distributions of merchantable heights by diameter appear unlikely. As a result, total height was used for volume calculations. Furthermore, to use merchantable height, a measure of form class or taper is required. The amount of labor involved in measuring taper may prove to be too time consuming for the objectives of this inventory. Generally, merchantability is measured in

16 foot logs and half logs. The use of these units has the potential to not capture growth between two consecutive measurement periods on a 5 year increment and to overestimate growth in the 3^{rd} or 4^{th} measurement period. To reduce this potential for sudden ingrowth of a log or half-log a finer level of granularity should be pursued. Total height, while often inaccurate, can prove more precise depending on the crew or individual measuring the tree. To improve on this it should be specified in the inventory methods that all total height measurements should be to the nearest foot and measured, not estimated.

The use of tree age in forest management is well documented. Many decisions are based around the changes across time, as well as the desired level of production for a certain amount of time. There is a strong need and desire for accurate estimates of age in forest management (Davis et al. 1960). Figure 8 indicates that there are issues surrounding the age estimates. The cause of the inaccuracies is unclear, but there are two points to be made. First, if no age was recorded on a plot, a '0' could have been the default, explaining the high level of volume at age 0. Second, on some plots the trees measured off-plot were a different age than the ones contained on the plot. Logically, as stand age increases volume should increase, barring intermediate harvests. However, this was not found at the forest level or by forest types within a state forest (Figure 9). While there is variation based on productivity there should be some visible pattern or increase from a subjective point of view. These results should be considered when determining the usefulness of measures such as Mean Annual Increment (MAI). MAI in terms of harvest scheduling or allowable cut is the volume at rotation age over the length of the rotation. MAI outside of the context of allowable cut could be used to determine the average rate of growth at the point measured. This is not a linear relationship in either instance, implying that the average growth rate changes over the length of a rotation, and must be assessed appropriately. The use of a single MAI to calculate allowable cut would not be possible. Periodic Annual Increment (PAI) is the more precise measure of growth and directly translates into allowable cut. Periodic is a more targeted measure of growth due to the growth being measured and the increment being the time between the two measures. The ability to correlate PAI with stand age should be considered, based on these results. Measures should be taken to correct the inaccuracies if there is a need to apply PAI to a stand age. Lacking an understanding of the true age of the forest can have substantial impacts on forest management.

Volume per Acre Outliers

The ability to distinguish errors that did not appear as extreme values is difficult, if not impossible. Box plots were generated for each state forest at the plot level in an attempt to identify potential errors or odd occurrences. Chickasaw State Forest was chosen as an example. All 15 state forests should be further investigated using this analysis. This process identified plot 04032 as an outlier which is estimated to contain 44,015 board feet per acre (Figure 10). Removing this plot reduced the lower limit estimate by nearly 300 and the upper by 1000 board feet (Table 3). Upon further investigation this revealed a relatively high amount of basal area ($198ft^{2)}$ which should be verified. Some of the outliers contained in the data could be accurate measures on the ground. The small sample sizes associated with CFI demand that each plot be as precise and accurate as possible. All outlier plots should be investigated for their accuracy. If a plot is considered accurate, it becomes the division's decision to determine if this plot falls within an area that is unique or not representative of the remaining area represented by the plot. The discussion on "handling" outliers on the state forest is beyond this study.

FVS vs Traditional

When determining the utility of a specific model it is important to evaluate and verify the outputs. Board feet estimates from FVS were compared to traditional calculations that were calculated using an Excel spreadsheet. The interest was not in FVS's ability to grow the trees but in the current estimate of volume by species at the plot level. Lasher's equation (USDA 2013) used by FVS to estimate board feet was compared to the d^2H equation (Oswalt et al. 2011) FIA uses to estimate board feet. Mean board feet per acre was compared between FVS, Traditional (FIA Eq.), and Traditional outliers removed. This analysis of different methods was not used to check the accuracy of the volume estimates, but to identify the potential for different estimates when using different models and equations. Fourteen of the estimates of FVS were greater than the estimate of the traditional method with one exception - John Tully (Tables 3, 4, and 5). The trend of over-estimation was investigated at the tree level to verify that there was not an expansion factor issue (Figure 12). The process of running FVS through SUPPOSE did not contain a reduction of cull for the merchantable portion of the tree. The consistent over-estimation can be partially attributed to the traditional method having a reduction of cull % from the final volume (Figure 13). This, however, does not explain all of the variation. To further investigate the point of variation, cubic foot volume was calculated and compared, revealing a 3% difference between the two methods (Figure 14). FVS uses Clark's profile model (USDA 2013) and the traditional came from the d^2H equation. Comparing the board foot estimates of the same trees resulted in a difference of 14% (Figure 15). The log rule associated with the Lasher equation used by FVS in not clear (USDA 2013). This could explain some of the variation, but the traditional estimates are based on Int. ¼ and should be larger for smaller diameters if the effect is due to a log rule reduction. The definite cause for different estimates of board feet also is not clear, other than they can be attributed to either the Lasher equation or BD00049. A thorough evaluation of the differences between these two equations should be conducted and the results compared to local volume tables or equations to identify the most accurate estimator.

Including a % cull reduction in the FVS model to account for the over estimation that is not due to the difference in the equations is recommended also.

Region estimates collected by the USFS FIA (Table 6) were calculated to present a third volume estimate. The estimates were not compared using confidence intervals due to the differences between methodologies and populations being potentially different. Generally, the unit estimates reported by FIA were similar to the estimates in this examination with the exception of John Tully State Forest. This can most likely be attributed to the management activities conducted on the state forest as well as the current structure of the forest. The average age of John Tully is 20.25 years, which resulted in a difference when comparing it to estimates that have had different management (see history of John Tully in overview of State Forests).

Design

The overall design was evaluated by assessing the sampling error as a percent of the mean by state forest (Table 7). The over sampling of Natchez Trace, Prentice Cooper, Pickett, and Chuck Swan could be redistributed to those state forests with higher sampling errors. This assumes that 711 is the total number of possible plots based on a financial limit. If the desire is to have a large enough sample to assume a normal distribution, the minimum should be set, by convention, to 30. If this condition is not satisfied a t-distribution should be used for estimates of confidence intervals and sample size calculations. The stratified estimate of total population was 1.1 billion board feet $\pm$ 74 million board feet at the 95% level (Table 8). This estimate was derived using the traditional calculations, considered to be the more conservative estimate based on the previous results. To provide a more precise estimate of the overall mean VPA, plots should be redistributed (Table 9). The optimum allocation will still over sample the same four state forests, due to the optimal allocation process containing both variability and area in its formula. Overall population estimates may not be the most important estimate of this inventory, however.

Changing the design and allocation of the CFI plots requires an understanding of the importance of the desired outcomes. The redistribution most likely should be based on the stratification of each individual state forest, depending on the variance associated with each stratum within forests. The overall sampling error associated with Natchez Trace was 12% and Chickasaw 22% (Table 7). This result is potentially misleading in terms of assessing the different forest types within the state forest, which are often used in making management decisions or analyzing policies. When delineated based on forest type, the lowest sampling error is 13% for Oak-Hickory and the highest is 112% for upland hardwoods (Table 10). This implies the estimate of Natchez Trace overall is acceptable, but the use of the data for examining specific forest types could be limited to a portion of the state forest. Likewise, for Chickasaw the lowest percent sampling error by forest type was 24% for Oak-Hickory while the largest was 157% for loblolly. While the overall mean per acre estimate provides insight into the forest-by-forest comparison, it does not provide insight into management decisions that should take place within each forest. The use of stratification within a state forest is not possible with the current design from a standpoint of increasing volume estimate precision with the same data. The plot-to-area ratio prohibits the use of stratification due to each plot having equal weight. This nullifies the benefit of a weighted average as well as the intensification process. Therefore, each state forest should be reevaluated for the percent of each forest type that comprises the total population. The use of the forest type algorithm used by FVS (Arner et. al 2001) would provide a classification system to describe the different stratum. A more precise estimate of the overall population means by state forest could be achieved by using stratification techniques (Avery and

Burkhart 2002). The classification process will not require additional permanent plots but the use of historical plot tally data or cruise data can be used. TDF should determine the appropriate grouping of forest types to avoid having too many strata. A desired or acceptable level of sampling error should be determined before reallocating plots. Table 11 depicts the number of plots needed to reach a 20% sampling error at the 95% level for the forest types on Natchez Trace. This percent is arbitrary but is included for reference. It may not be appropriate based on the desired results for the division. Loblolly/Shortleaf and Oak-Hickory were over sampled to reach 20% (Table 10). This creates an opportunity to reallocate plots to different forest types without incurring more cost or effort and achieving a desired level of confidence. Chickasaw was included as an example where a single forest type was not over sampled. If the number of plots needed cannot be implemented, TDF should determine the impacts of each forest type on production to determine the course of action for increasing confidence in the most important forest types.

The use of forest type grouping by region will provide direct comparisons between state forests to assess the management activities, growth rates, policies, and changes. The volume of Loblolly/Shortleaf on Chickasaw (Table 12) is estimated to be 9,399 board feet per acre with a CV of 104% while on Natchez Trace (Table 10) is estimated to be 19,259 with a CV of 41%. It is important to consider the amount of relative variation (CV), age, productivity, climate, aspect, and management when making inference between two state forests. Determining the appropriate inference to make in regard to the differences between state forests is beyond the scope of this investigation.

Chapter VI
Recommendations

Field Work

The use of merchantable height should be reevaluated to clearly specify the desired upper stem diameter. This measure should also be avoided when comparing growth due to its subjective nature. For this reason, total height, being a more objective measure, should be used when determining volume. Rounding total height will present issues in future growth estimates. The methodology for measuring total height should specify that total height should be measured to the nearest foot. To better understand the measure of quality, tree grade should be collected. This practice will enhance the results in making management decisions. Lacking an understanding of quality in a hardwood region presents unique situations in terms of the value of stands. Trees recorded as outside the plot should be carefully evaluated to determine their exact location. The methodologies should specify that all fields should be reported, even those containing zeroes, to remove the ambiguity in measurements such as cull.

Units

This study presented volume estimates in board feet due to the practice of marketing the product in such units. This was based on custom and not on the accuracy of the measure. Cubic foot estimates do not suffer the same problems associated with board feet estimates. Board feet are subject to different log rules and at times these can be unknown as seen in FVS. Growth analysis should be computed in cubic feet and then converted to the log rule of choice. The use of total height presents issues when determining the merchantable portion of the tree. Local volume tables should be compared to estimates of FVS and FIA equations to determine the most accurate estimate of board feet. While board feet is crucial in making management or financial decisions the use of cubic feet or basal area as a measure of growth should be considered.

Age

The current assessment of plot age should be reevaluated. The methodology should specify that the trees being used to determine age must be dominant or co-dominant and appear to have been present during the entire life of the stand, meaning the trees did not grow into a dominant position after the original cohort established dominance. The use of the age numbers should also be carefully interpreted in the context of allowable cut.

FVS

It is important to note that model validation and model verification differ. Validation is testing a model's prediction to observed or measured values. Verification is the process of determining if the model is using its components correctly. FVS should be validated for accuracy, the average error between the predicted and observed values and precision, the average deviation of predicted values from the true value. The validation process should include comparing predicted board feet estimates to measured values or predicted mortality to measured mortality. The verification process should determine if the model is implementing the correct expansion factors and growth equations. Clark's model should be compared outside of SUPPOSE to verify that the correct equation is being used. All tree list files should be analyzed to verify expansion factors. While the goodness of non-calibrated FVS estimates may suffice in some measurements it may be important to calibrate estimates such as board feet. All per acre estimates should be compared to historical estimates to determine how reasonable they are. There are many statistical techniques for model testing that are beyond the scope of this investigation. The USFS produced a "Model Validation Protocol for FVS" that would serve well as the starting point for model validation. (USDA 2010)

Sampling Design

The current sampling design should be revised to a stratified sampling design. This will allow for more precise estimates within each state forest as well as overall. TDF should determine the appropriate number of strata as well as the grouping by species to use. The number of plots should be redistributed based on the variance of each state forest as well as the acceptable sampling error.

The objectives of this study were to evaluate the quality, use of FVS, and overall design. The assessment of data quality will need to be repeated after each measurement cycle. The future use of FVS will need to be determined by TDF based on the findings in this study. A model is only as good as its data and cannot over compensate for error. The overall design may take multiple measurement cycles to stabilize depending on the variation associated with the growth by different strata. While the objectives of this study were addressed, it is worth noting, that the ability to meet all of TDF's original objectives may not be realistic given the intensity as well as the level of measurement. The ability to determine growth by species can be addressed for sawtimber trees, but may prove difficult with other tree classes i.e., seedling or sapling. Addressing growth and yield models becomes increasingly difficult when attempting to grow trees from "seed to cut". Modeling or predicting the growth for closed canopy sawtimber trees may be possible given the data, but further modeling into other stages in forest succession may prove to be highly erratic. This however should not be seen as a reason to not continue on with the measurements. There are multiple other outputs that can be generated using the data collected in this study. The generation of local height equations should be considered a high priority once the data quality is at an acceptable level.

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APPENDICES

APPENDIX A

SPECIES CODES AND VOLUME COEFFICIENTS

Table 15. Species code and equation used by each species (Oswalt et. al. 2011).

SPCD	Common name	Species number	SPCD_EQ[a]	SPCD	Common name	Species number	SPCD_EQ[a]
10	Fir spp.	10	10	320	Norway maple	320	318
12	Balsam fir	12	10	321	Rocky Mountain maple	321	Chojnacky 1988
16	Fraser fir	16	10	323	Chalk maple	323	317
43	Atlantic white-cedar	43	43	330	Buckeye, horsechestnut	330	330
58	Pinchot juniper	58	Chojnacky 1994	331	Ohio buckeye	331	330
59	Redberry juniper	59	Chojnacky 1994	332	Yellow buckeye	332	330
61	Ashe juniper	61	Chojnacky 1994	334	Texas buckeye	334	330
63	Alligator juniper	63	Chojnacky 1994	341	Ailanthus	341	999
66	Rocky Mountain juniper	66	Chojnacky 1994	345	Mimosa, silktree	345	491
67	Southern redcedar	67	67	356	Serviceberry	356	999
68	Eastern redcedar	68	68	367	Pawpaw	367	999
69	Oneseed juniper	69	Chojnacky 1994	370	Birch spp.	370	370
90	Spruce spp.	90	90	371	Yellow birch	371	371
93	Engelmann spruce	93	90	372	Sweet birch	372	371
97	Red spruce	97	90	373	River birch	373	370
106	Common pinyon	106	Chojnacky 1994	379	Gray birch	379	371
107	Sand pine	107	107	381	Chittamwood, gum bumelia	381	999
110	Shortleaf pine	110	110	391	American hornbeam,		
111	Slash pine	111	111		musclewood	391	999
115	Spruce pine	115	115	400	Hickory spp.	400	400
121	Longleaf pine	121	121	401	Water hickory	401	400
122	Ponderosa pine	122	Hann and Bare 1978	402	Bitternut hickory	402	400
123	Table Mountain pine	123	123	403	Pignut hickory	403	400
126	Pitch pine	126	126	404	Pecan	404	400
128	Pond pine	128	128	405	Shellbark hickory	405	400
129	Eastern white pine	129	129	406	Nutmeg hickory	406	400
131	Loblolly pine	131	131	407	Shagbark hickory	407	400
132	Virginia pine	132	132	408	Black hickory	408	400
140	Mexican pinyon pine	140	Chojnacky 1994	409	Mockernut hickory	409	400
202	Douglas-fir	202	Hann and Bare 1978	410	Sand hickory	410	400
221	Baldcypress	221	221	421	American chestnut	421	999
222	Pondcypress	222	222	422	Allegheny chinkapin	422	999
241	Northern white-cedar	241	241	423	Ozark chinkapin	423	999
260	Hemlock spp.	260	260	450	Catalpa spp.	450	999
261	Eastern hemlock	261	260	451	Southern catalpa	451	999
262	Carolina hemlock	262	260	452	Northern catalpa	452	999
299	Unknown conifer	299	10	460	Hackberry spp.	460	460
310	Maple spp.	310	318	461	Sugarberry	461	460
311	Florida maple	311	311	462	Hackberry	462	460
313	Boxelder	313	313	463	Netleaf hackberry	463	460
314	Black maple	314	317	471	Eastern redbud	471	999
315	Striped maple	315	999	481	Yellowwood	481	491
316	Red maple	316	316	491	Flowering dogwood	491	491
317	Silver maple	317	317	492	Pacific dogwood	492	491
318	Sugar maple	318	318	500	Hawthorn	500	999
319	Mountain maple	319	999	501	Cockspur hawthorn	501	999

continued

Table 16. Species code and equation used by each species (Oswalt et. al. 2011).

SPCD	Common name	Species number	SPCD_EQ[a]	SPCD	Common name	Species number	SPCD_EQ[a]
502	Downy hawthorn	502	999	742	Eastern cottonwood	742	740
510	Eucalyptus	510	999	743	Bigtooth aspen	743	741
521	Common persimmon	521	521	744	Swamp cottonwood	744	740
531	American beech	531	531	745	Plains cottonwood	745	740
540	Ash spp.	540	540	755	Mesquite	755	Chojnacky 1988
541	White ash	541	540	756	Western honey mesquite	756	Chojnacky 1988
543	Black ash	543	540	758	Screwbean mesquite	758	Chojnacky 1988
544	Green ash	544	540	760	Cherry and plum spp.	760	999
545	Pumpkin ash	545	540	761	Pin cherry	761	999
546	Blue ash	546	540	762	Black cherry	762	762
548	Carolina ash	548	999	763	Chokecherry	763	762
551	Waterlocust	551	999	765	Canada plum	765	999
552	Honeylocust	552	552	766	Wild plum	766	999
555	Loblolly-bay	555	555	800	Oak deciduous	800	812
571	Kentucky coffeetree	571	999	802	White oak	802	802
580	Silverbell	580	580	804	Swamp white oak	804	804
591	American holly	591	591	806	Scarlet oak	806	806
600	Walnut	600	601	808	Durand oak	808	808
601	Butternut	601	601	809	Northern pin oak	809	830
602	Black walnut	602	602	810	Emery oak	810	Chojnacky 1988
605	Texas walnut	605	601	812	Southern red oak	812	812
611	Sweetgum	611	611	813	Cherrybark oak	813	813
621	Yellow-poplar	621	621	816	Bear oak, scrub oak	816	842
641	Osage-orange	641	999	817	Shingle oak	817	817
650	Magnolia spp.	650	652	819	Turkey oak	819	817
651	Cucumbertree	651	651	820	Laurel oak	820	820
652	Southern magnolia	652	652	822	Overcup oak	822	822
653	Sweetbay	653	653	823	Bur oak	823	823
654	Bigleaf magnolia	654	651	824	Blackjack oak	824	824
655	Mountain magnolia	655	651	825	Swamp chestnut oak	825	825
660	Apple spp.	660	999	826	Chinkapin oak	826	826
680	Mulberry spp.	680	680	827	Water oak	827	827
681	White mulberry	681	999	828	Nuttall oak	828	813
682	Red mulberry	682	680	830	Pin oak	830	830
691	Water tupelo	691	691	831	Willow oak	831	831
692	Ogechee tupelo	692	999	832	Chestnut oak	832	832
693	Blackgum	693	693	833	Northern red oak	833	833
694	Swamp tupelo	694	694	834	Shumard oak	834	834
701	Eastern hophornbeam	701	999	835	Post oak	835	835
711	Sourwood	711	999	836	Delta post oak	836	836
712	Paulownia, empress-tree	712	999	837	Black oak	837	837
721	Redbay	721	999	838	Live oak	838	838
722	Water-elm, planertree	722	999	840	Dwarf post oak	840	840
731	Sycamore	731	731	841	Dwarf live oak	841	840
740	Cottonwood and poplar spp.	740	740	842	Bluejack oak	842	842
741	Balsam poplar	741	741	843	Silverleaf oak	843	Chojnacky 1988

continued

Table 17. Species code and equation used by each species (Oswalt et. al. 2011).

SPCD	Common name	Species number	SPCD_EQ[a]	SPCD	Common name	Species number	SPCD_EQ[a]
844	Oglethorpe oak	844	842	970	Elm spp.	970	970
845	Dwarf chinakapin oak	845	842	971	Winged elm	971	970
846	Gray oak	846	Chojnacky 1988	972	American elm	972	970
901	Black locust	901	901	973	Cedar elm	973	970
911	Palmetto spp.	911	999	974	Siberian elm	974	970
919	Western soapberry	919	999	975	Slippery elm	975	970
920	Willow	920	920	976	September elm	976	970
921	Peachleaf willow	921	920	977	Rock elm	977	970
922	Black willow	922	920	989	Mangrove	989	999
927	White willow	927	920	992	Melaleuca	992	999
931	Sassafras	931	999	993	Chinaberry	993	999
935	American mountain-ash	935	999	994	Chinese tallowtree	994	999
950	Basswood spp.	950	950	995	Tung-oil-tree	995	999
951	American basswood	951	950	996	Smoketree	996	999
952	White basswood	952	950	997	Russian-olive	997	999
953	Carolina basswood	953	950	999	Unknown hardwood	999	999

Table 18. Coefficients by Species (Table 15) for FIA cubic foot volume (equation CU000067) from a 1' stump to a 4" top (Oswalt et al. 2011).

	Coefficients	
	Sawtimber	
SPCD_EQ	D1	D2
10	0.879371	0.001845
43	1.668389	0.001822
60	-0.104252	0.002145
67	-0.104252	0.002145
68	-0.104252	0.002145
90	0.879371	0.001845
107	0.377006	0.002239
110	-0.687060	0.002211
111	-0.611225	0.002088
115	0.118241	0.002168
121	-0.443190	0.002165
123	0.870587	0.002205
126	-0.379670	0.002171
128	-0.279600	0.002093
129	0.604023	0.001857
131	-0.658316	0.002107
132	0.333364	0.002118
221	1.757944	0.001752
222	1.044195	0.001712
241	0.879371	0.001845
260	-0.216081	0.001798
311	-0.202284	0.001818
313	0.518892	0.001802
316	0.680247	0.001742
317	0.518892	0.001802
318	0.352087	0.001838
330	0.218924	0.001833
370	0.543581	0.001751
371	0.169526	0.001893
400	-0.793179	0.001884
460	0.500522	0.001670
491	-0.202284	0.001818
521	-1.173042	0.002028
531	1.468854	0.001765
540	0.172701	0.001851
552	-0.202284	0.001818
555	0.735415	0.001775
580	0.518892	0.001802
591	0.762909	0.001965
601	0.518892	0.001802
602	0.421890	0.001596
611	-0.629168	0.001955
621	0.485232	0.001807

	Coefficients	
	Sawtimber	
SPCD_EQ	D1	D2
651	0.735415	0.001775
652	0.735415	0.001775
653	0.735415	0.001775
680	-0.202284	0.001818
691	1.749738	0.001659
693	0.690730	0.001767
694	1.284413	0.001760
731	2.326908	0.001649
740	0.518892	0.001802
741	0.518892	0.001802
762	-0.607326	0.001957
802	0.148434	0.001880
804	0.248363	0.001823
806	0.003343	0.001887
808	-0.085426	0.001783
812	-0.085426	0.001783
813	1.212451	0.001791
817	0.248363	0.001823
820	0.846919	0.001840
822	0.248363	0.001823
823	0.248363	0.001823
825	0.376354	0.001818
826	0.248363	0.001823
827	1.195722	0.001795
830	0.248363	0.001823
831	-0.460755	0.001904
832	-0.069945	0.001818
833	0.793996	0.001779
834	0.248363	0.001823
835	0.301286	0.001791
837	-0.515373	0.001775
838	0.344387	0.001580
899	-0.035319	0.001807
824	-0.035319	0.001807
840	-0.035319	0.001807
842	-0.035319	0.001807
836	-0.035319	0.001807
901	0.603856	0.001483
920	0.518892	0.001802
950	0.034400	0.001882
970	-0.316500	0.001851
999	0.823520	0.001630

Table 19. Coefficients by species (Table 15) for converting CU000067 to cubic foot volume of the saw log portion of the tree (Equation CU000069) (Oswalt et al. 2011).

	Coefficients			Coefficients	
SPCD_EQ	H1	H2	SPCD_EQ	H1	H2
10	0.987226	-4.396825	651	1.016073	-15.025004
43	1.006045	-4.962611	652	1.016073	-15.025004
60	0.987563	-4.027958	653	1.005781	-14.518615
67	0.987563	-4.027958	680	0.970888	-12.114880
68	0.987563	-4.027958	691	0.973498	-12.868316
90	0.987226	-4.396825	693	0.967984	-13.248708
107	1.005598	-4.595382	694	0.975950	-12.390384
110	1.017129	-5.035009	731	0.977294	-16.118257
111	1.018317	-5.202751	740	0.993648	-14.095485
115	1.012739	-5.021693	741	0.993648	-14.095485
121	1.007357	-4.383530	762	0.967082	-11.074226
123	1.019967	-3.831951	802	0.984900	-12.754068
126	0.990799	-4.465552	804	0.970577	-11.942936
128	1.015474	-4.750206	806	0.985882	-12.214161
129	0.985634	-4.484123	808	1.004199	-14.775319
131	1.018534	-5.661877	812	1.004199	-14.775319
132	0.988876	-4.339684	813	1.011594	-16.475117
221	0.976887	-6.372196	817	0.970577	-11.942936
222	0.982780	-4.980440	820	0.962858	-10.854013
241	0.987226	-4.396825	822	0.970577	-11.942936
260	0.979075	-4.860084	823	0.970577	-11.942936
311	0.970888	-12.114880	825	1.022046	-16.551048
313	0.993648	-14.095485	826	0.970577	-11.942936
316	0.957247	-12.838405	827	0.951738	-10.055145
317	0.993648	-14.095485	830	0.970577	-11.942936
318	0.986670	-13.285690	831	0.976525	-12.140112
330	0.993648	-14.095485	832	0.968616	-11.614055
370	0.990427	-14.816790	833	0.925404	-10.109039
371	0.970888	-12.114880	834	0.970577	-11.942936
400	0.975054	-11.967499	835	0.981927	-11.738632
460	0.884844	-10.966955	837	0.973573	-13.391067
491	0.970888	-12.114880	838	0.956531	-10.588513
521	1.017439	-13.174563	899	0.970577	-11.942936
531	0.939240	-10.377629	824	0.970577	-11.942936
540	0.990354	-13.866570	840	0.970577	-11.942936
552	0.970888	-12.114880	842	0.970577	-11.942936
555	1.016073	-15.025004	836	0.970577	-11.942936
580	0.993648	-14.095485	901	0.920003	-9.999206
591	0.970888	-12.114880	920	0.993648	-14.095485
601	0.993648	-14.095485	950	0.977669	-12.161698

Table 20. Coefficients by species (Table 15) for converting cubic foot volume from a 1' stump to a 4" top to board feet volume (equation BD000049).(Oswalt et al. 2011)

	Coefficients			Coefficients	
SPCD_EQ	I1	I2	SPCD_EQ	I1	I2
10	-32.968494	40.900754	651	-43.831114	51.473501
43	-36.443637	44.723860	652	-43.831114	51.473501
60	-31.928229	40.082406	653	-32.151472	38.751286
67	-31.928229	40.082406	680	-33.469593	40.320487
68	-31.928229	40.082406	691	-62.218744	70.635109
90	-32.968494	40.900754	693	-42.670508	50.056472
107	-39.657770	48.447531	694	-45.206541	53.020202
110	-40.778119	49.493703	731	-45.419797	53.050199
111	-44.573295	53.682127	740	-46.585716	54.641538
115	-30.697896	38.676749	741	-46.585716	54.641538
121	-37.533739	46.221683	762	-46.585716	54.641538
123	-36.169514	44.588514	802	-40.853917	48.314853
126	-47.178011	56.153368	804	-39.207446	46.599115
128	-39.081750	47.663171	806	-41.609919	49.261334
129	-38.021863	46.299422	808	-39.405006	46.869861
131	-45.233296	54.320184	812	-39.405006	46.869861
132	-30.487486	37.943803	813	-57.253809	66.161822
221	-39.852794	47.638868	817	-39.207446	46.599115
222	-37.780331	45.512476	820	-39.258381	46.972932
241	-32.968494	40.900754	822	-39.207446	46.599115
260	-35.837266	43.682868	823	-39.207446	46.599115
311	-33.469593	40.320487	825	-52.928852	61.522970
313	-46.585716	54.641538	826	-39.207446	46.599115
316	-37.873060	44.918110	827	-33.821051	41.219217
317	-46.585716	54.641538	830	-39.207446	46.599115
318	-23.292189	29.478650	831	-46.836658	55.060205
330	-46.585716	54.641538	832	-37.716845	44.770685
370	-23.210675	29.141604	833	-34.016058	40.773236
371	-33.469593	40.320487	834	-39.207446	46.599115
400	-43.385922	51.122382	835	-41.637640	49.438943
460	-46.585716	54.641538	837	-42.235900	49.659282
491	-33.469593	40.320487	838	-32.557196	39.284646
521	-33.469593	40.320487	899	-39.207446	46.599115
531	-7.036861	11.665187	824	-39.207446	46.599115
540	-44.046785	51.632536	840	-39.207446	46.599115
552	-33.469593	40.320487	842	-39.207446	46.599115
555	-43.831114	51.473501	836	-39.207446	46.599115
580	-46.585716	54.641538	901	-7.456203	11.992934
591	-33.469593	40.320487	920	-46.585716	54.641538
601	-46.585716	54.641538	950	-37.777411	44.944982
602	-16.280751	21.457858	970	-33.168491	39.961348
611	-50.712592	59.264535	999	-39.207446	46.599115
621	-54.639851	63.549737			

APPENDIX B

DISTRIBUTION OF AGE BY STATE FOREST

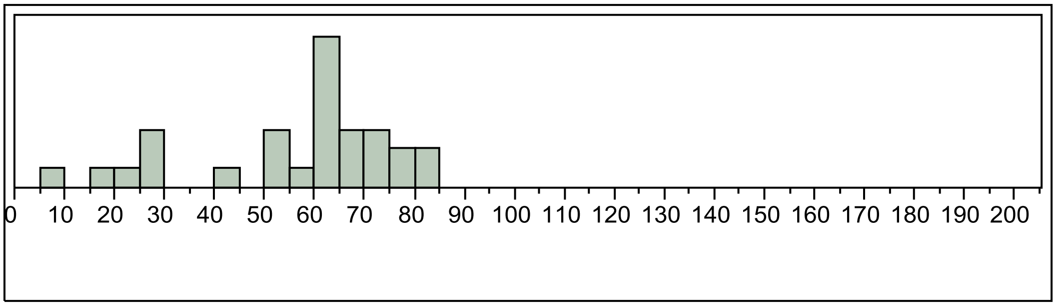

Figure 18. Bledsoe State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

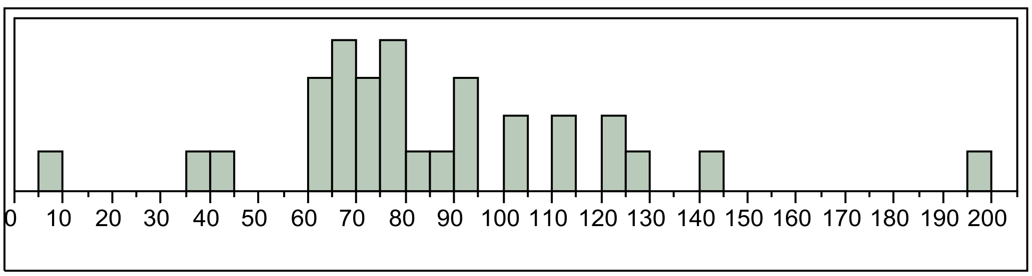

Figure 19. Cedars State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

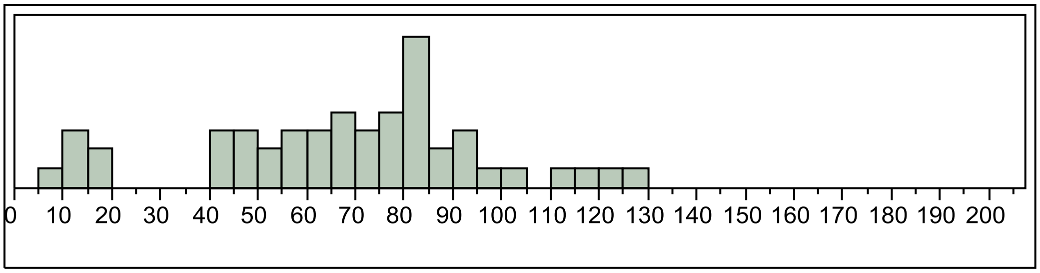

Figure 20. Chickasaw State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

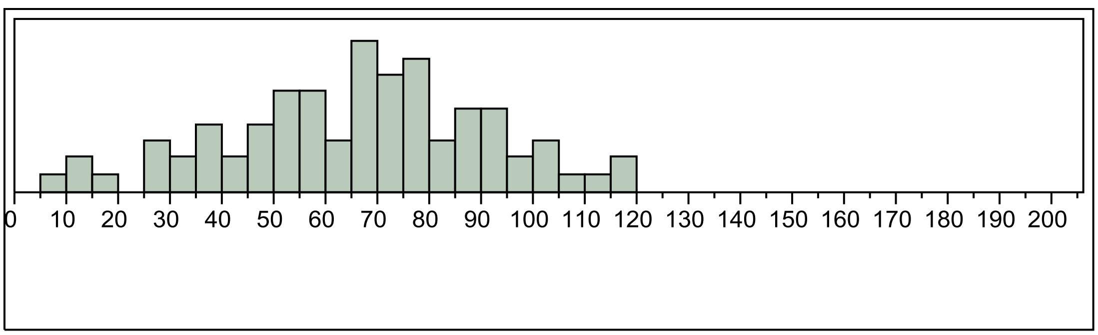

Figure 21. Chuck Swan State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

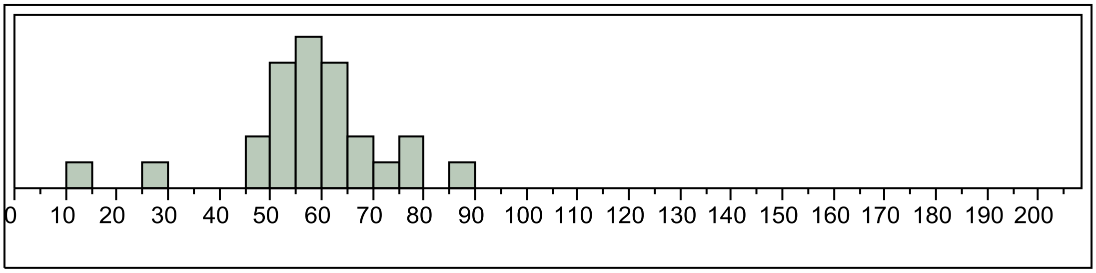

Figure 22. Franklin State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

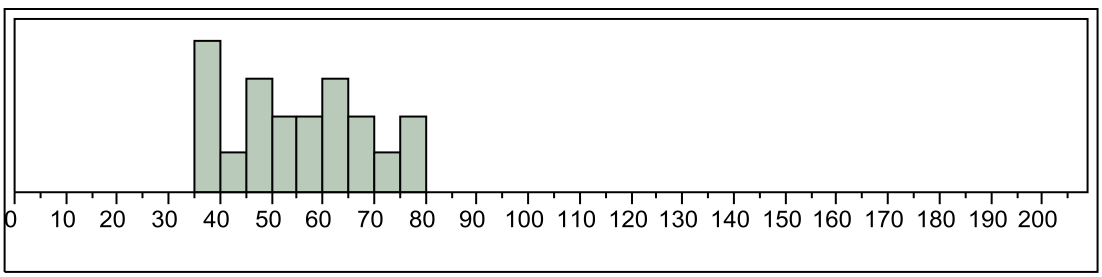

Figure 23. Martha Sundquist State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

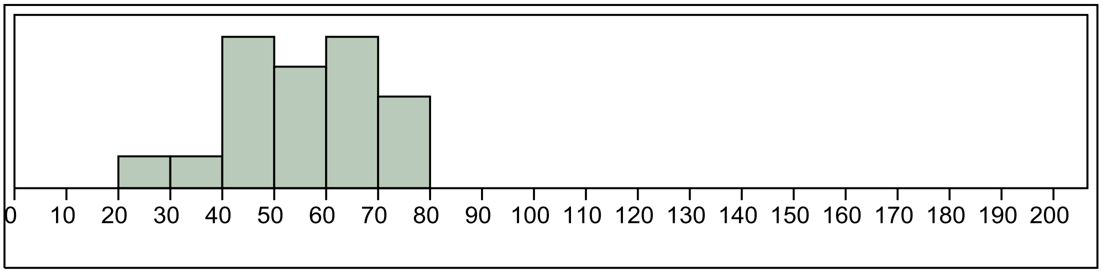

Figure 24. Lewis State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

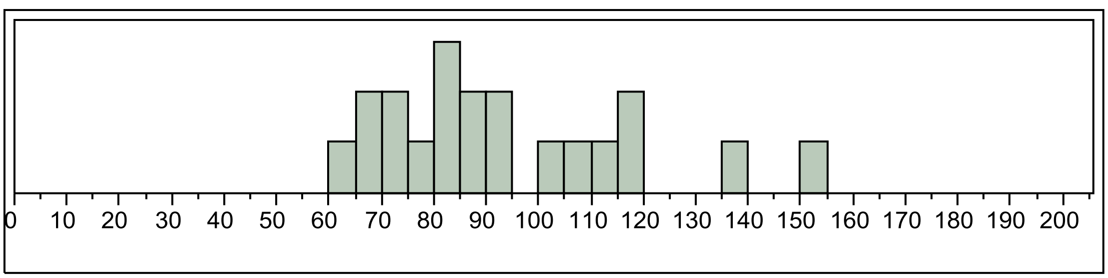

Figure 25. Lone Mountain State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

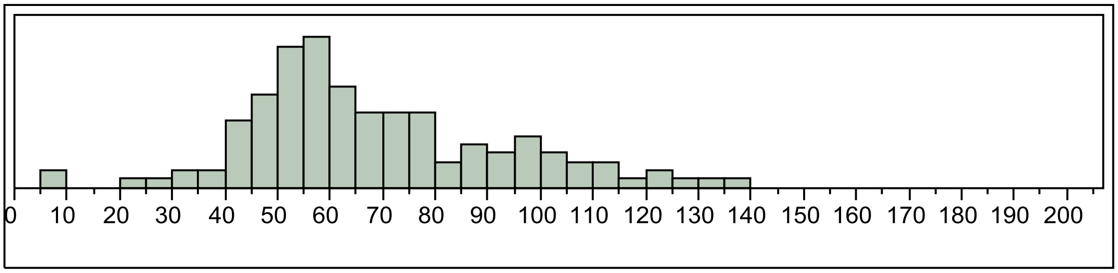

Figure 26. Natchez State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

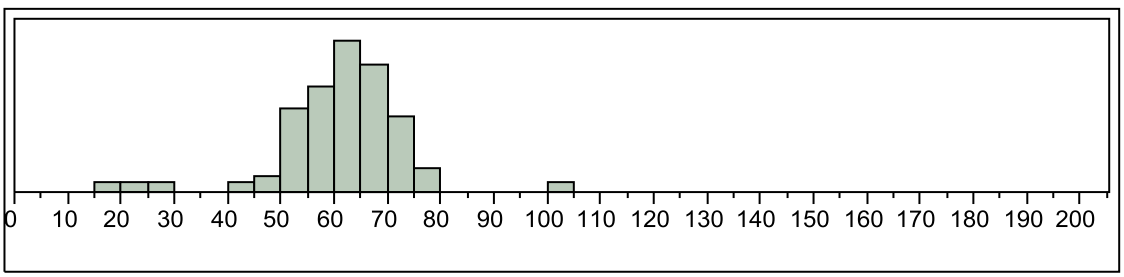

Figure 27. Pickett State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

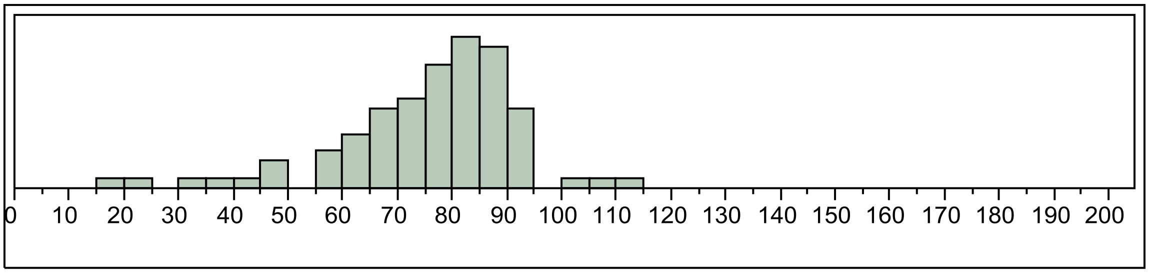

Figure 28. Prentice Cooper State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

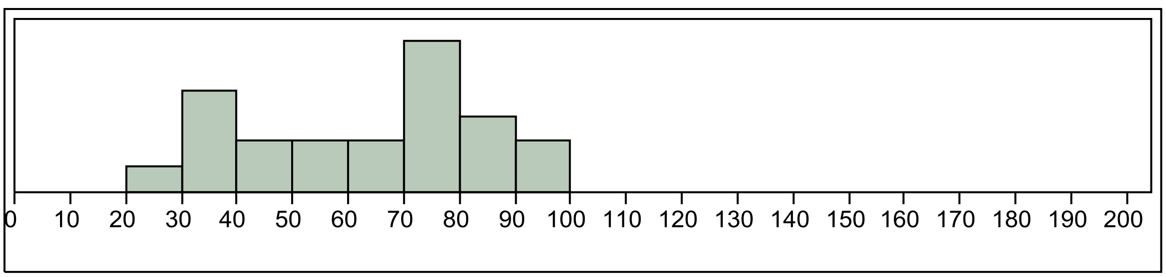

Figure 29. Scott State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

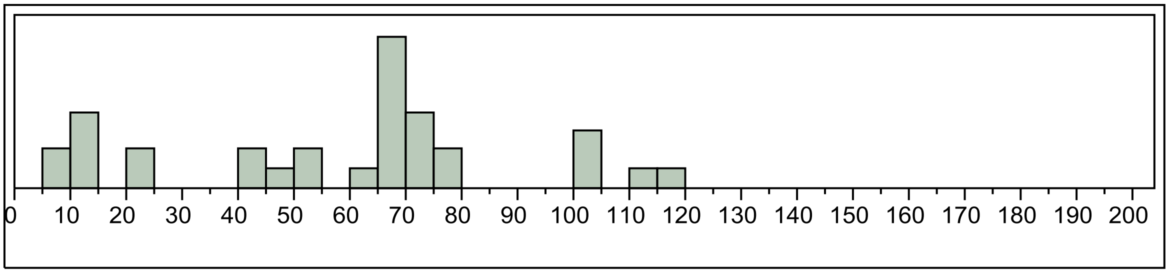

Figure 30. Standing Stone State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

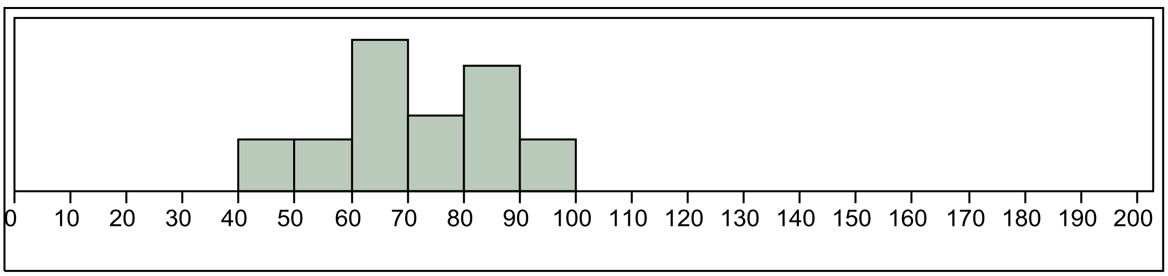

Figure 31. Stewart State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

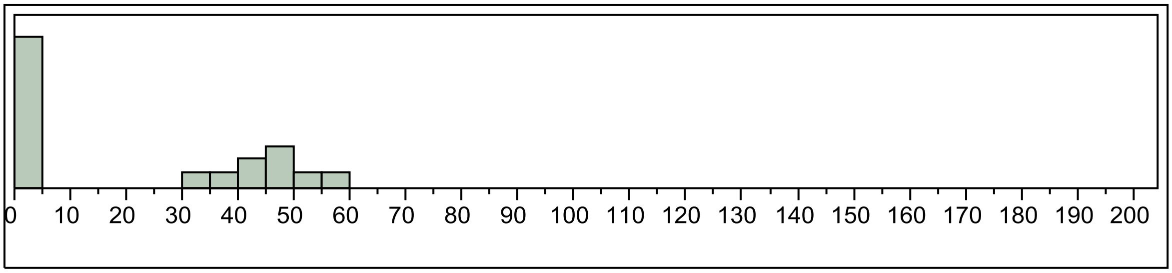

Figure 32. John Tully State Forest distribution of plot age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

APPENDIX C
DIAMETER AND HEIGHT RELATIONSHIPS

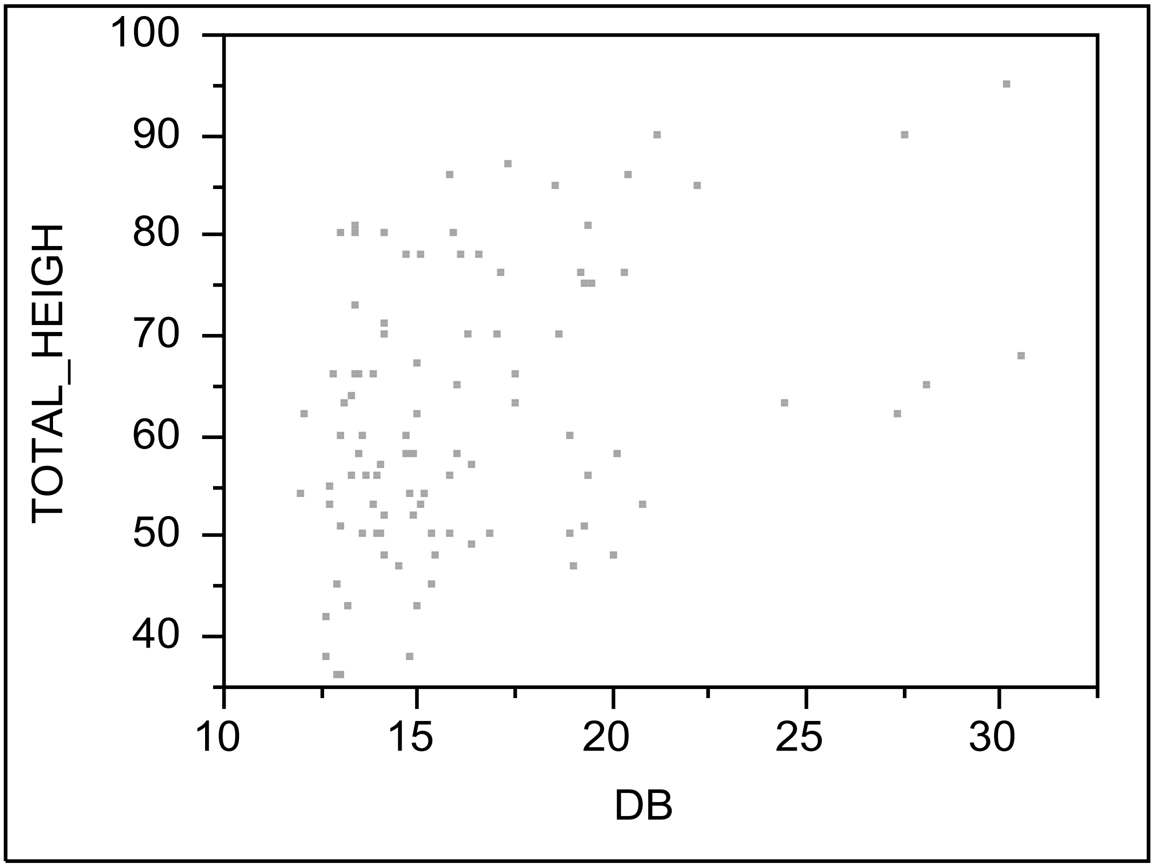

Figure 33. Cedars of Lebanon X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

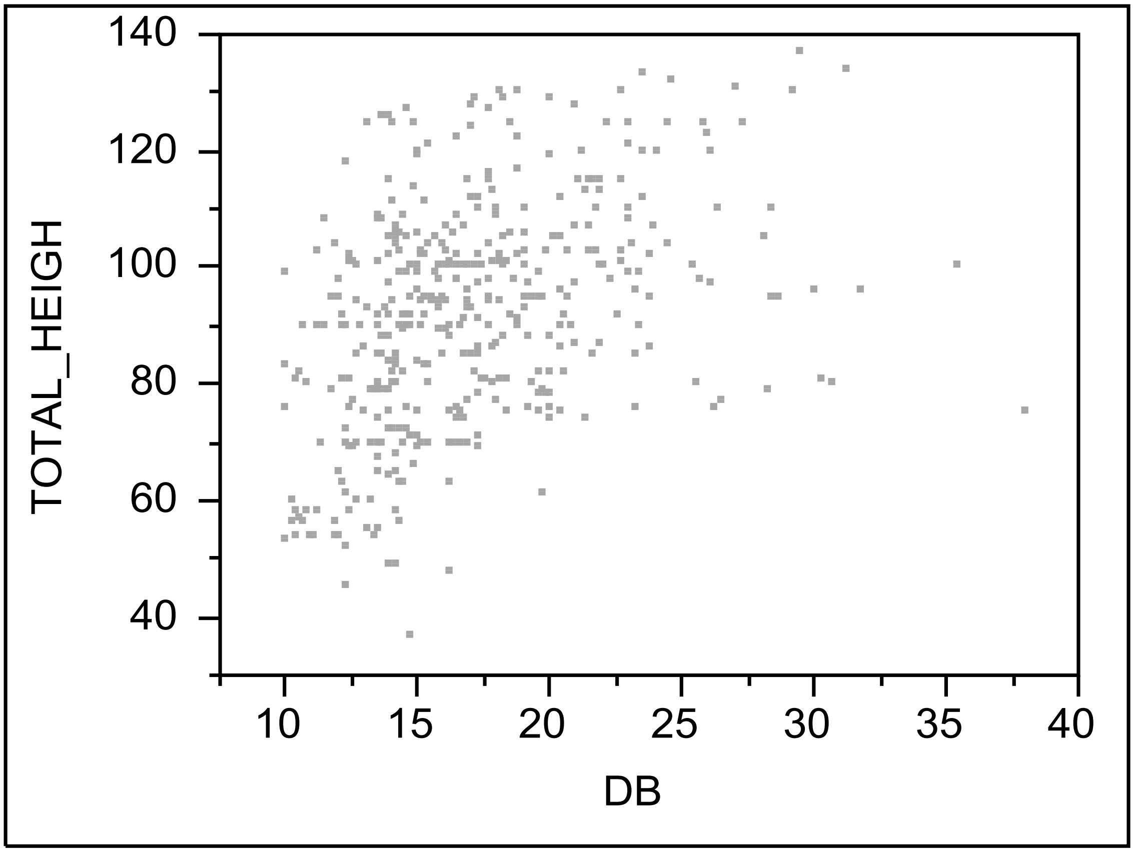

Figure 34. Chickasaw X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

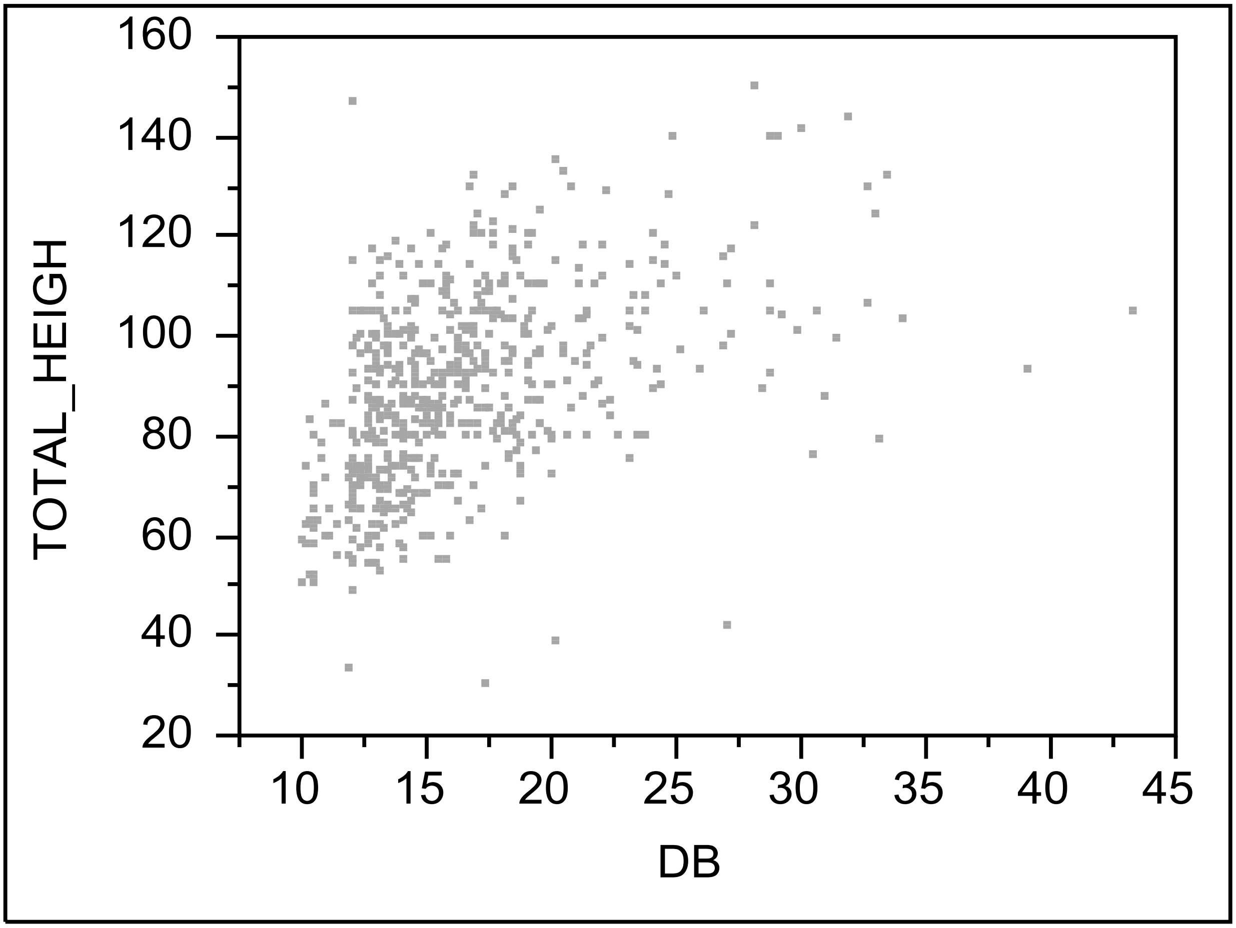

Figure 35. Chuck Swan X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

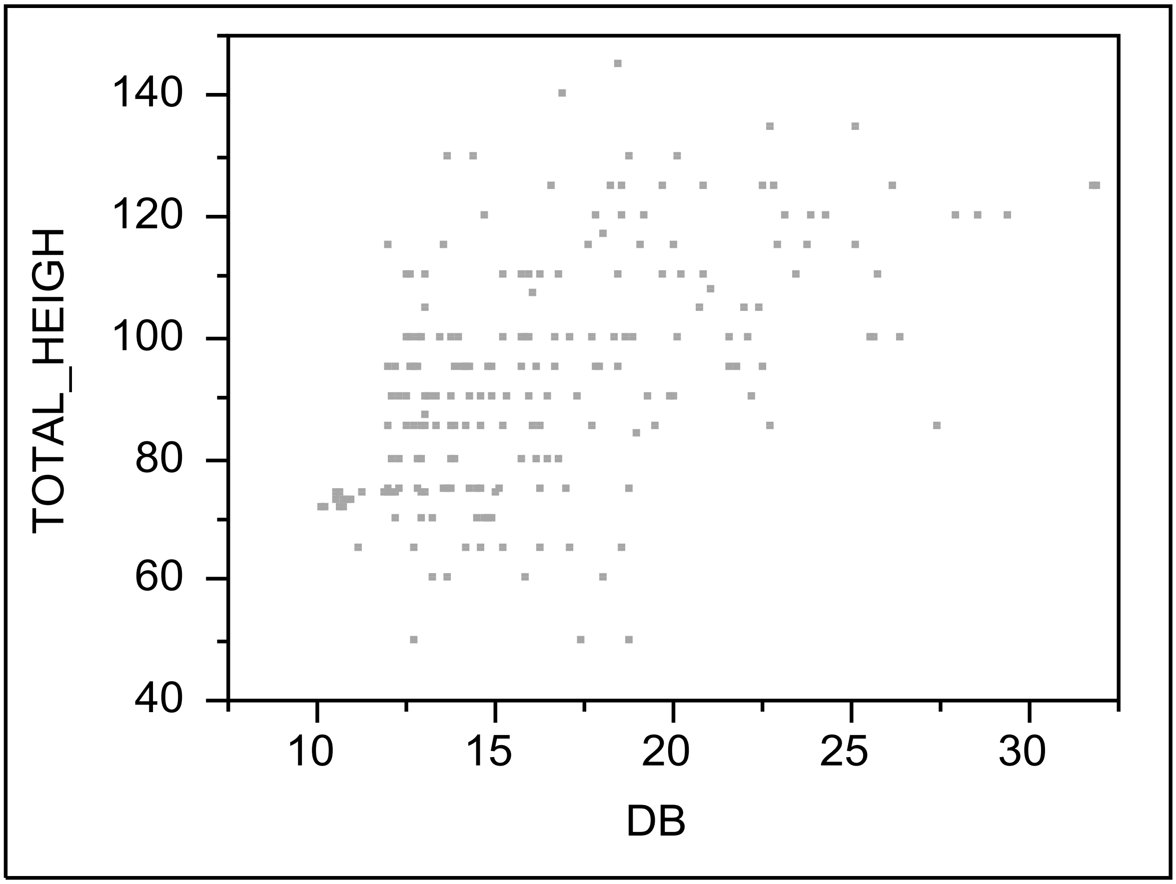

Figure 36. Franklin X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

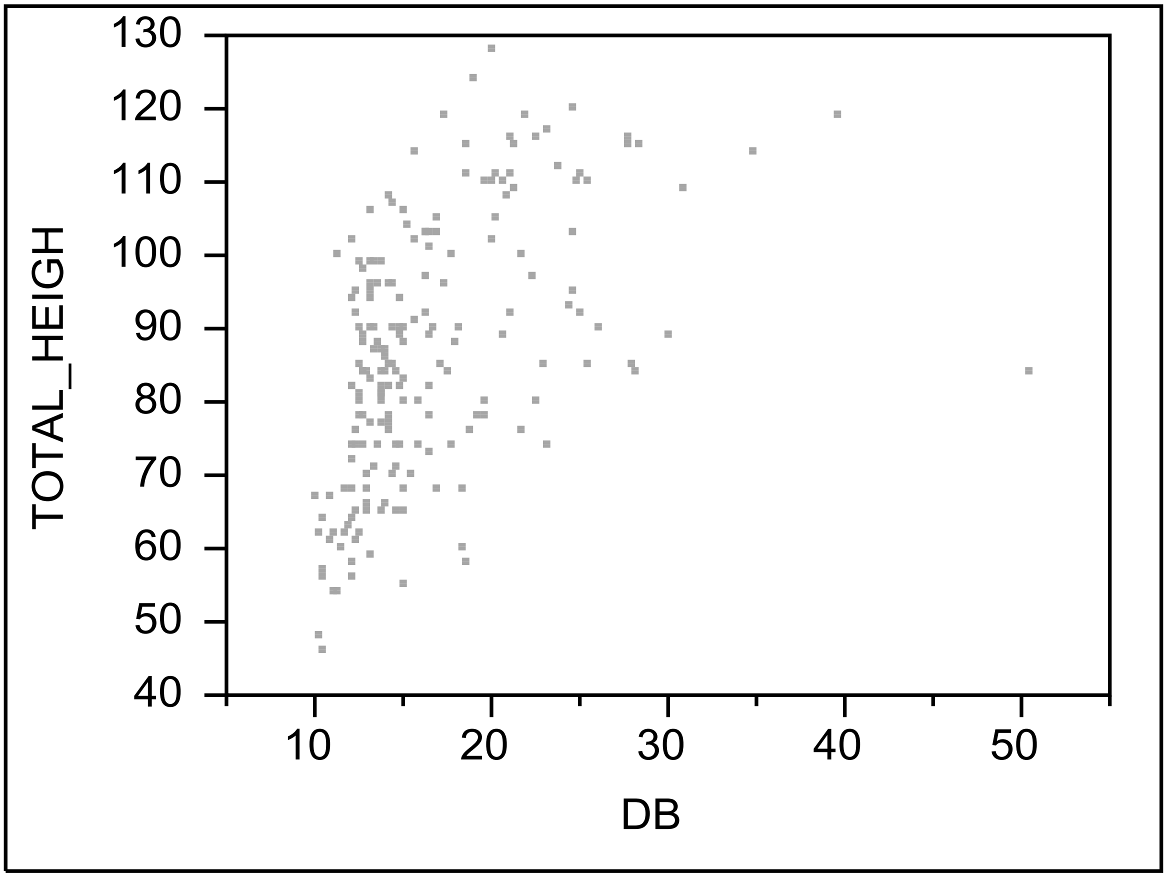

Figure 37. Martha Sundquist X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

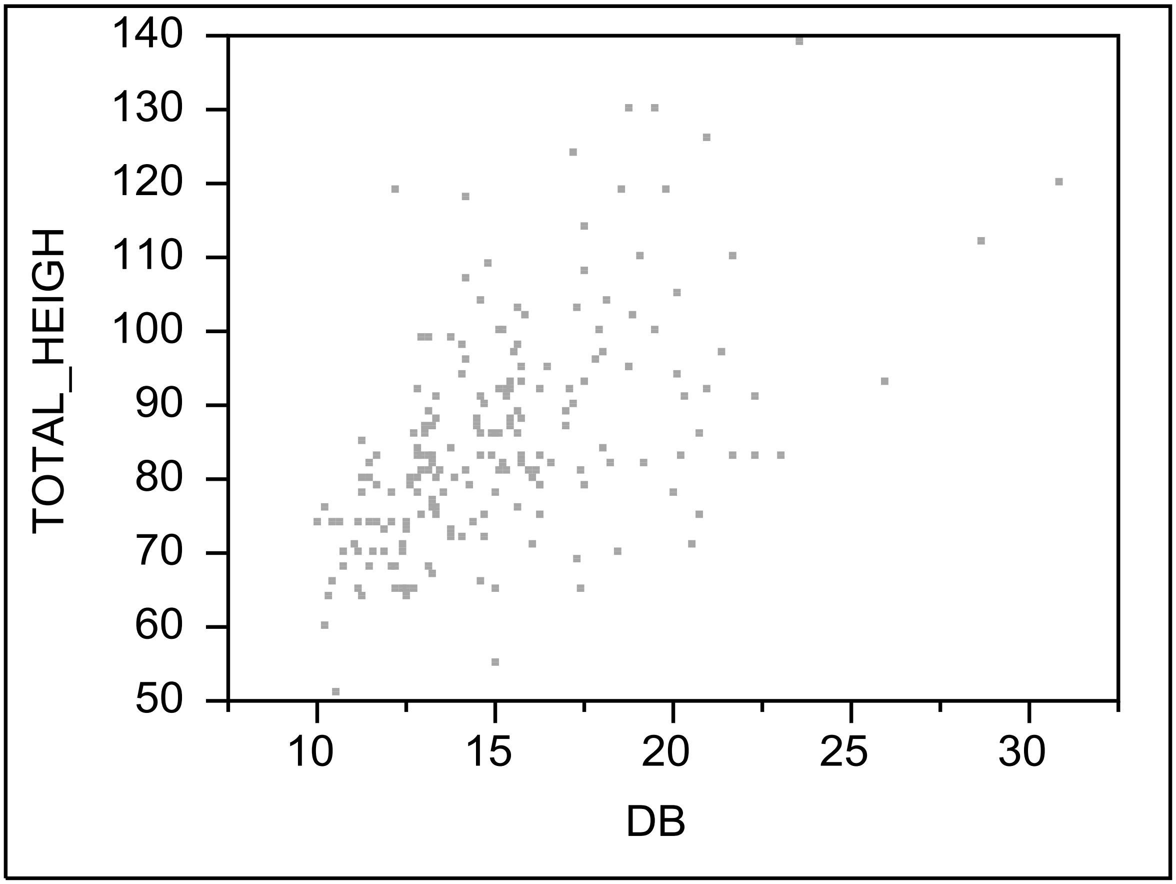

Figure 38. Lewis X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

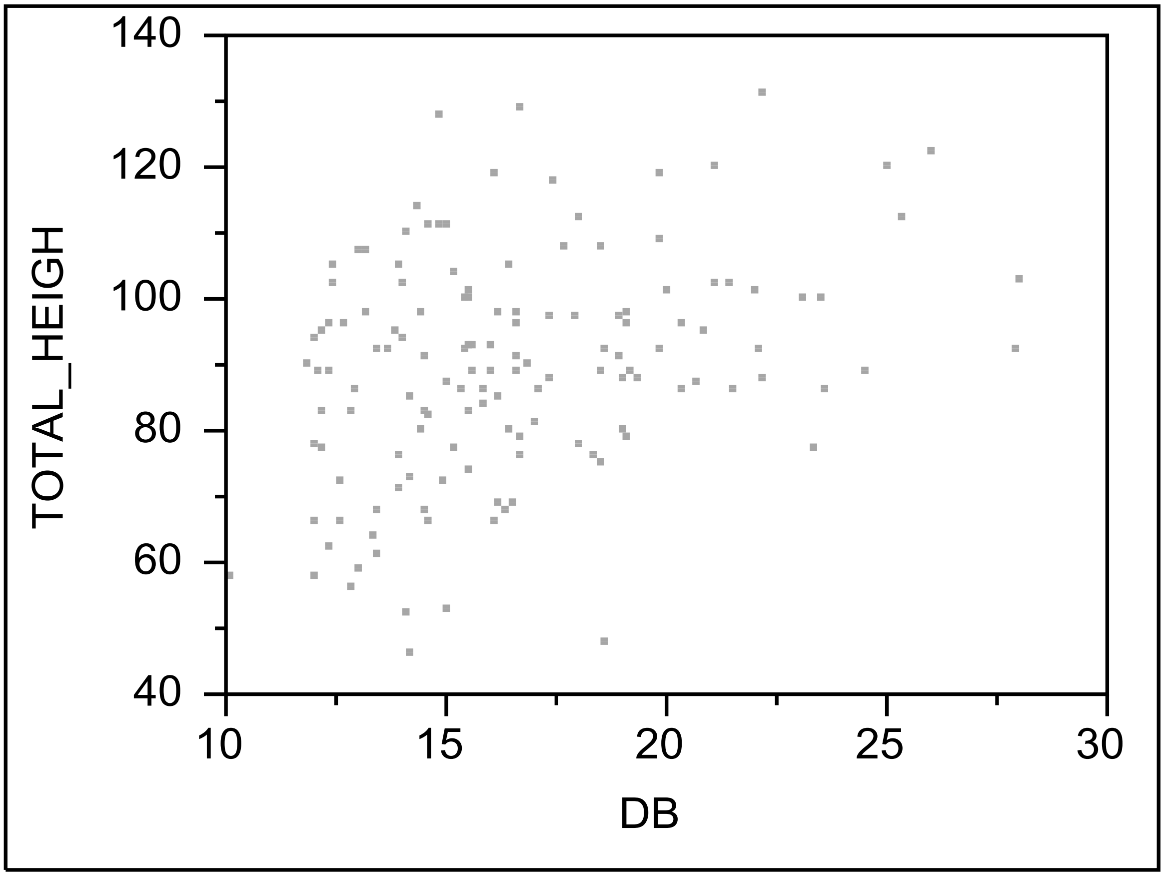

Figure 39. Lone Mountain X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

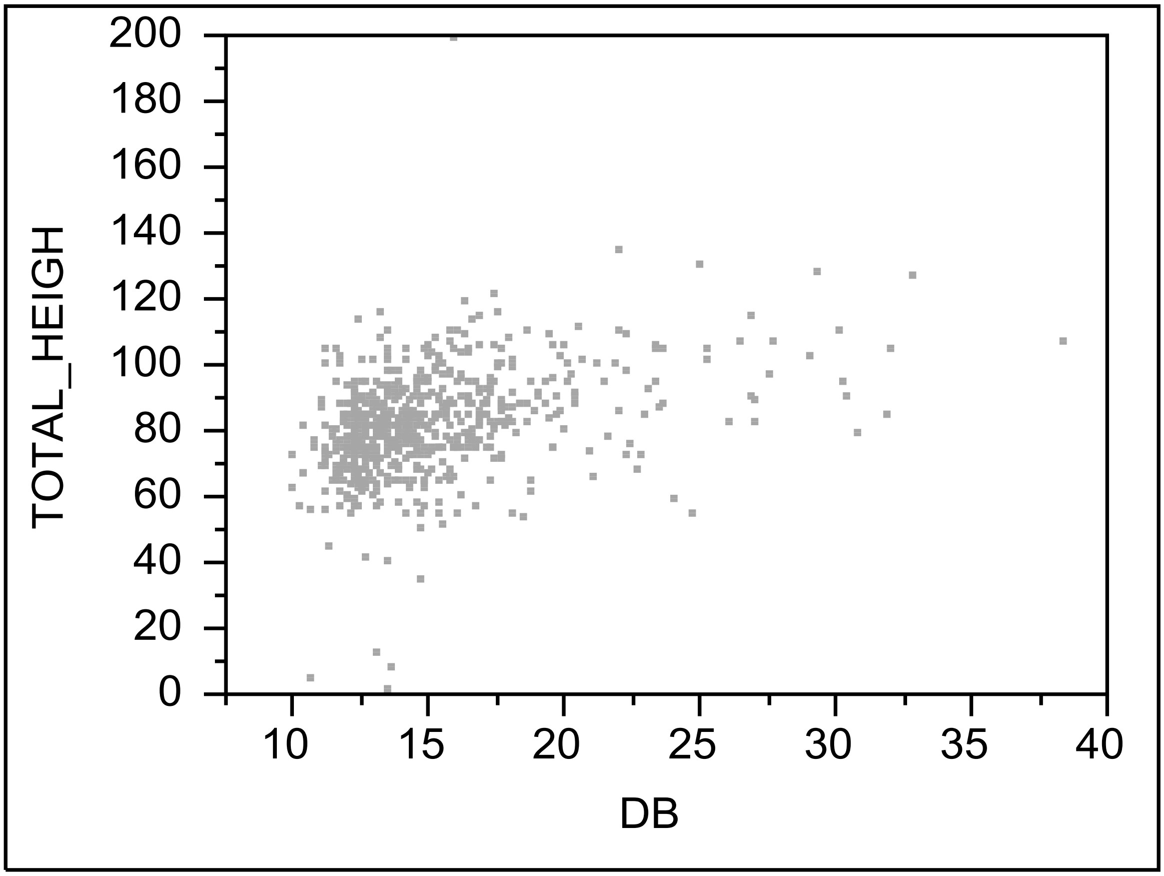

Figure 40. Pickett X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

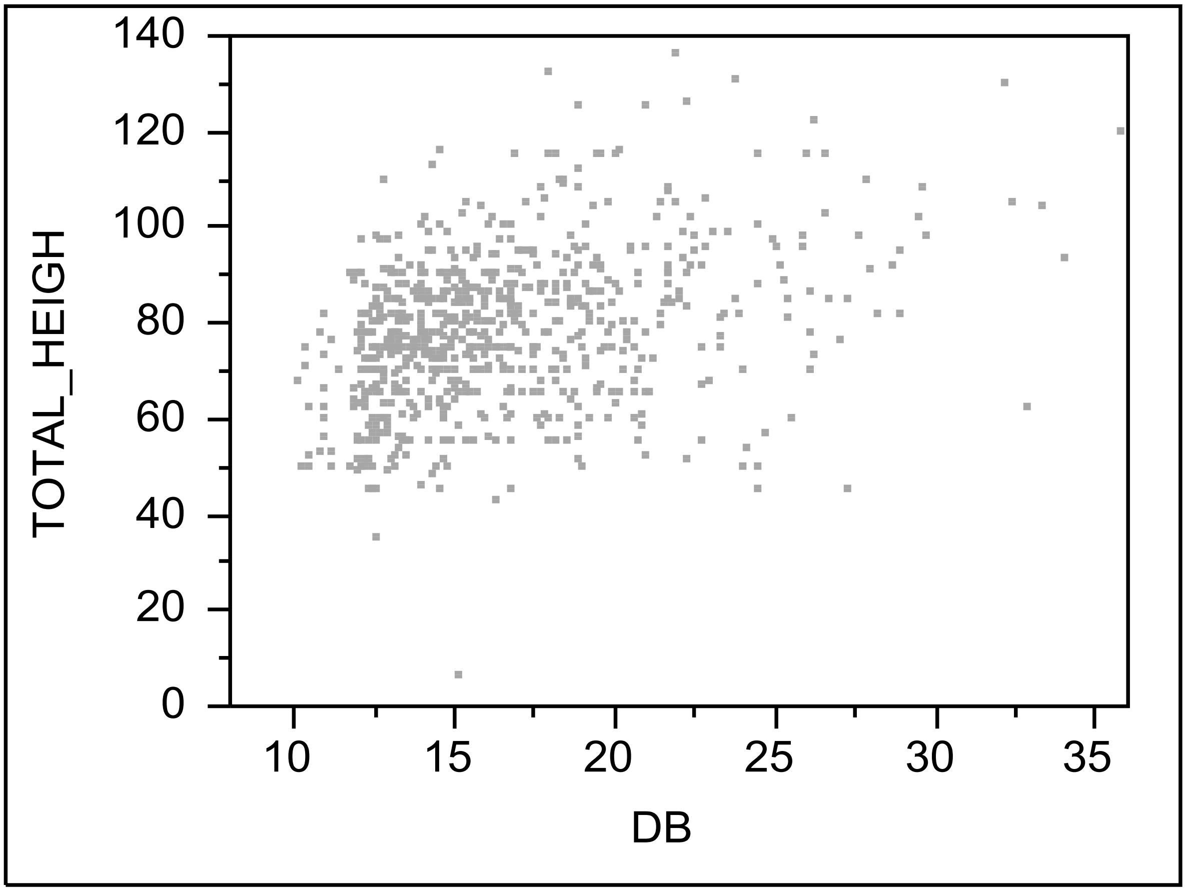

Figure 41. Prentice Cooper X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

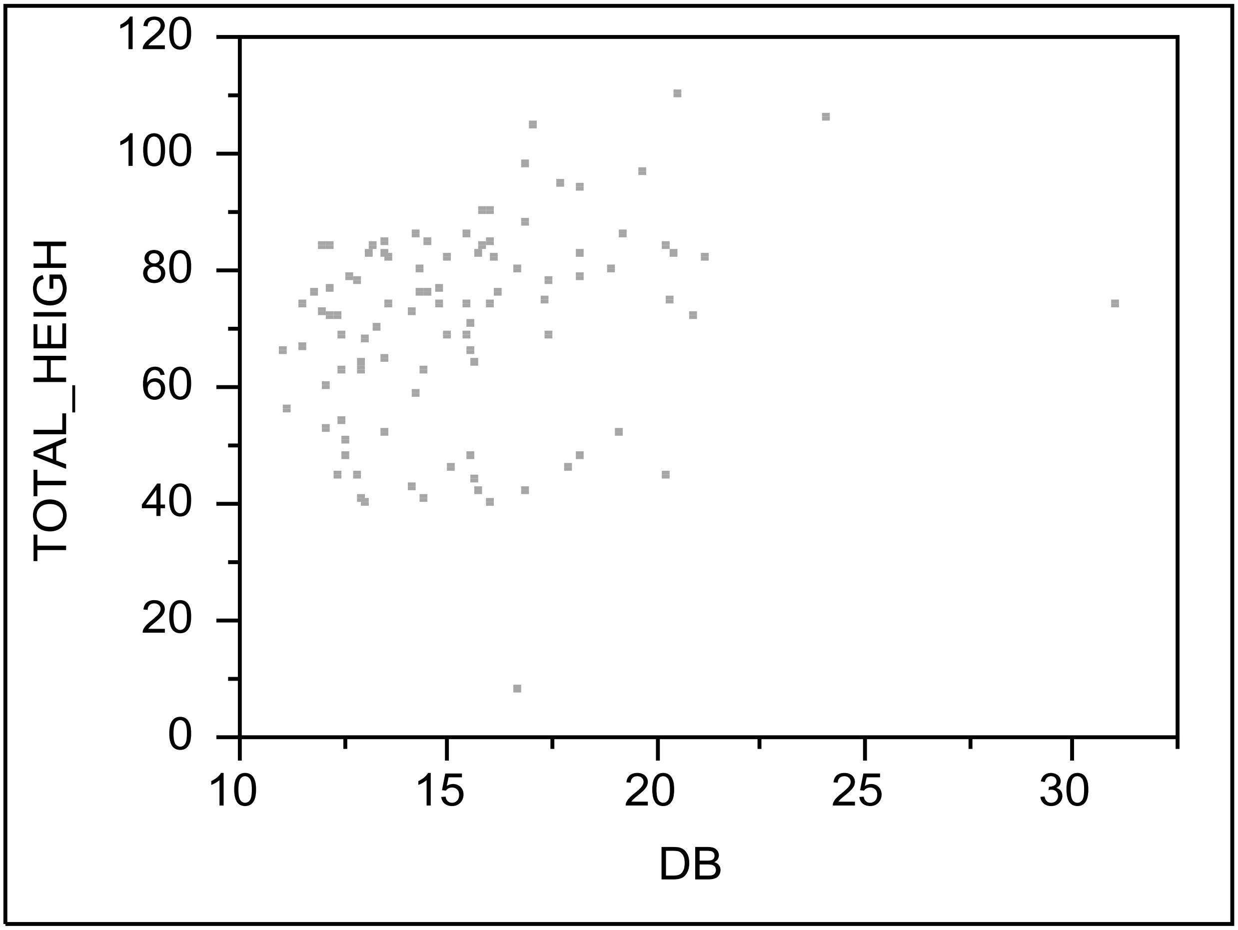

Figure 42. Scott X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

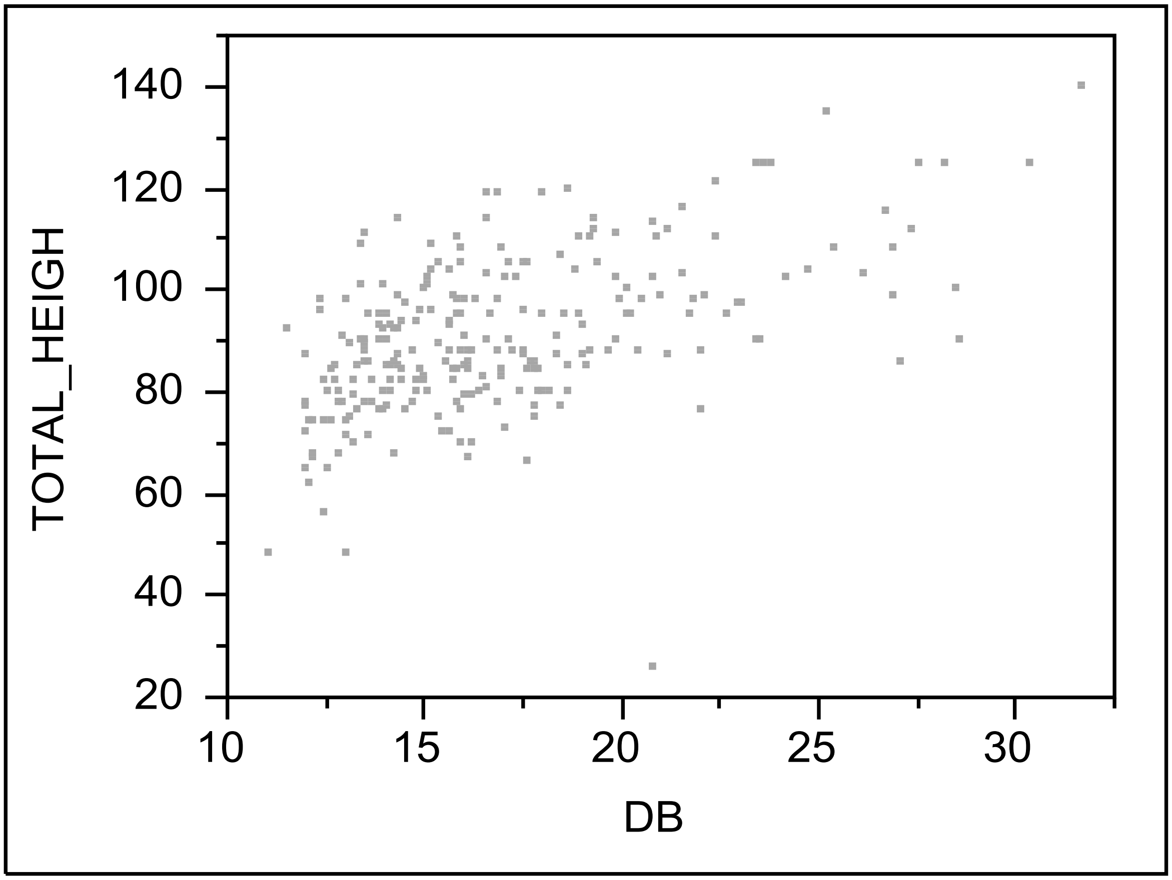

Figure 43. Standing Stone X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

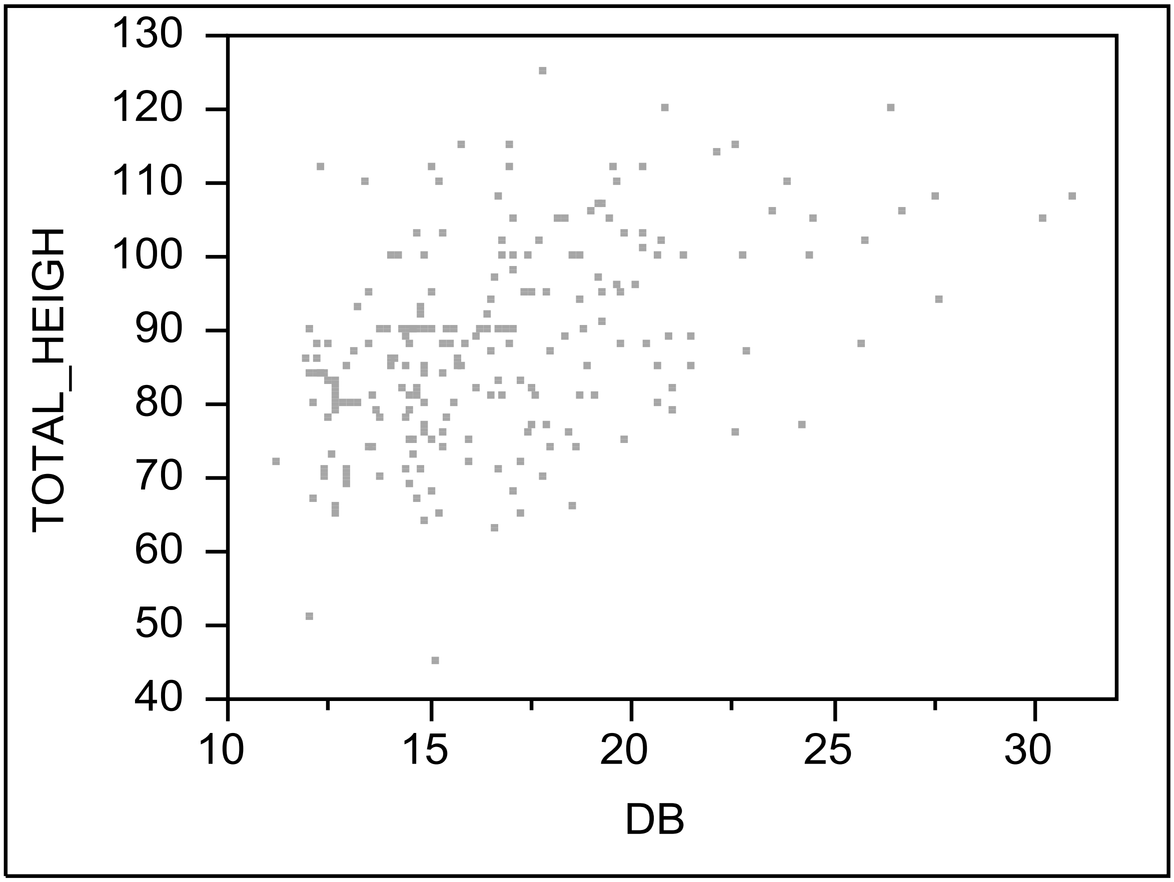

Figure 44. Stewart X Y scatter of relationship between diameter, (DBH) in inches, and total height, in feet. Trees measured on 1/5 acre permanent CFI plots implemented by Tennessee Division of Forestry (TDF) in 2007.

APPENDIX D

DISTRIBUTION OF VOLUME WITH BOX PLOT INCLUDED

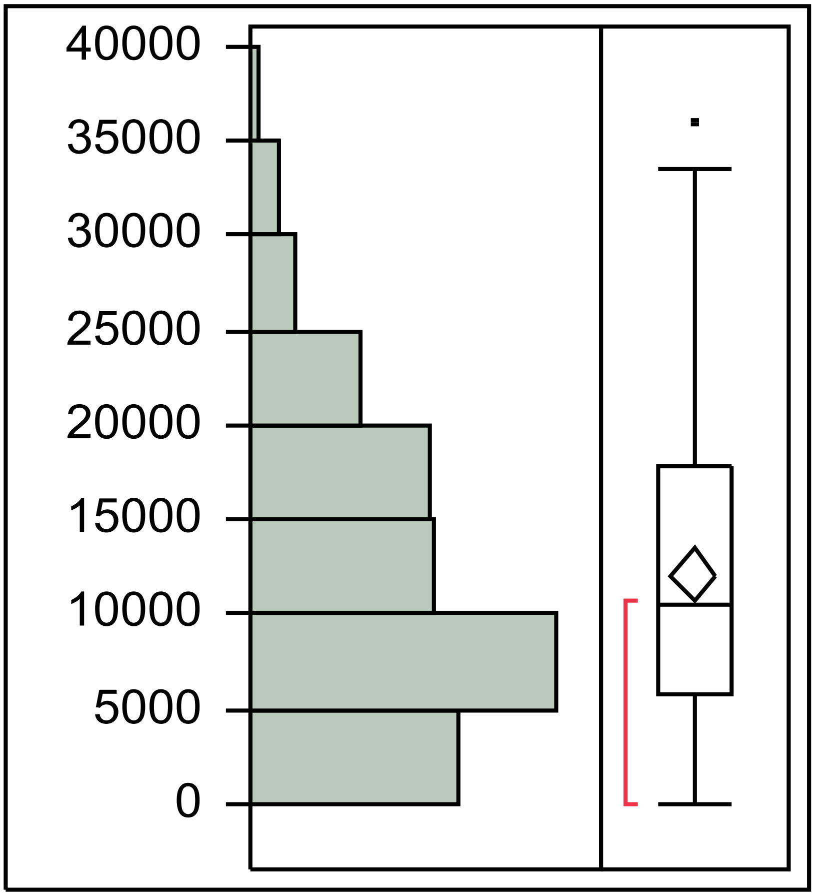

Figure 45. Natchez Trace State Forest All Plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

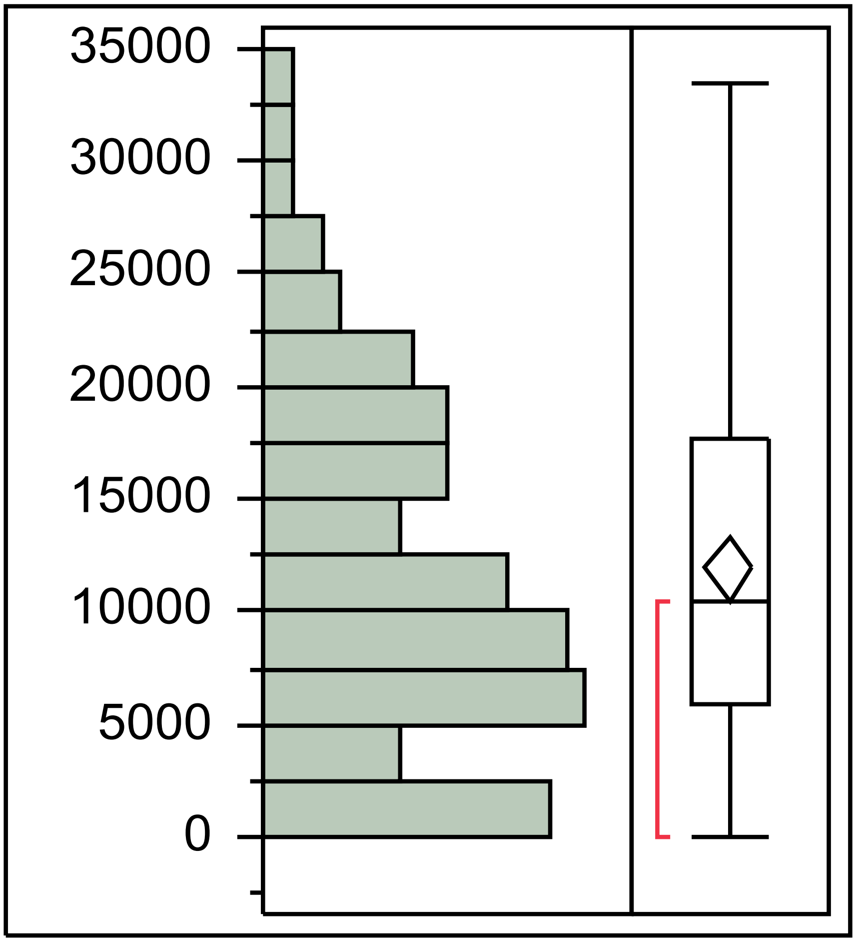

Figure 46. Natchez Trace State Forest Outliers Removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

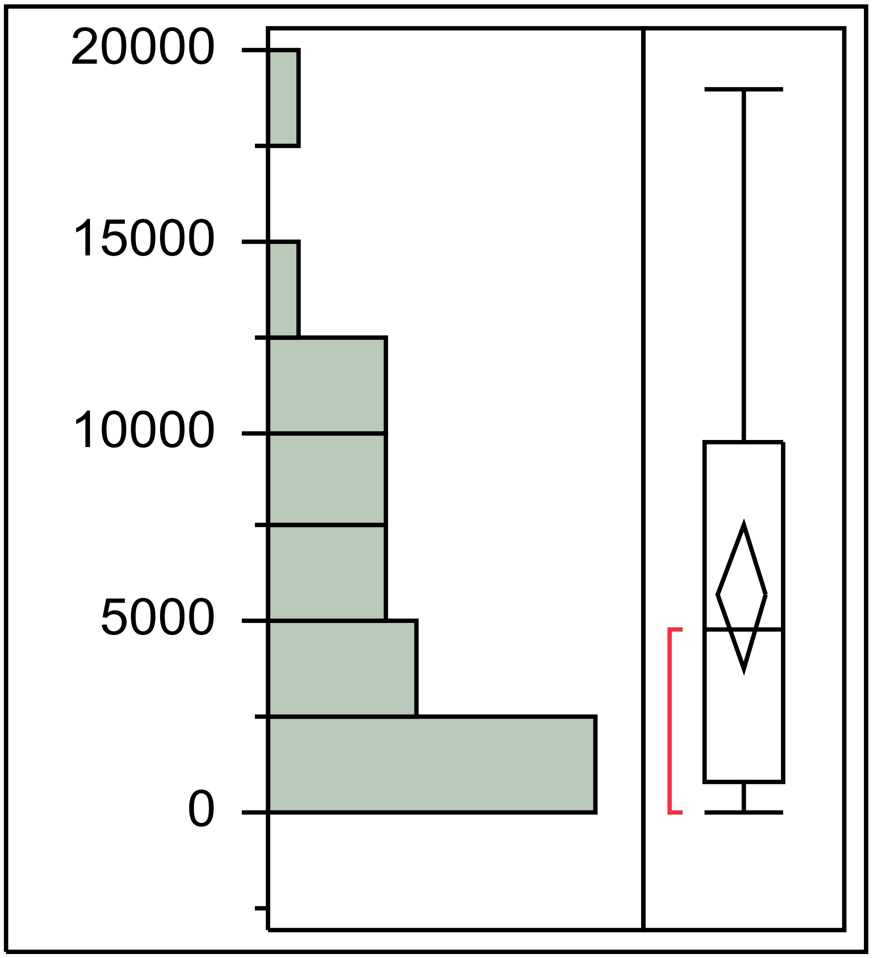

Figure 47. Bledsoe State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

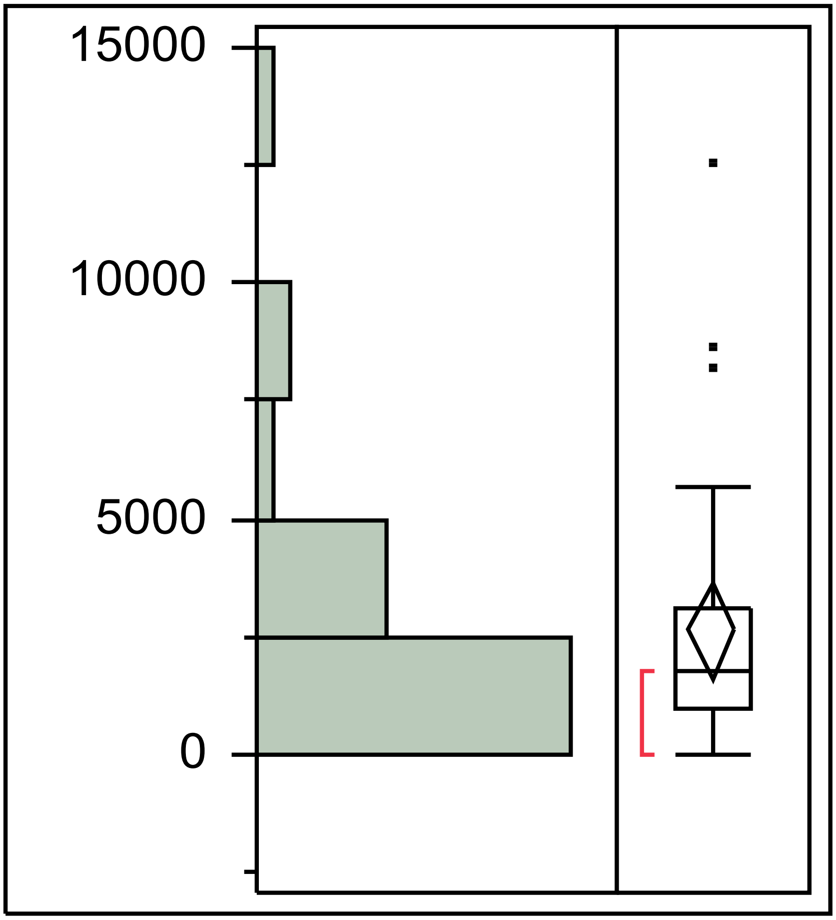

Figure 48. Cedars of Lebanon State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

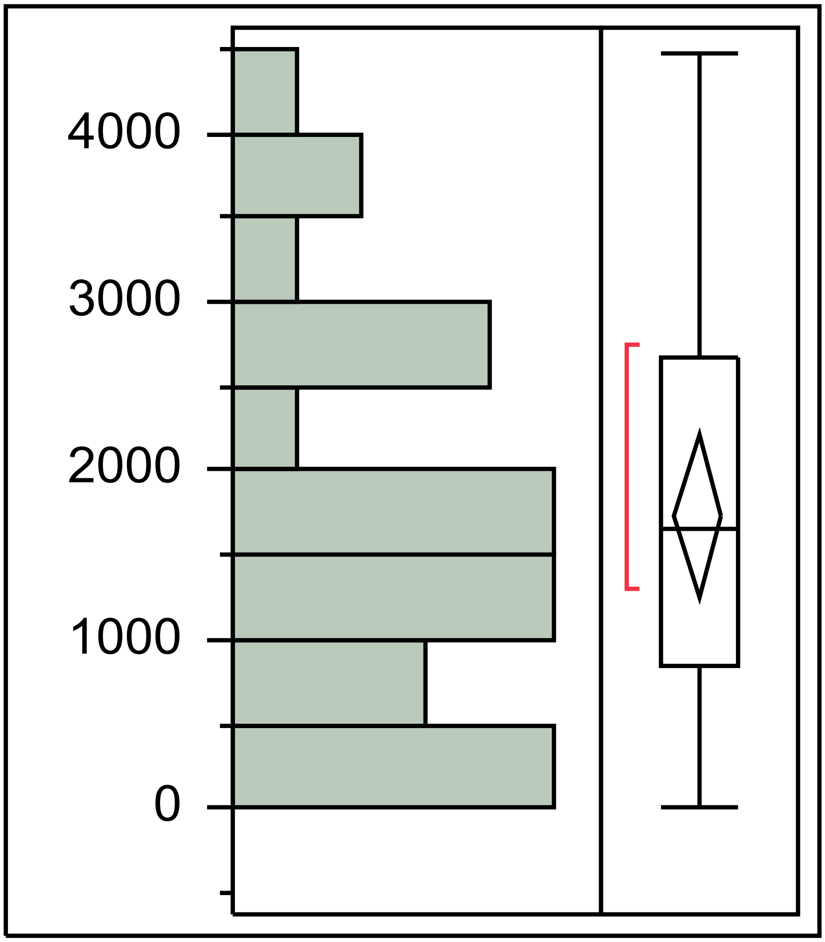

Figure 49. Cedars of Lebanon State Forest with outliers removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

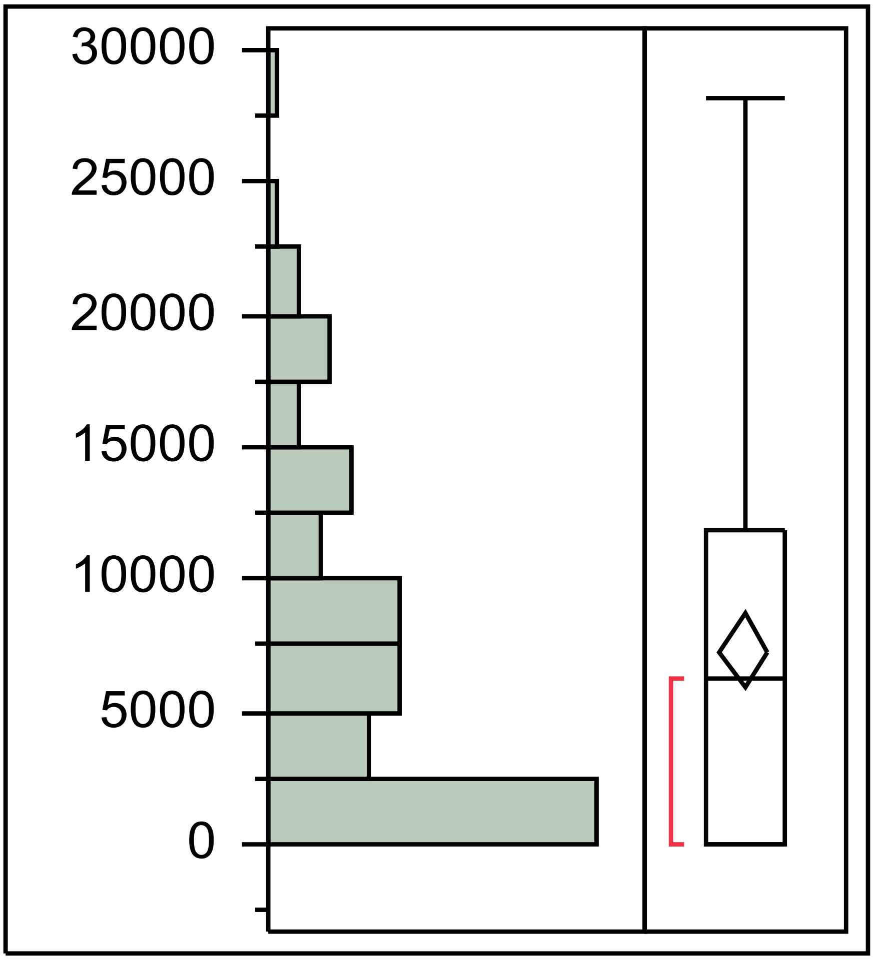

Figure 50. Chuck Swan State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

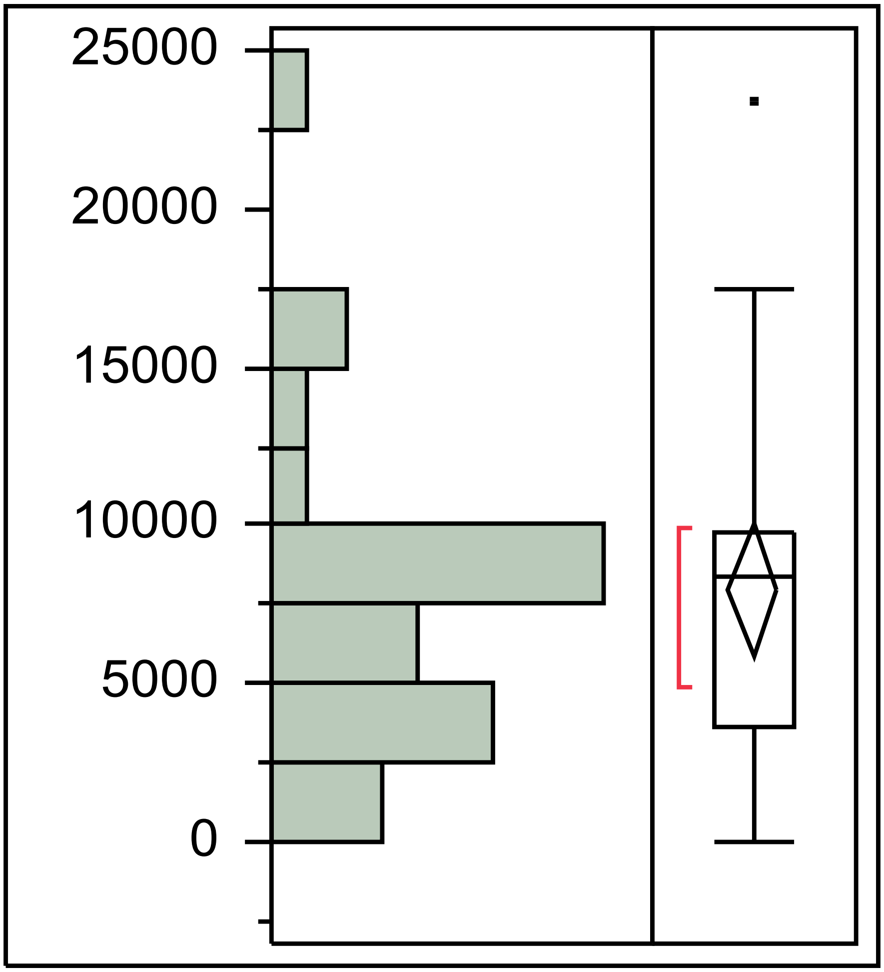

Figure 51. Franklin SF all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

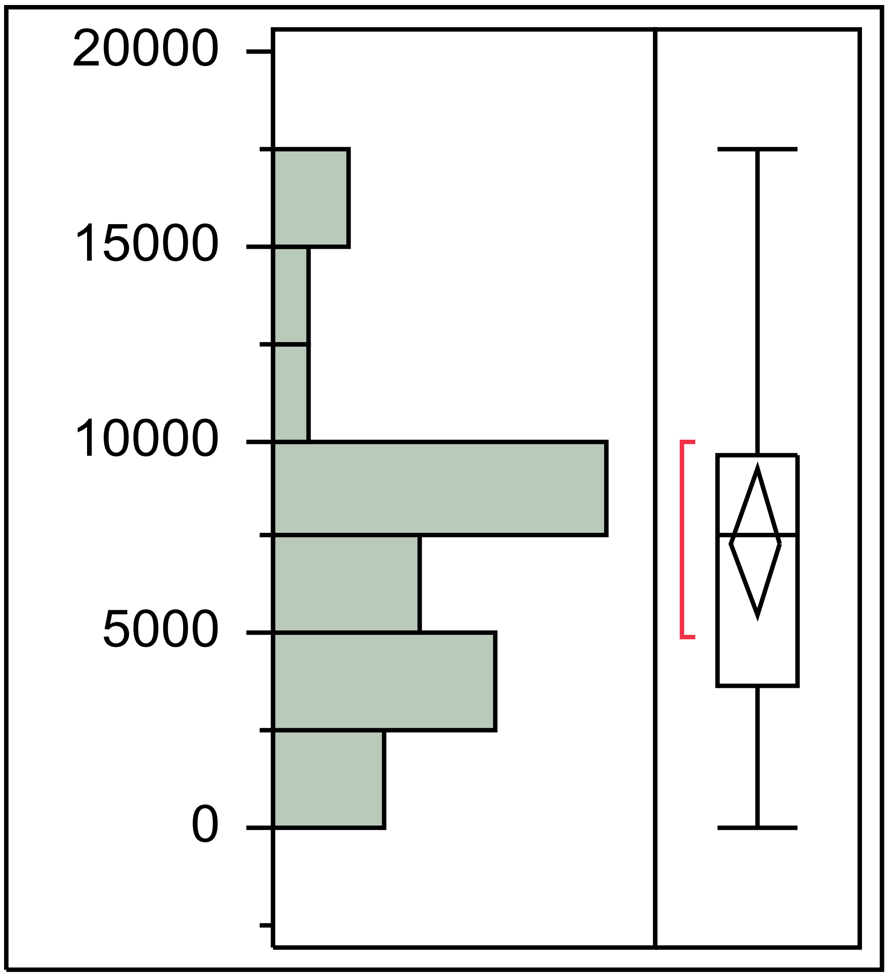

Figure 52. Franklin State Forest Outliers removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

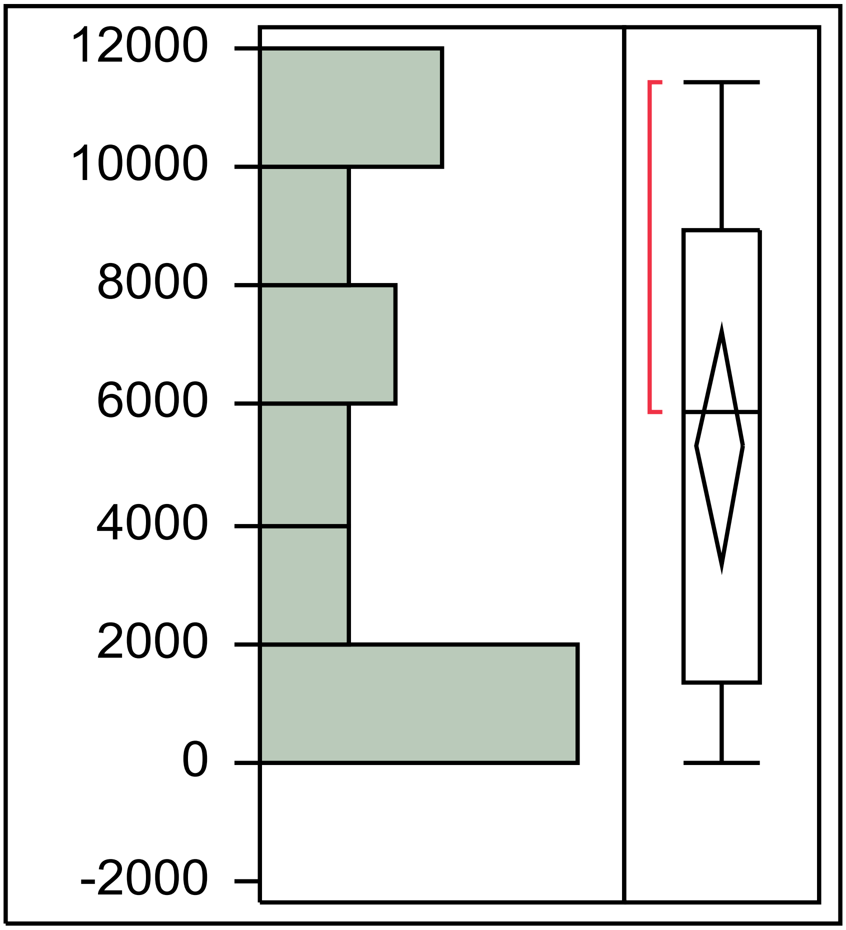

Figure 53. Lone Mountain State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

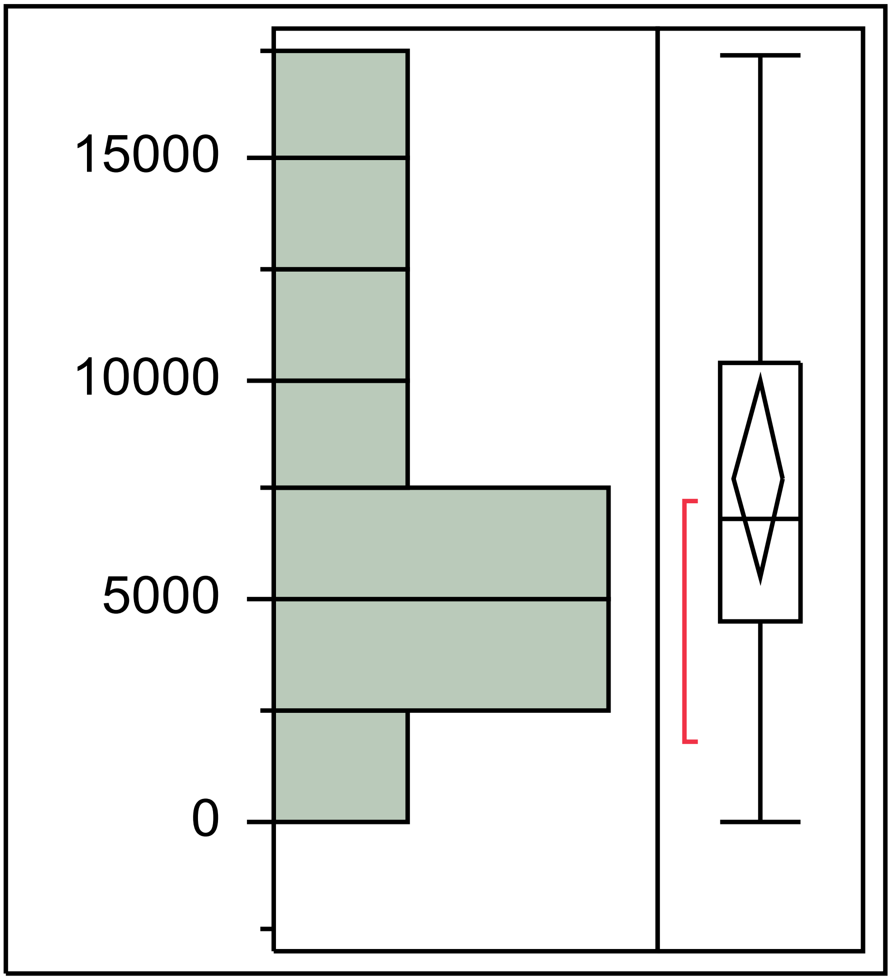

Figure 54. Lewis State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

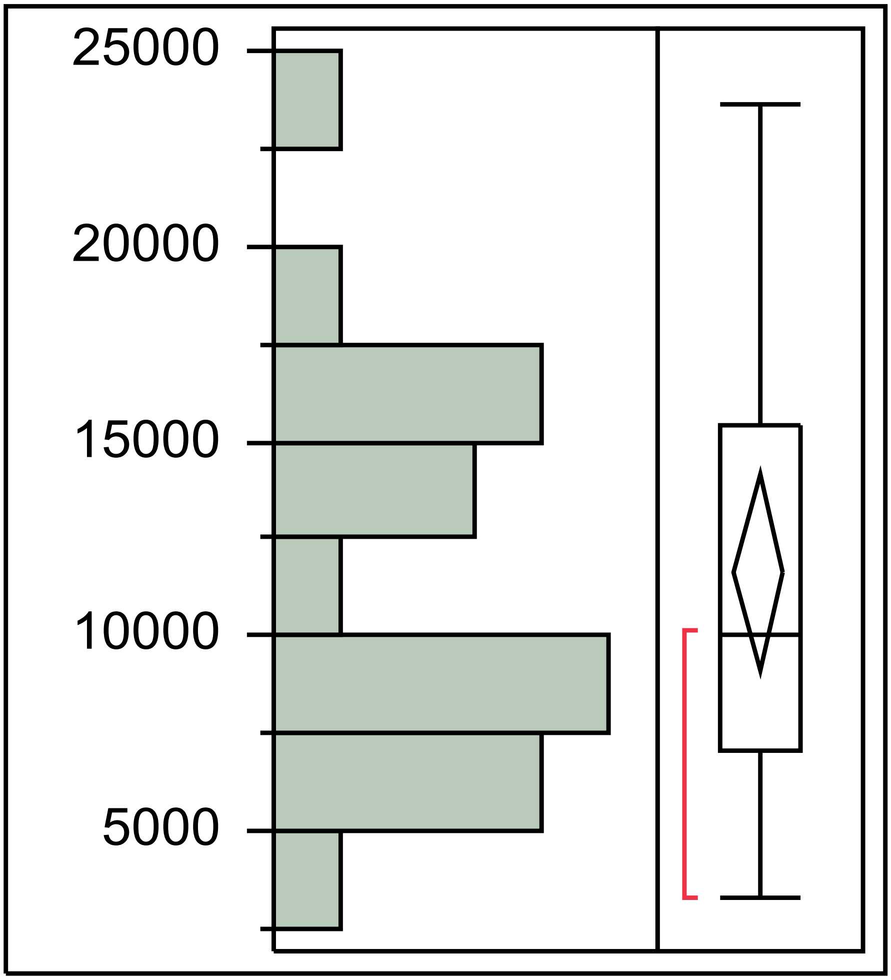

Figure 55. Martha Sundquest State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

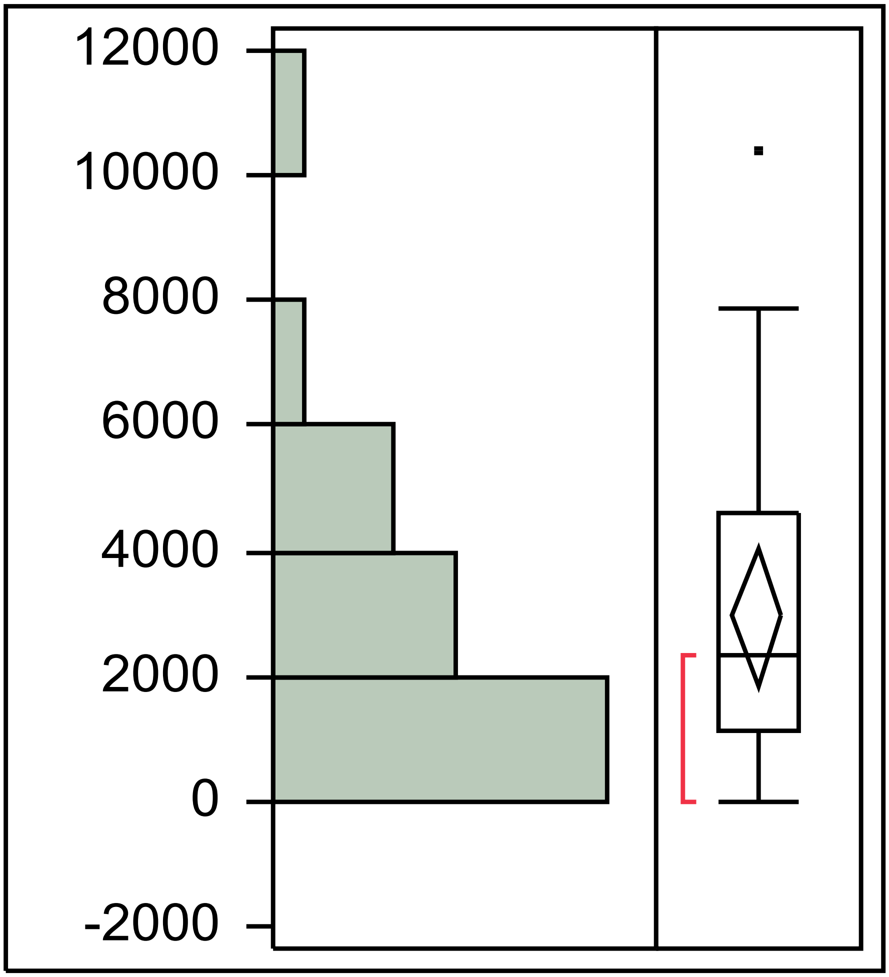

Figure 56. Scott State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

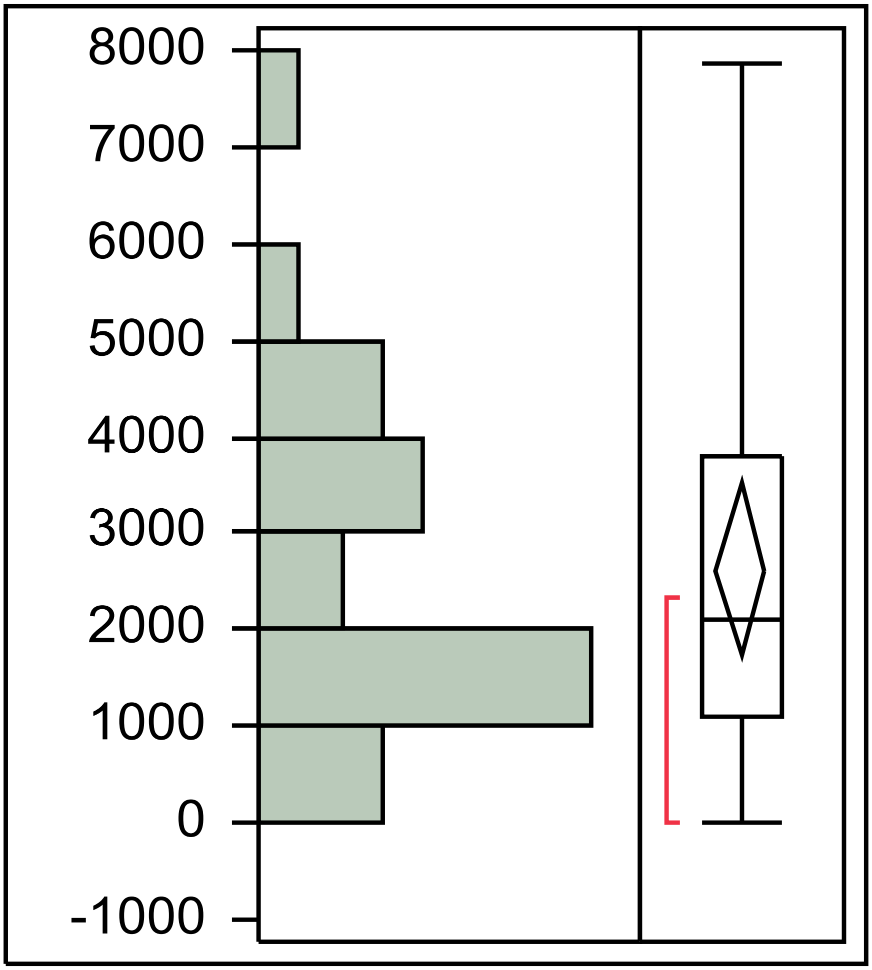

Figure 57. Scott State Forest Outliers removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

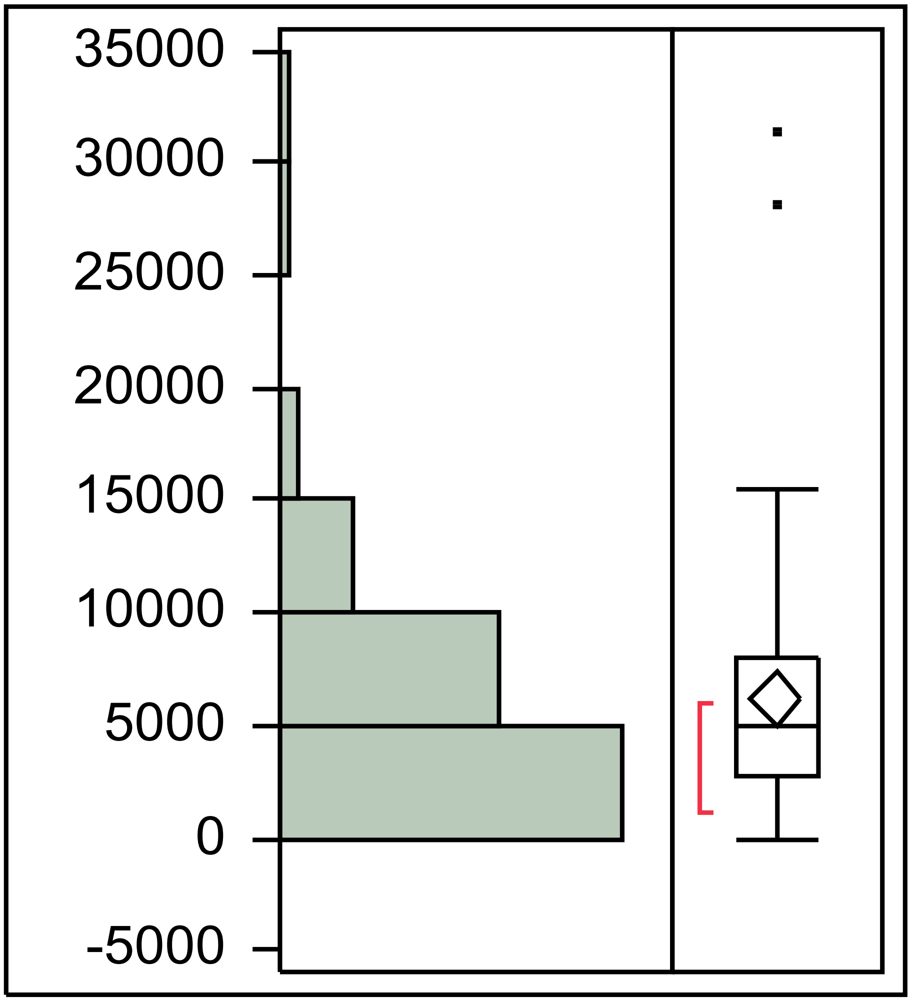

Figure 58. Pickett State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

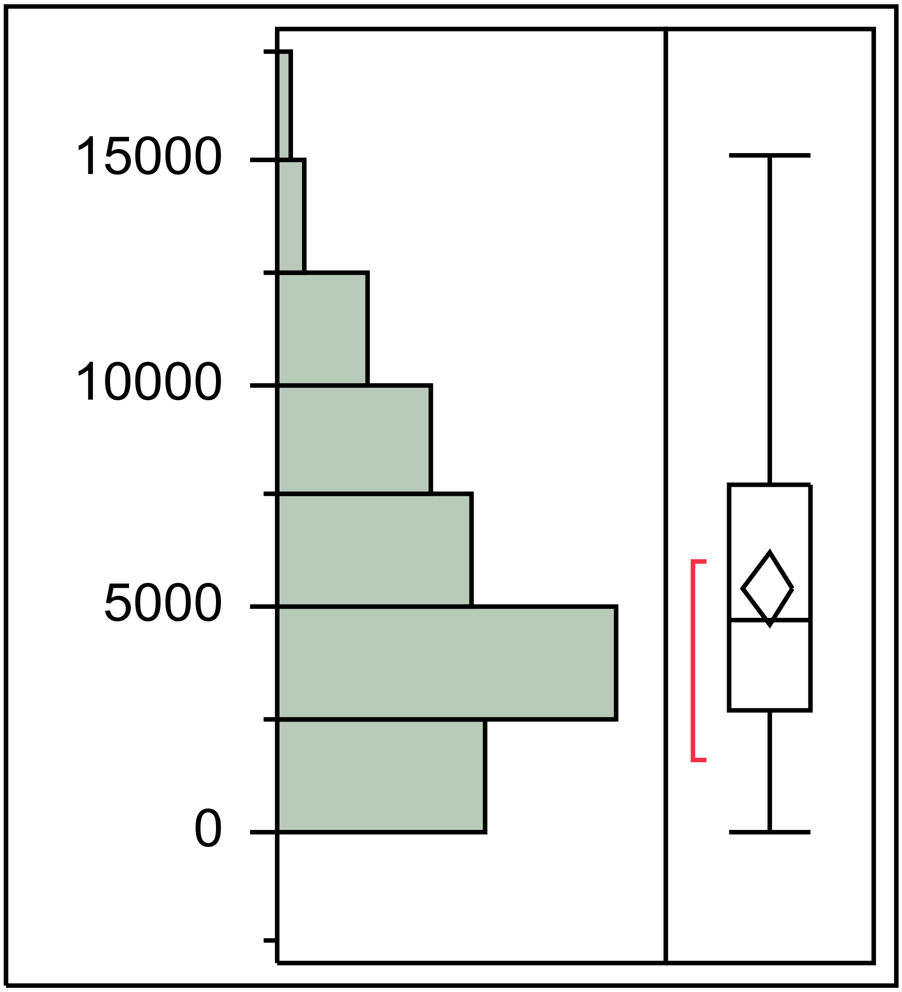

Figure 59. Pickett State Forest Outliers removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

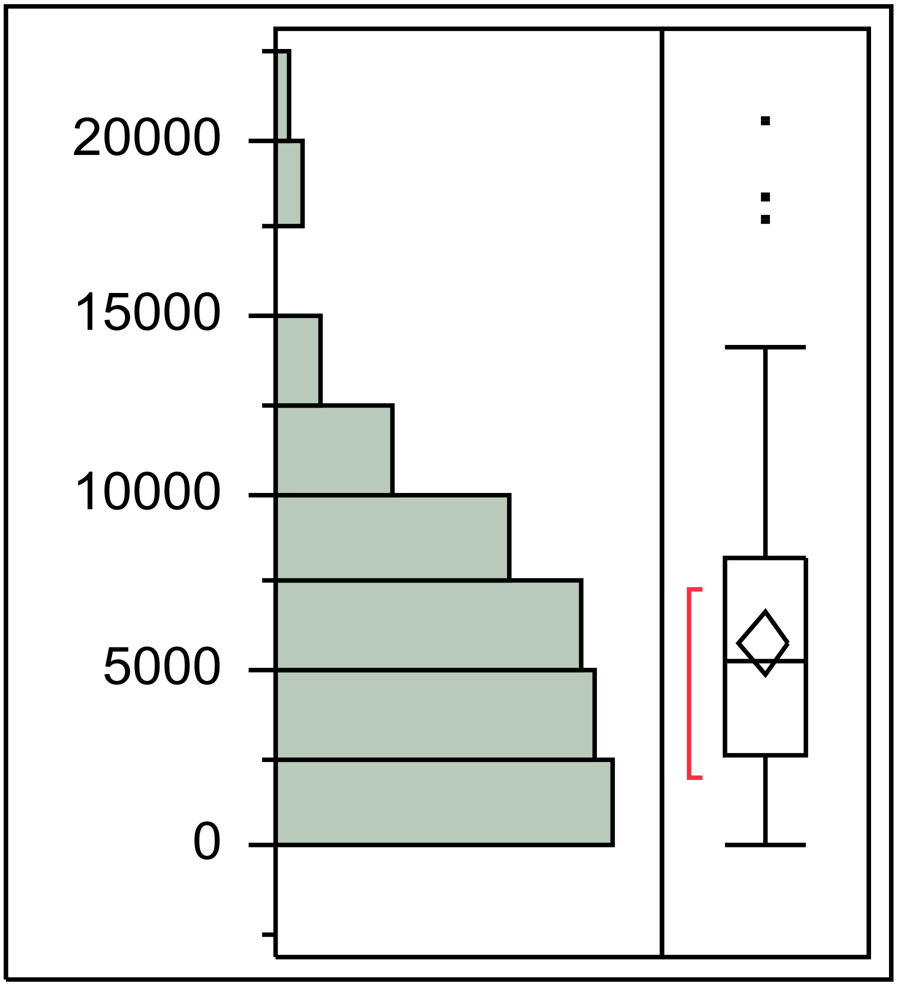

Figure 60. Prentice Cooper State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

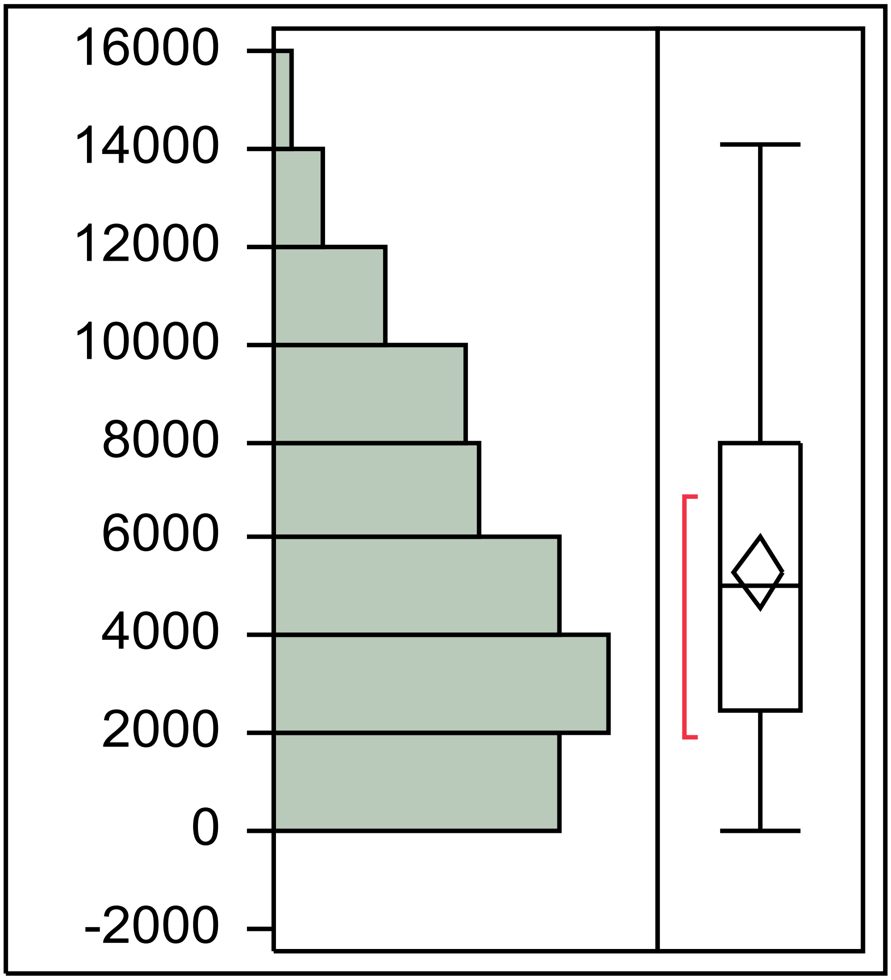

Figure 61. Prentice Cooper State Forest Outliers removed. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

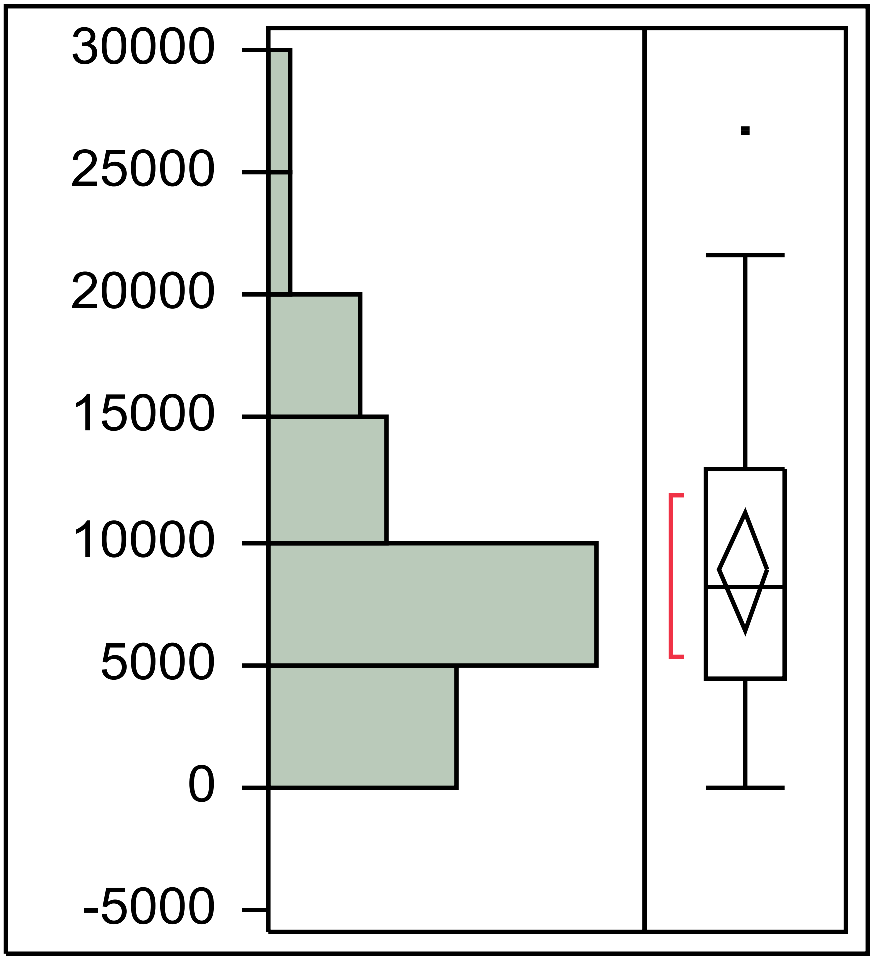

Figure 62. Standing Stone State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

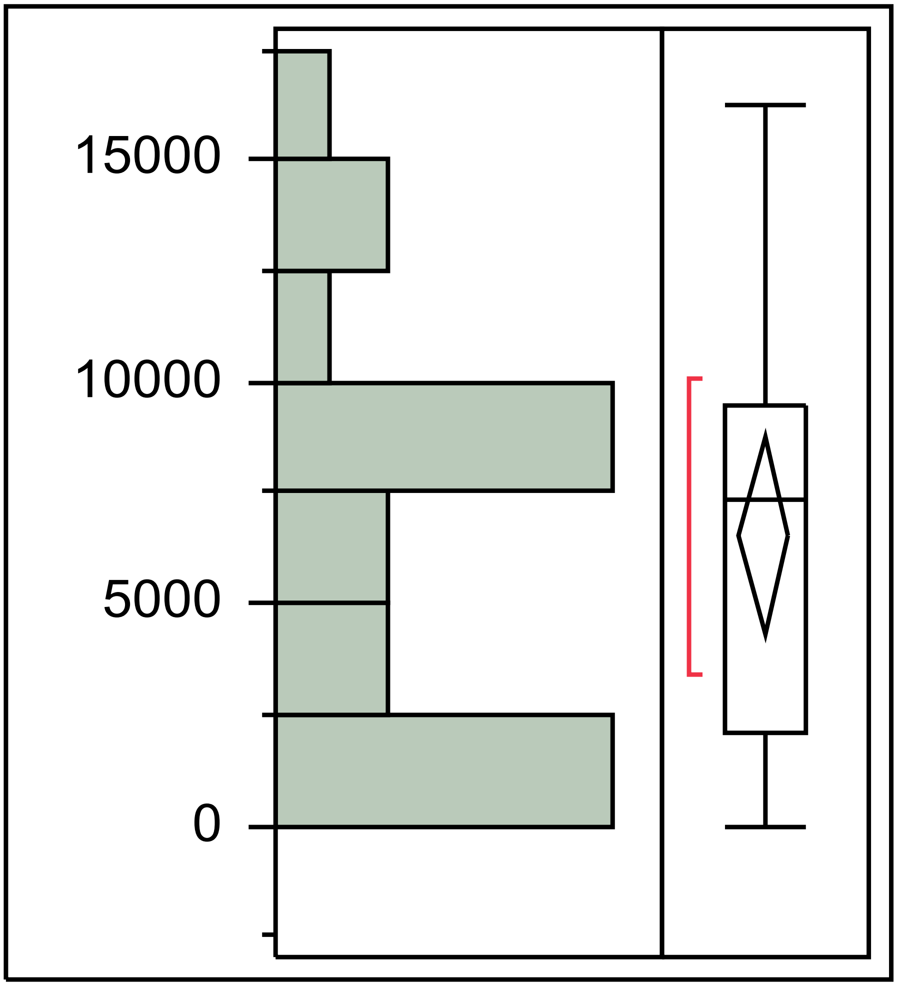

Figure 63. Stewart State Forest all plots. Box plot with whiskers used for determining the presence of outliers, distribution of plots included for reference. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

APPENDIX E

DISTRIBUTION OF VOLUME PER ACRE ESTIMATES BY AGE

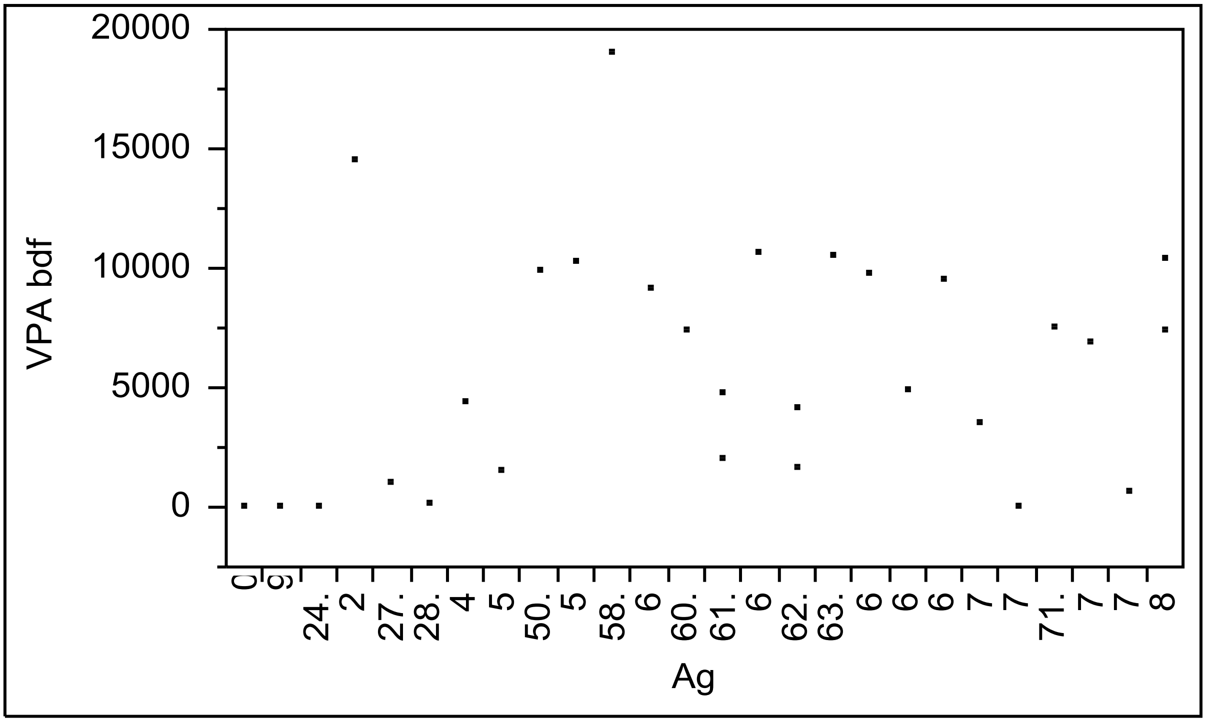

Figure 64. Bledsoe State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

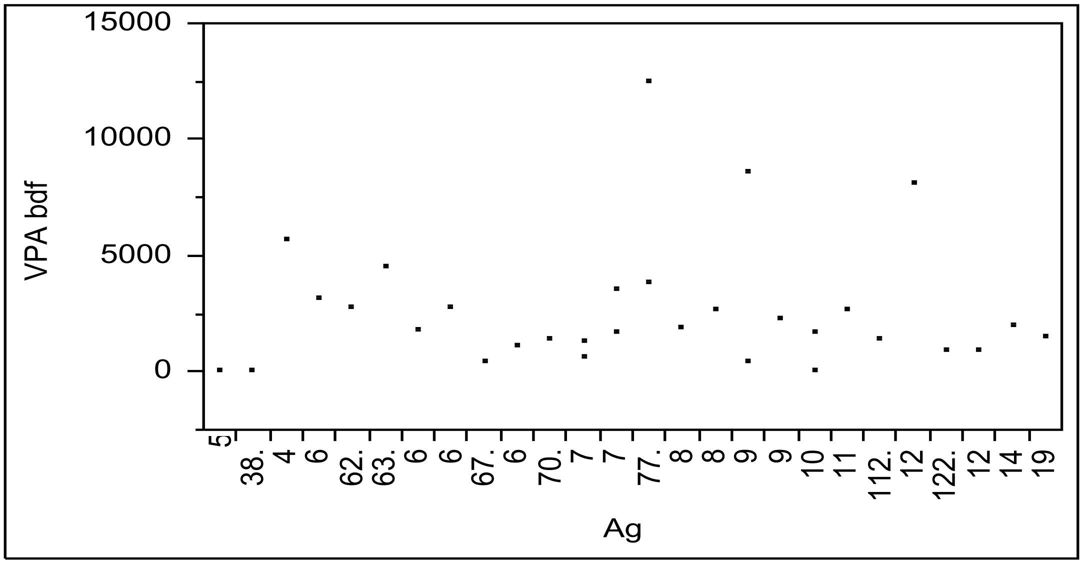

Figure 65. Cedars of Lebanon State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

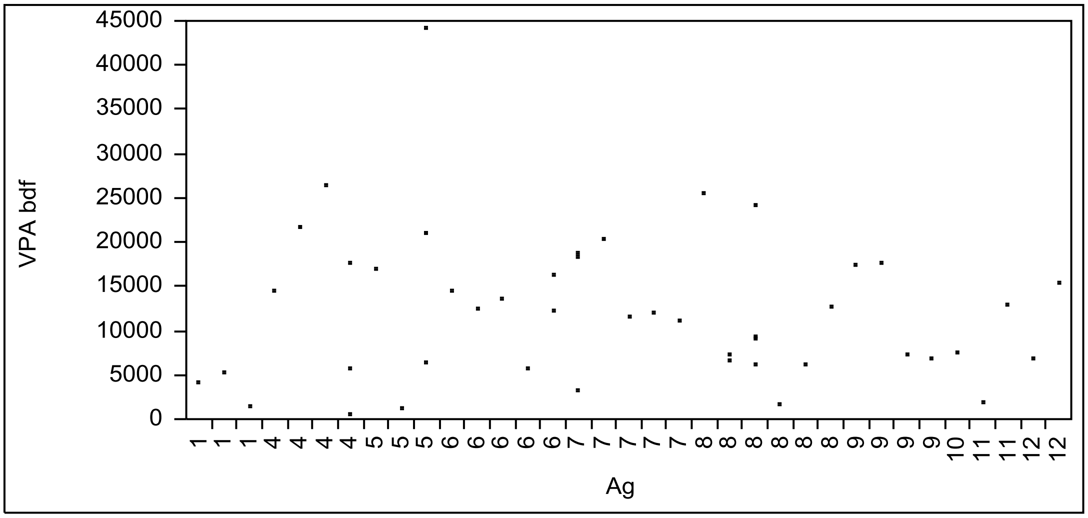

Figure 66. Chickasaw State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

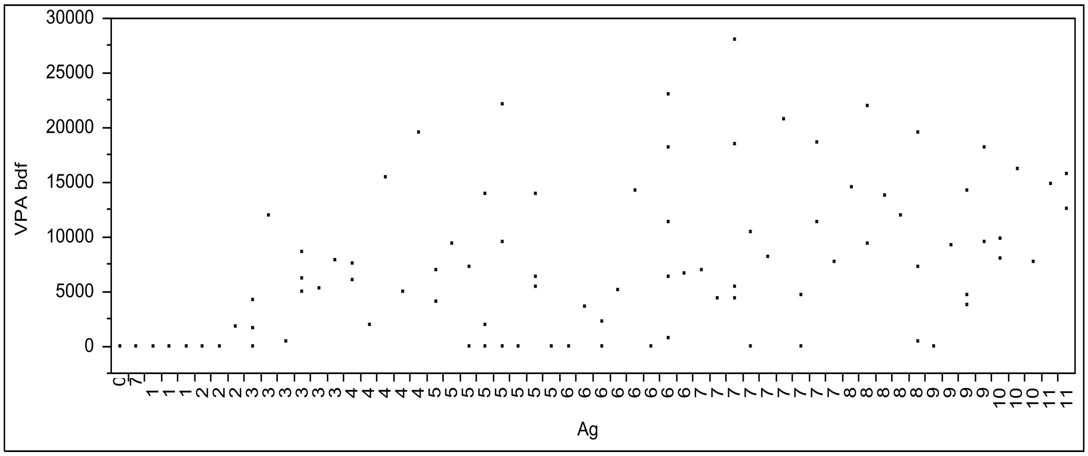

Figure 67. Chuck Swan State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

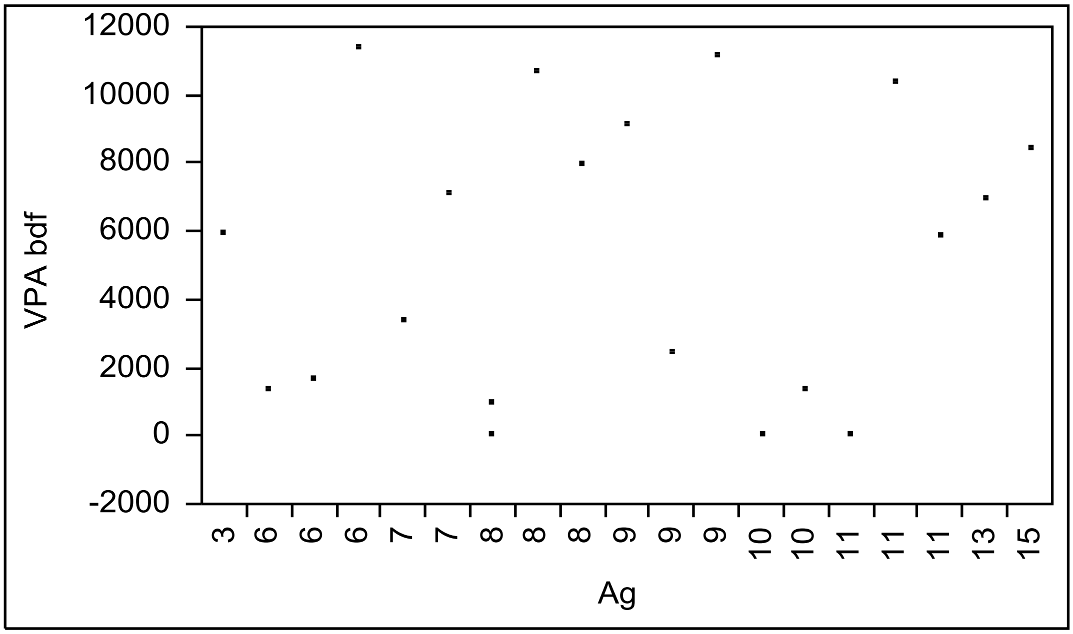

Figure 68. Lone Mountain State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

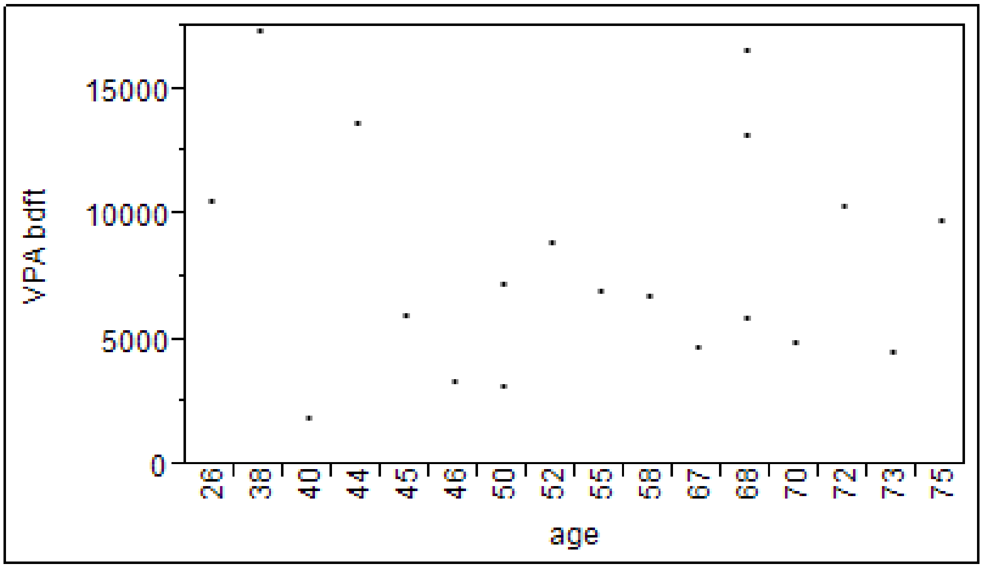

Figure 69. Lewis State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

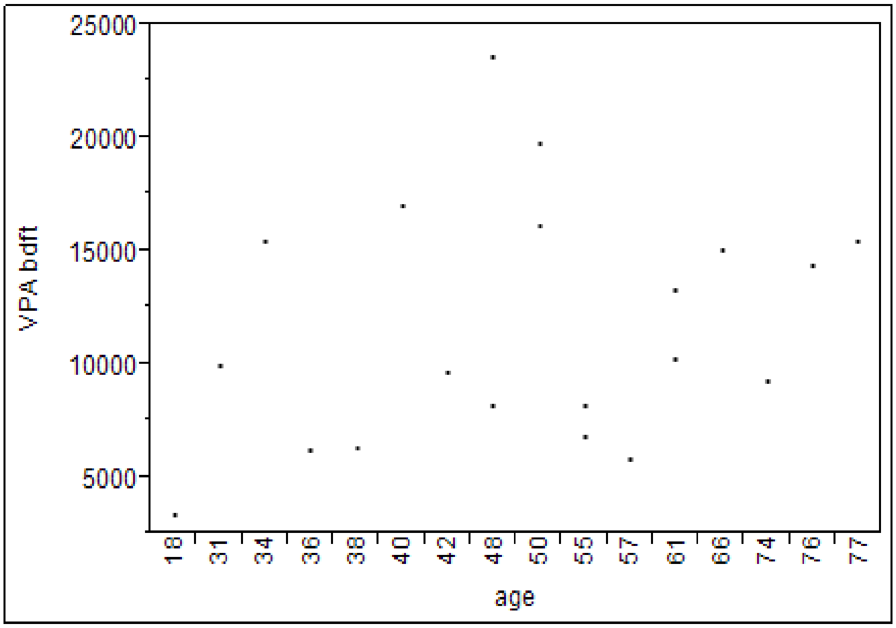

Figure 70. Martha Sundquist State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

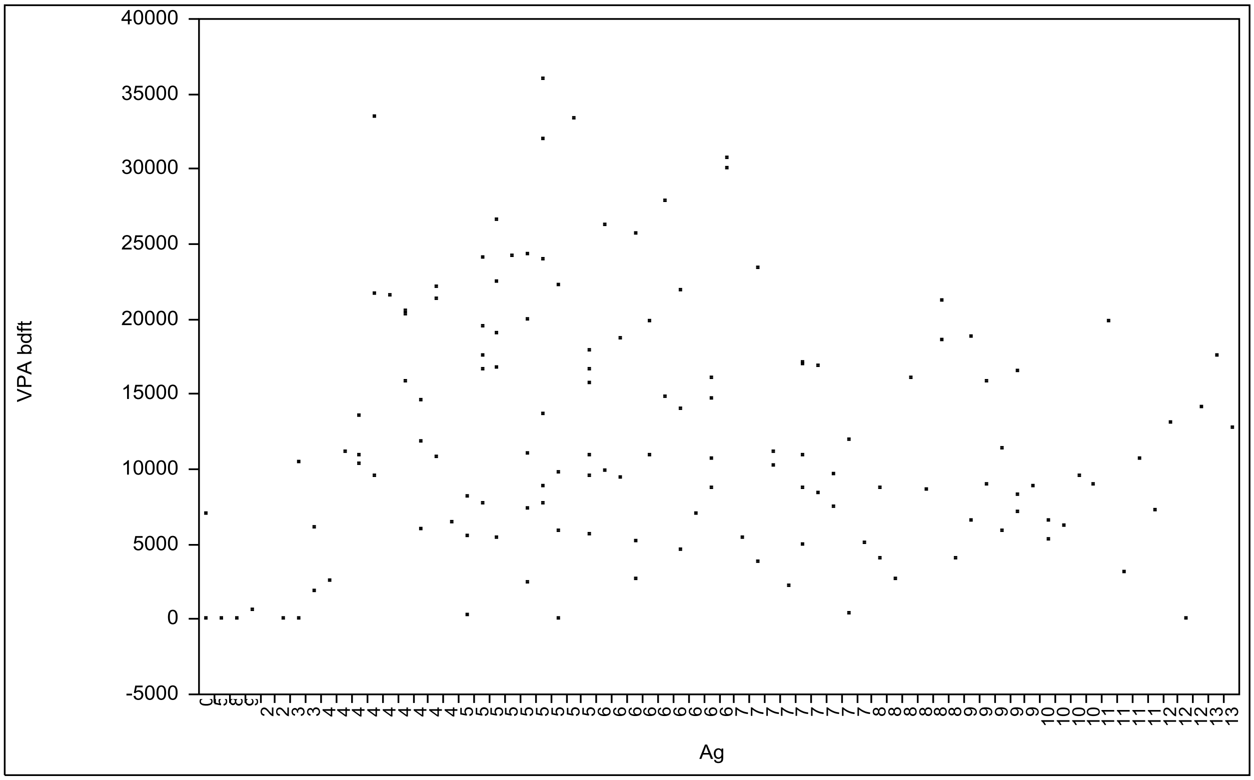

Figure 71. Natchez Trace State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

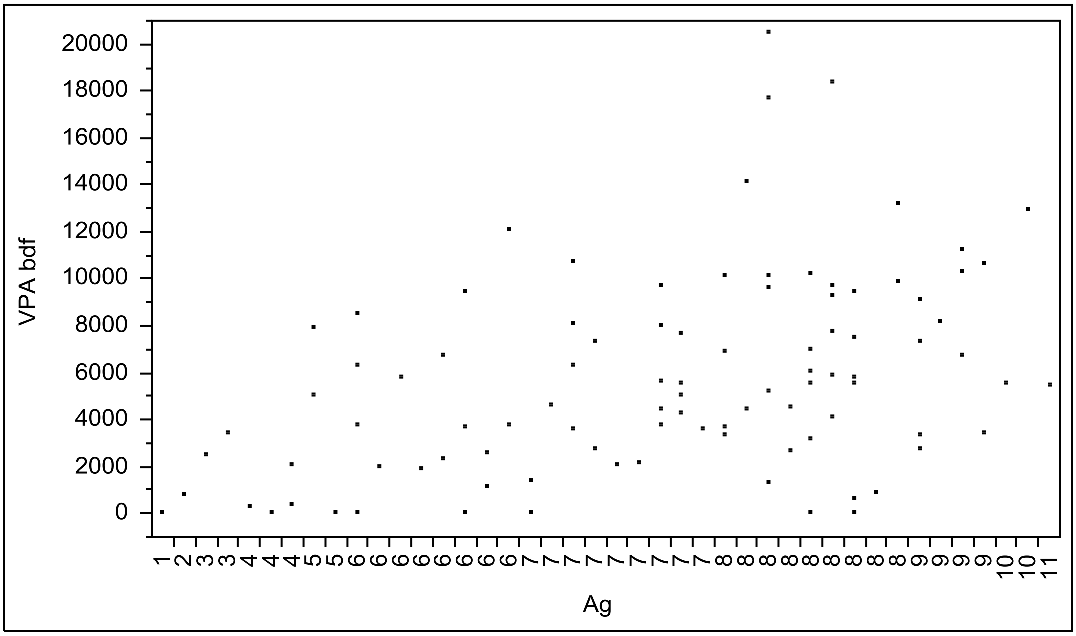

Figure 72. Prentice Cooper State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

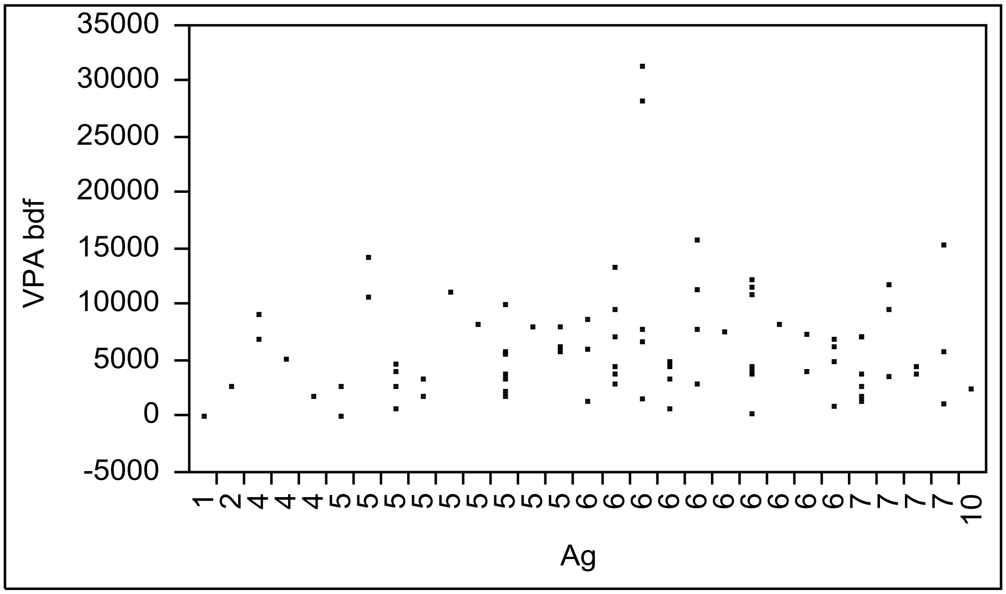

Figure 73. Pickett State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

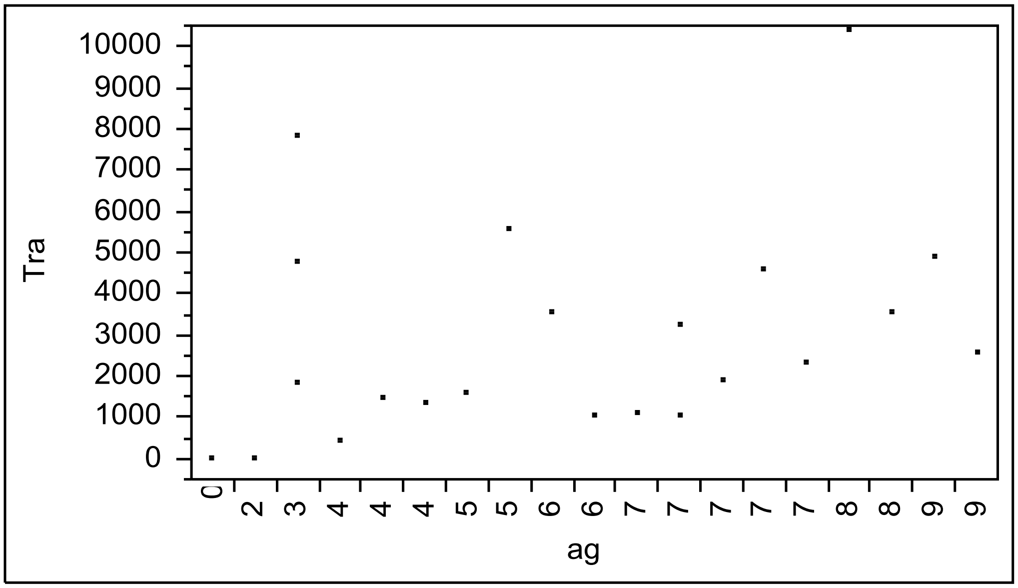

Figure 74. Scott State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

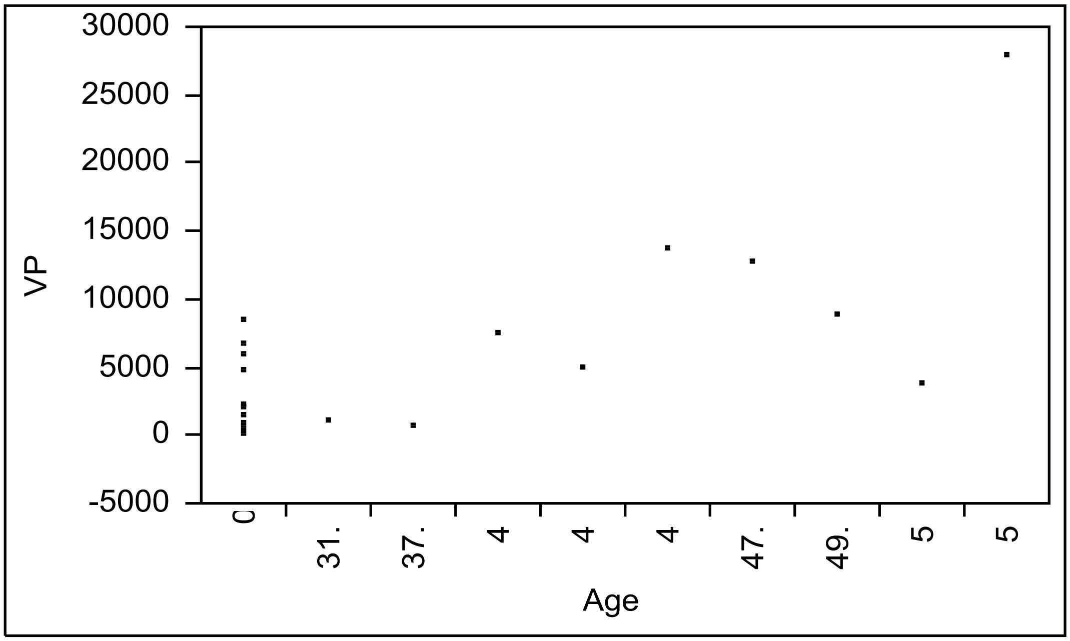

Figure 75. John Tully State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

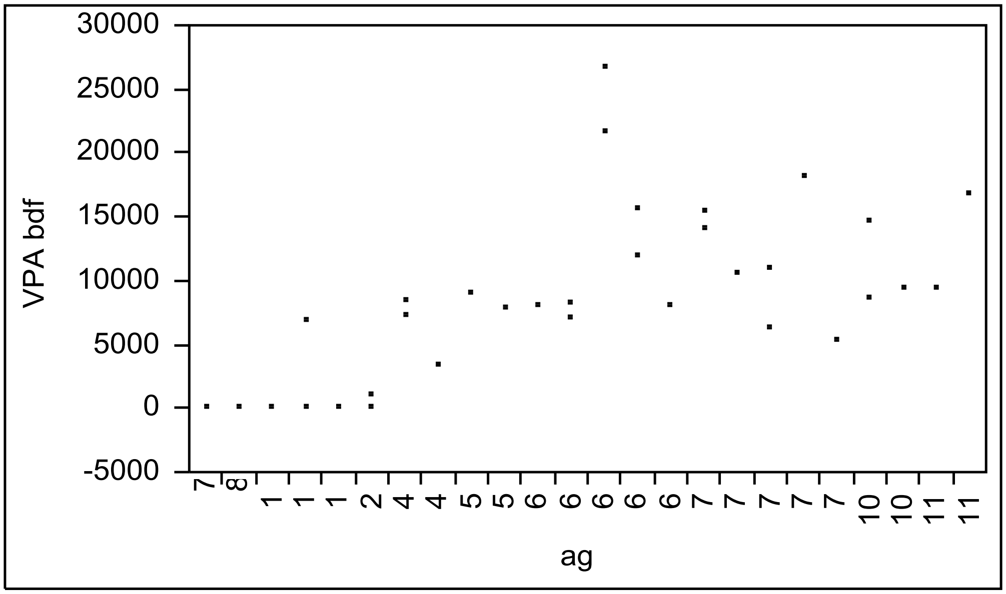

Figure 76. Standing Stone State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

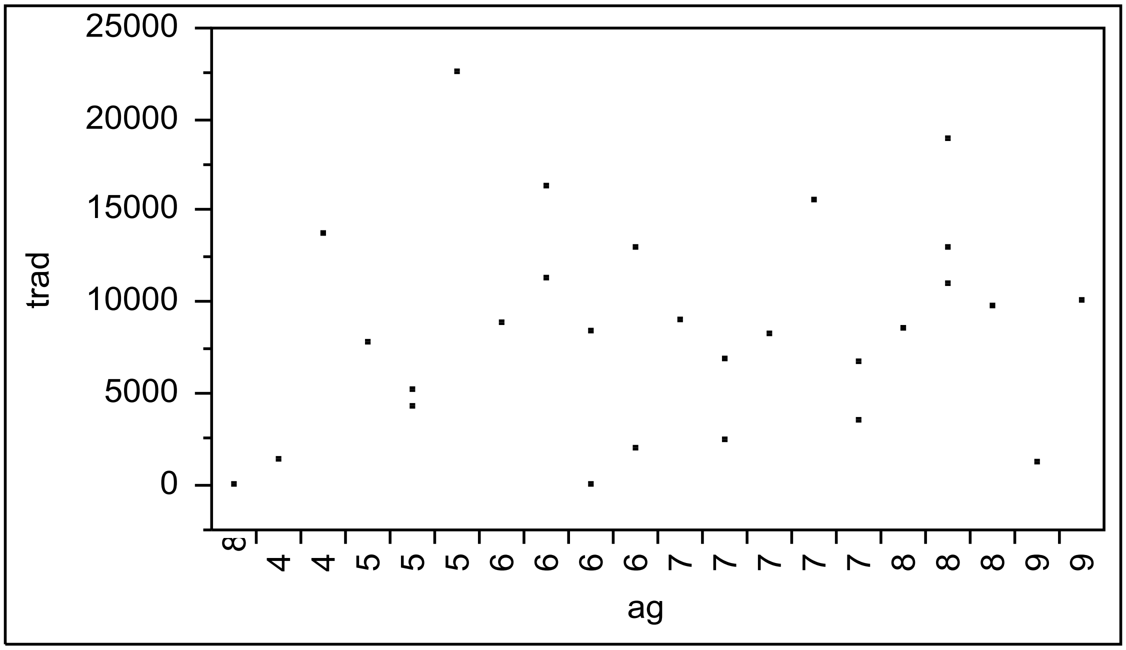

Figure 77. Stewart State Forest distribution of VPA by age. Data collected by TDF in 2007 using 1/5 acre permanent plots in a CFI design. The volume was calculated using FIA's equation (BD000049) (Oswalt et al. 2011).

VITA

Matthew Holt came to The University of Tennessee after graduating from Arlington high school in Arlington, Tennessee. He earned a B.S. in Forestry with a concentration in resource management in 2012. He entered graduate school in August 2012, working towards a M.S. in Forestry concentrating in biometrics. During his tenure as a master's student he worked as a graduate research assistant and graduate teaching assistant. The author is a member of the Society of American Foresters (SAF) and The Forest Guild.