Theses and Dissertations

Theses and Dissertations

1-1-2011

Initial Estimation of Forest Inventory Sizes for Timber Sales from Easily Observed Stand Attributes

Joshua Philip Skidmore

Follow this and additional works at: https://scholarsjunction.msstate.edu/td

INITIAL ESTIMATION OF FOREST INVENTORY SIZES FOR TIMBER SALES

FROM EASILY OBSERVED STAND ATTRIBUTES

By

Joshua Philip Skidmore

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Forestry
in the Department of Forestry

Mississippi State, Mississippi

April 2011

Copyright 2011

By

Joshua Philip Skidmore

INITIAL ESTIMATION OF FOREST INVENTORY SIZES FOR TIMBER SALES

FROM EASILY OBSERVED STAND ATTRIBUTES

By

Joshua Philip Skidmore

Approved:

Thomas G. Matney Professor of Forestry Committee Co-Major Professor	Emily B. Schultz Professor of Forestry Committee Co-Major Professor
Zhaofei Fan Assistant Professor of Forestry Committee Member	Andrew W. Ezell Department Head and Graduate Coordinator of the Department of Forestry
George M. Hopper Dean of the College of Forest Resources	

Name: Joshua Philip Skidmore

Date of Degree: April 30, 2011

Institution: Mississippi State University

Major Field: Forestry

Major Professor: Thomas G. Matney and Emily B. Schultz

Title of Study: INITIAL ESTIMATION OF FOREST INVENTORY SIZES FOR TIMBER SALES FROM EASILY OBSERVED STAND ATTRIBUTES

Pages in Study: 41

Candidate for Degree of Master of Science

Preliminary plots are required when beginning a cruise for a timber sale in order to get an idea of how much variation in volume exists within the sale area. This variation is known as the coefficient of variation (CV) and is subsequently used to estimate the number of plots needed to implement the cruise to a desired level of accuracy (allowable error). By looking at a large number of sale inventories and finding similarities among key attributes (trees per acre, diameter at breast height and an estimate of variance), two models were derived based on simple stand observations to aid field personnel in determining a more accurate estimate of the CV. Furthermore, the models estimate the number of 1/10 acre plots needed to sample a stand to within a $\pm 10\%$ allowable error at the 90% confidence level for total tonnage.

DEDICATION

To my wife Sarah and two children, Jillian and Josiah. I am sorry daddy could not be there during those days and nights he had to work in his office. Thank you for your patience and love throughout this endeavor. Yes, we can color and go play now!

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

v

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

Designing a good timber inventory for purposes of a timber sale is a complicated task and requires not only conceptual knowledge, but skills acquired through years of experience. Inventory sampling methods vary, but often, agency or company employees simply rely on a 10% cruise rule or use a company "standard", not knowing its origin or why they use it (Hamilton, 1979). Due to the fact that most of the revenue involved in forestry business revolves around the timber cruise and subsequent sale of timber, inventory estimation is of utmost importance to the forester's company or client. One of the most common questions about a timber sale cruise is "How many plots do I put in?" Once an appropriate cruise is selected for the timber type, the number of plots that should be installed ultimately depends on the inherent variation in the targeted volume measurements. The methods for determining the required number of sample plots is to use equations for infinite populations (Cochran, 1977) or finite populations (Avery, 2002).

Most field personnel are not familiar with the calculation of CV for measurement variables or do not realize its effects on cruising results. Some are also unfamiliar with confidence levels or sampling errors. Many cruisers in Mississippi are using 1/10 acre fixed plot or basal area factor 10 (BAF 10) prism point methods. When asked how many plots they are putting in, the most common response is 10% (by area) for a fixed plot or 1

1

point per acre for a prism. This is often far too many plots or points, and money as well as time is being wasted.   For small areas the opposite can also be true. Statistically speaking, they may be no more functionally precise in their estimation using a 10% cruise than they would be with a cruise of 8% or less, depending on plot size and variability. There is a great need for easily understood, statistically efficient and economically viable procedures to determine sampling intensity for timber sale inventories. This begins with the use of a software program or by hand calculating the number of samples needed to achieve the desired precision level. To do this correctly, one would need to take sample plots before the cruise began or have a previously known estimate of CV.

T-Cruise® (World Wide Heuristic Solutions Inc. 2010. T-Cruise® and T-Cruise Mobile® software. Version 5.0. Starkville, Mississippi) data was collected from 88 sales conducted by the Mississippi Forestry Commission (MFC) during fiscal year (FY) 2010 and 2011 and is available for statistical analysis and for evaluating the number of plots needed to be statistically efficient at the 90% confidence level within $\pm$ 10% of the volume estimation. This information may be useful in developing an a priori method to determine the number of plots needed to meet selected confidence levels. A priori determination would save the forester from having to install pre-cruise plots, as well as give the cruise planner an estimate of the expected time and financial resources required.

Economic Importance

Harvested timber in Mississippi has traditionally been one of the top economic products of the state. Forested land accounts for approximately 65% of the land base in Mississippi (Oswalt et al, 2009). The value associated with forest products has been over

2

one billion dollars for many years (Henderson et al, 2008) making the estimation of timber value on the stump a very important process.   After 16 years of topping the one billion dollar mark, forestry harvesting impacts in Mississippi fell below this mark in 2009 for the first time since 1992 (Mississippi State University, 2009). This decrease in revenues may be largely attributed to lower timber prices along with the economic recession and less demand for lumber due to the decline in the housing market. During an economic downturn it is even more important to both the timber sellers and buyers that every dollar is accounted for and that a fair price is being paid. The process of selling timber stands starts with the initial cruise to determine what that fair price is. It is also of high public importance when cruises are carried out on Mississippi's sixteenth-section lands as money from these harvests is directly tied to local school systems and educational funding.

Mississippi Forestry Commission Cruising Methods

The Mississippi Forestry Commission is charged with the management of sixteenth-section forest land in Mississippi. These sections of land are public trust lands that were specifically set aside in 1803 (before Mississippi became a state) to provide revenue for the public school system (Clark, 2007). The MFC manages approximately 430,000 acres of forested lands on these sections. In the recent past, the MFC has traditionally placed inventory plots on a 5 x 2 chain grid using 1/10 acre plots (10% cruise) for a final harvest sale or a 1%-5% cruise for a thinning. Prism cruises have also been conducted placing anywhere from one point per acre to one point per ten acres. Both the MFC and timber buyers purchasing the timber have made many sales and purchases using these methods. MFC foresters manually calculated stand volumes using

3

United States Forest Service (USFS) tables (USDA, 1986), WinYield© software (Hepp, T.E. 1994. WINYIELD© software. Version 1.0. Norris, Tennessee), or by using locally created Microsoft Excel® spreadsheets (Microsoft Corporation. 2003. Microsoft Excel® software (2003). Redmond, Washington.). Although many sales occurred, little data was evaluated for precision. Sales were conducted not knowing how close the estimate of volume was to reality or the percent error associated with the estimates. Timber was sold by the ton, cord or per thousand Doyle board feet (DMBF). Scale tickets were not required of buyers and data was not kept to determine if sales were actually meeting predicted standing volumes.

The inconsistent implementation of inventory methods and volume estimation statewide had a direct correlation to a lack of knowledge about alternate cruising techniques, the cost of needed equipment, current software options, and proper training of employees. Much of the cruising was done by individuals who did not have the scholastic background that registered foresters must now obtain. Many cruisers, thinking they were increasing quality, over-cruised a stand but instead were wasting both time and money by doing more work than necessary without improving results. Adopting proper cruising techniques and having increased precision levels for a cruise leads to increased confidence in a bid acceptance or rejection by those who have cruised stands to a statistically sound level.

During FY 2010, the MFC conducted 345 timber sales resulting in approximately $30 million in revenue for the state and local school systems (McGinnis, R. 2010. Personal communication. District Forester for the Capital District, Mississippi Forestry Commission. Jackson, MS. July 11). In FY 2010 the MFC began a new inventory system on timber sales utilizing hand-held data recorders (RECON® and NOMAD® sold by

4

Trimble, Inc. 2010. Sunnyvale, California.), with SOLO Forest® (Tripod Data Systems Inc. (TDS). 2010. SOLO Forest® software. Version 4.0.5. Corvallis, Oregon), GIS, T-Cruise® and T-Cruise Mobile® inventory software. MFC foresters began to incorporate random cruise design as well as stratification into their cruising regime. Data were downloaded from the hand-held data recorders to T-Cruise® on a personal computer (PC) for all timber sales. Detailed reports are kept to document sale precision, volumes, revenues and sale history. However, the question of how many plots will be required still arises at the outset of a timber sale.

Forest Inventories

Conducting a sound forest inventory is a complex combination of purposeful planning, statistical knowledge and consistent field input (experience). Depending on the desired summary reports, inventories can span from collecting information about a specific stand to an entire forest at a regional level. The techniques used to implement an inventory depend on the outputs desired and the size of the inventory. They should always be designed based on the purpose they serve. Poorly designed or implemented cruises for a sale or for management and planning can cause large errors and result in high costs to individual landowners (Borders et al, 2008).

Large scale inventories such as the nationwide USFS Forest Inventory and Analysis (FIA) inventory require many samples over varying ecosystems (Frayer, 1999). The purpose of FIA is to document species composition, acreage and how the ecosystem changes over time (USDA, 2010). This inventory is appropriately precise on a substrate or regional level, but not on a county or stand level. The Mississippi Institute for Forest Inventory (MIFI) was created to develop and maintain a state inventory designed to

5

obtain spatially oriented estimates of volumes/weights/biomass by forested stand and tree attributes (Parker et al, 2005). The MIFI inventory provides county level estimates of cubic feet of wood and bark from stump to the pulpwood top with an error of +/- 15% at the 95% confidence level. Although the MIFI estimates are more precise at the county level than FIA estimates, neither inventory is suitable for the relatively small areas involved in timber sales. Stand level inventories must be specifically designed to precisely measure stand and tree attributes for estimating volumes/weights/biomass for timber sales and management planning.

Inventory Training and Implementation

Training and oversight in timber cruising are important factors in conducting proper timber inventories. FIA plots are monitored by highly trained field foresters. These foresters undergo a rigorous training regime and are monitored and checked often by their supervisors (Bingham, B. 2010. Personal communication. FIA Coordinator, Mississippi Forestry Commission. Tupelo, MS. July 8). FIA employees have a pre-designed cruise, with permanent plots using standards set forth by the USFS for measuring the plots. These inventory locations and methods do not vary and serve a different purpose than a timber sale cruise. With timber sales, each sale is unique in respect to products, size, location and stand condition; therefore, a standardized approach to every timber sale will not work. MFC foresters normally supervise a one to two county area and sell timber only on the forested sixteenth-section stands in their area. Any one forester may only cruise and sell three to five stands a year. Thus, the field personnel do not get routine practice and training. Infrequent cruising can create problems due to lack of experience. Two stands that may look similar to a cruiser may

6

actually result in highly variable estimates of tonnage and errors when the same numbers of plots are installed. This may not be a serious problem with timber buyers who cruise on a daily basis, but they could also benefit from a priori sample size determination in the case where the number of plots could be reduced saving time and money.

Another aspect of implementing good inventories is an understanding of random sampling techniques. Many foresters may not be using random sampling techniques because of a lack of knowledge concerning random cruise design. Grid cruising has been the normal procedure used by the MFC and the timber buyers with whom they deal. Random plot design is important because random plots lend themselves to inventory designs with fewer plots when stands are stratified correctly. With a random sample, the forester can start with a fewer number of plots at the outset and add random plots as needed using plot allocator software or other random methods. They also have the option to create more plots than they need while only sampling a fraction of them initially. However, either of these methods can be deceptive and dangerous because in order to add or delete plots and maintain a random design, the plots must be visited (measured) in a completely random order as well. Foresters are unlikely to visit plots in a random order over a sampling area because of the additional time required in walking through the same stand areas multiple times.

Determining Sample Size

CV is a measure of the standard deviation in relation to the mean (Freese, 1962). It is a unitless number which is useful in many statistical analyses as it allows comparison of two samples which may not be identical in size, method of collection or other variable, such as species diversity. A low CV indicates that the required sample size will be lower

7

than with a high CV. In forested stands, a CV of 30 or less is usually considered low (a uniform stand). A stand with a CV in this range would have consistent tree per acre (TPA) counts as well as similar size diameters at breast height (DBH), basal area (BA) and product designations. Many young stands which have never been thinned or experienced any major events (like fire, hurricane or insect damage) which might alter the stand makeup would fall into this category. Alternately, stands with a CV over 50 have a higher degree of variability in tonnage measured among plots.

The CV of a sample, as well as the plot size and total stand acres, may affect the required number of plots if a finite population equation is used to calculate sample size. If the infinite population equation is used, CV is the only influence when allowable error remains constant. The infinite population sample size estimation equation will be the primary focus of this study as almost all samples were over 30 acres, making stand size less influential in sample size calculations. Sample size estimates based on CV have been previously developed. Howard Stauffer (1982) created a sample size table using iterative methods for simple random sampling. If CV is known or estimated, the table is useful at the 95% confidence level for various allowable error levels. Standards used by the MFC require a 90% confidence level.

Generally speaking, larger plot sizes and larger sample numbers (number of plots) will reduce the error by reducing the variance per plot and the standard error or variance around the mean (Xiao et al, 2004; Evans and Viengkham, 2000). Reduced error will in turn reduce the number of plots required to achieve the desired level of precision. Sample size has been defined as a function of the allowable error (R), the confidence level (t-value), and the error as it relates to the mean (CV) (Lynch, 2003). The iterative sample size estimation equation for finding the appropriate number of sample plots

8

needed to meet the statistical precision of $\pm$ 10% of the total tonnage at the 90%

confidence level for an infinite population is:

$$n_{i+1} = \left(\frac{CV * t_{n-1,\alpha/2}}{E} \right)^2$$

(1)

Where:

n_{i+1} = the number of plots needed; CV = coefficient of variation; E = the allowable error;

$t_{n-1,\alpha/2}$ = student's t-value at n-1 degrees of freedom.

The allowable error (E) in all sales examined remains constant at 10%. The t-

value at the 10% level for an infinite population at α=.05 is 1.645. Equation 1

demonstrates that CV is the only measurable influence on sample size.

The iterative sample size estimation equation for finding the appropriate number

of sample plots needed to meet the statistical precision of $\pm$ 10% of the total tonnage at

the 90% confidence level for a finite population is:

$$n_{i+1} = \cfrac{1}{\cfrac{1}{N} + \left[\cfrac{E}{\left(t_{n_i-1,\alpha/2} \right) CV} \right]^2}$$

(2)

Where:

n_{i+1} = the number of plots needed; N = the population sample size; E = the allowable error

percentage as a whole number; $t_{n-1,\alpha/2}$ = student's t-value at n_i -1 degrees of freedom; CV

= coefficient of variation.

Using Equation 2, stand size becomes a factor as well, though stand size tends to

have less influence as it increases. This is the equation used by T-Cruise. The equation

repeats until "n" repeats.

9

Determining Plot Size

An interesting concept to note when using Equation 1, is that regardless of plot size (or use of a prism), the CV becomes the only variable when precision levels are constant.   Using a 1/10 acre is no better or worse than a 1/20 acre plot if the CV is the same. Although one may choose any plot size, the overall variability of the stand remains the same. Larger plot sizes typically have a lower CV if spatial distribution is truly random. The plot size will determine how much of that variability is accounted for with a plot. For example, if one examines two plots from a fictional cruise in a stand of large, mature sawtimber, a 1/20 acre plot will have a higher CV when compared to a 1/5 acre plot in the same stand. A 1/20 acre plot size could include a plot with four sawtimber trees or a plot with only one tree. The variation in volume (standard deviation) and CV between the two plots would be high. Therefore, many samples would be required to meet the precision goals. Conversely, if a larger plot size were used (1/5 acre), the average volume on each plot should have a smaller associated variation from plot to plot (if for example both plots tallied 12 trees).

Fewer plots are needed when using larger plot sizes, though larger plots take more time to implement. Plot optimization methods like those developed by Zeide (1980) for deciding on the number and size of plots should be used in determining the type of plot. Zeide (1980) showed that the optimum plot size is one which allows the same amount of time to take the plot as it takes to travel between plots while still achieving a desired accuracy. The main concept to remember is that the larger the plot size, the lower the variability of the volumes among plots. Larger plot sizes result in lower CV estimates and fewer plots required to meet a desired level of precision, yet smaller plot sizes may accurately capture CV and are easier to implement.

10

Objectives

The study objective was to create a decision model that could be used by timber cruisers in the field to help them estimate the required number of plots needed (before the cruise began) by answering some easily measured or estimated stand attributes. This would help cruisers achieve statistical efficiency on a timber cruise without the cost of taking sample plots to determine CV. Another benefit of this type of model is that cruisers would not need to understand CV or have to measure it directly.

Using T-Cruise® software, the MFC conducted cruises to estimate the tonnage of individual timber products (per acre and total) for a timber sale. Timber is sold by the MFC in tons for pulpwood, chip-n-saw and sawtimber. Due to the availability of data under current MFC standards, estimates of the plots needed to achieve a +/- 10% allowable error at the 90% confidence level on a total tonnage basis using 1/10 acre sized plots was the primary focus of this study.

11

CHAPTER II

METHODS

Data Collection

Eighty-eight, 1/10 acre timber inventory sale data files (T- Cruise® data files)

were collected from MFC FY 2010 and 2011 timber sales. Timber sales occurred for

different products and species. The two general classes of species groups used by the

MFC were pine and hardwood. Products for pine included pulpwood, chip-n-saw, and

sawtimber. Hardwood products were categorized as pulpwood, pallet or sawtimber.

Although some local variations existed in how data were actually collected in the field,

the general rules used in product classification are given in Table 1:

Table 1   Product top and diameter limits used by the MFC during timber sale
             inventories in FY 2010 and FY 2011.

Species Group	Product	DBH Size Class
Pine	Pulpwood (3" top)	4.6" – 7.5"
	Chip-N-Saw (6" top)	7.6" – 10.5"
	Sawtimber (8" top)	10.6" +
Hardwood	Pulpwood (4" top)	4.6" – 7.5"
	Pallet (6" top)	7.6" – 11.5"
	Sawtimber (10" top)	11.6" +

The MFC precision goal for sale cruises was a $\pm$ 10% error of the total tons per

acre at the 90% confidence level (Skidmore, 2010). This was the standard for every

stand when it could be achieved cost-effectively. All final harvest (clear-cut) sales met

12

these standards with a maximum cruise set at the 10% level. A 10% cruise was the common cruise used by buyers who were bidding on MFC timber. The reasoning behind the maximum 10% cruise standard was that since the buyers were cruising to this level, any disagreement on volumes would not be due to a difference in percent cruise. All pay-as-cut (PAC) sales were cruised to the same precision level until a maximum of a 5% cruise had been conducted. PAC sales are sales where timber is purchased and paid for per unit (per ton in this study) as it was cut. The 5% maximum cruise was used on these sales as they usually represented a thinning and generally required fewer plots to achieve precision goals. The thinnings were also monitored pre-, during and post-harvest so a lower percentage cruise was deemed acceptable.

Analysis

Field data entered into T-Cruise Mobile® software included the species group, DBH, product class and height (merchantable or total) for each tree. These measurements were later downloaded into T-Cruise® on a PC where volume was computed based on the parameters set in templates. Tree volumes were based on profile equations assigned to each species group and measured tree DBH and height. CV estimates were derived from the statistical reports produced for the entire cruise and not by species or product. Sales were conducted and information processed on a tonnage basis. T-Cruise .tcd files contained the templates and embedded data. There were 11 template options available to the employees of the MFC, which were updated at least 3 separate times within the 2010 fiscal year. There was a slight difference in volume calculations between updates in these templates. Reports from the sale data were examined using T-Cruise Reports® software (Landmark Spatial Solutions LLC, 2010. T-

13

Cruise Reports® software. Warner Robbins, GA). Statistical reports were run at the 90% confidence level for total tonnage.

Once the data was processed through T-Cruise Reports®, it was manually exported to a Microsoft Excel© spreadsheet. Data recorded on each sale included: county, location, type of sale (final harvest or thinning), cover type (pine, hardwood or mixed), average DBH, average BA, average TPA, stand acres, CV, standard error, standard deviation, average tons per acre (total of all product classes), and plots required (TPR) by T-Cruise® to meet statistical goals. Other data gathered by field personnel or calculated by hand included an estimate of variability (VAR), years since last disturbance, type of last disturbance (thinning, storm, or fire) and estimated percent damaged or removed timber.

An estimate of variability data (VAR) was calculated using information from T-Cruise Reports® and was divided into three categories: low, average and high. Categories were based on the average standard deviation in volume. Low variability stands had a standard deviation of less than 24.9 tons per acre. An average variability stand had a standard deviation of 25-39.9 tons per acre and a high variability stand had a standard deviation of 40 tons per acre or greater. These limits were based on natural breaks found in the line graphs of the standard deviations of the observed data sets. Low variability stands composed 27% of the samples, average variability sands composed approximately 56% of the samples and high variability stands 17% of the samples.

The above data categories were initially used to examine the relationships among categories, their significance to CV, and the number of plots required. Regression analysis and scatter plots were used to examine data for evidence of linear or non-linear

14

relationships. Tests conducted between variables in Microsoft Excel© are summarized in Table 2.

Table 2   Variable pairs examined for linear and non-linear relationships using regression and scatter plots.

Variable Pair [a]				Variable Pair [a]		
TPA	vs.	CV		Cover Type	vs.	CV
lnTPA	vs.	CV		Years	vs.	CV
DBH	vs.	CV		Acres	vs.	CV
lnDBH	vs.	CV		VAR	vs.	CV
BA	vs.	CV		CV	vs.	TPR
lnBA	vs.	CV				

a)   ln = natural logarithm; Cover Type = pine, mixed or hardwood; Years = number of years since last disturbance; VAR = estimated variance of a stand; Acres = acres sold in the sale; TPR = plots required by T-Cruise®

Once the initial relationships were examined, SAS® 9.2 (SAS Institute Inc. 2009. SAS® software. Version 9.2. Cary, North Carolina) was used to get detailed statistical information on those relationships that emerged as important from the original scatter plots obtained in Microsoft Excel©. The natural log of the average DBH of the stand (lnDBH), the natural log of the average TPA of the stand (lnTPA), and the estimate of variability (VAR) based on the standard deviations of individual sales emerged as promising factors.   A multiple linear regression was conducted using these three variables to predict CV. A second multiple linear regression was also examined using lnDBH and lnTPA without the use of VAR to reduce the necessity of estimating this variable in the field.

Only sales which met the MFC standard of $\pm$ 10% error at the 90% confidence level or had been cruised to within two plots of achieving this level were used for final modeling. Therefore, the final data set examined included 88 sales for tonnage. All of

15

the inventories examined for this study were 1/10 acre cruises. There were not enough useable sales to compare categories such as 1/20, 1/5 or BAF 10 cruises independently. Modeling was checked to ensure no linear violations occurred. The predicted CV was then used to calculate the plots required for infinite populations using Equation 1 and for finite populations (similar to T-Cruise®) using Equation 2.

16

CHAPTER III

RESULTS

Equation 3 predicts the CV of an inventory sale conducted on a total tonnage

basis where the allowable error is $\pm$ 10% at the 90% confidence level.

CV = 338.22976 - (61.41485*lnDBH) - (32.79829*lnTPA) + (9.15326*VAR)　　　　(3)

Adjusted R^2=79.6%, Root MSE = 5.73

Where:

lnDBH = the natural log of the average DBH of the stand; lnTPA = the natural log of the

average TPA of the stand; and VAR = an estimate of variance based on standard

deviations between plot volumes (low, average or high).

.
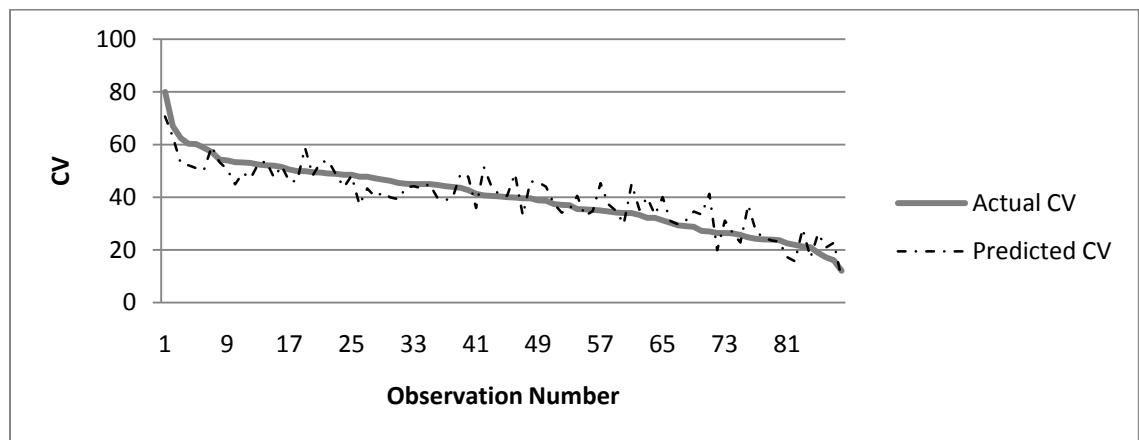
Figure 1　　　Graph of the actual CV versus the predicted CV from 88 1/10 acre timber
　　　　　　sale inventories using Equation 3 (with the variance estimate).

17

Table 3   Comparison of Predicted CV versus Actual CV using Equation 3 and data
         from 88 1/10 acres timber inventories.

Actual CV	Percentage of total plots
Within 5	66%
Within 10	94%
Within 15	100%
Average underestimated CV	-5
Average overestimated CV	5

An alternate equation (Equation 4) was developed for cases where variance could

not be estimated by field personnel or where a less precise initial estimate was allowable.

$$CV = 278.79004 - (39.67178 * lnDBH) - (29.56239 * lnTPA) \tag{4}$$

Adjusted R^2=63.4%; Root MSE = 7.68

Where:

lnDBH = the natural log of the average DBH of the stand; lnTPA = the natural log of the

average TPA of the stand.
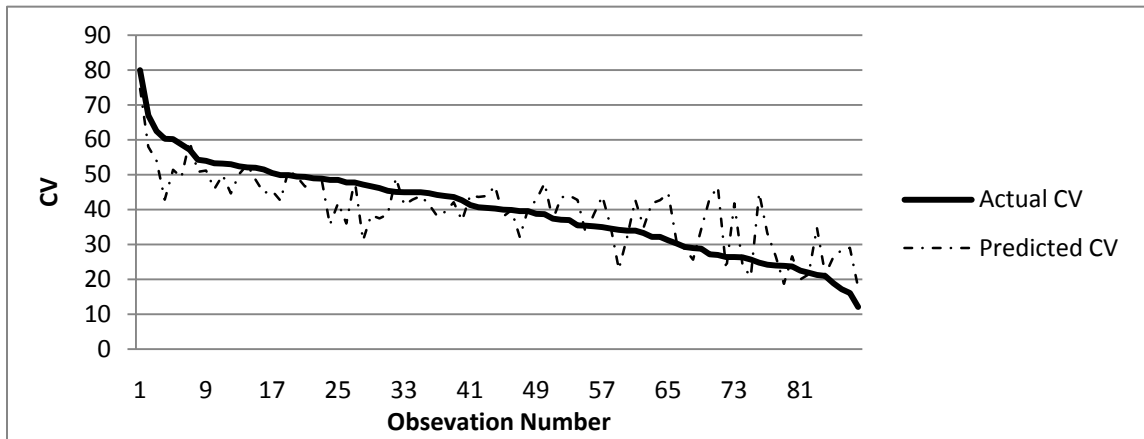
Figure 2   Graph of the actual CV versus the predicted CV from 88 1/10 acre timber
         sale inventories using Equation 4 (without the variance estimate).

Table 4   Comparison of Predicted CV versus Actual CV using Equation 4 and data from 88 1/10 acre timber inventories.

Actual CV	Percentage of total plots
Within 5	55%
Within 10	84%
Within 15	94%
Average underestimated CV	-6
Average overestimated CV	7

Estimated CV's were then used to calculate the estimated number of plots needed to achieve the desired statistical precision from Equation 1 (infinite population) and Equation 2 (finite population).

Table 5   Summary of the estimate of the calculated number of plots to estimate per acre tonnage at the 90% confidence level for selected CV's using Equation 3 with an infinite population.

Sample Size = 88	Number	Percent
# plots overestimated	42	48%
# plots underestimated	43	49%
Highest Estimate Difference	29	
Lowest Estimate Difference	-24	
Actual Plots Needed	Number	Percent
Within 5	31	35%
Within 10	60	68%
Within 15	68	77%
Within 20	78	89%
Within 30	88	100%

Table 6   Summary of the estimate of the calculated number of plots to estimate per acre tonnage at the 90% confidence level for selected CV's using Equation 3 with a finite population.

Sample Size = 88		
	Number	Percent
# plots overestimated	45	51%
# plots underestimated	39	44%
Highest Estimate Difference	26	
Lowest Estimate Difference	-31	
Actual Plots Needed	Number	Percent
Within 5	35	40%
Within 10	58	66%
Within 15	72	82%
Within 20	76	86%
Within 30	87	99%

Table 7   Summary of the estimate of the calculated number of plots to estimate per acre tonnage at the 90% confidence level for selected CV's using Equation 4 with an infinite population.

Sample Size = 88		
	Number	Percent
# plots overestimated	40	45%
# plots underestimated	43	49%
Highest Estimate Difference	38	
Lowest Estimate Difference	-44	
Actual Plots Needed	Number	Percent
Within 5	31	35%
Within 10	49	56%
Within 15	61	69%
Within 20	74	84%
Within 30	84	95%

Table 8   Summary of the estimate of the calculated number of plots to estimate per acre tonnage at the 90% confidence level for selected CV's using Equation 4 with a finite population.

Sample Size = 88		
	Number	Percent
# plots overestimated	42	48%
# plots underestimated	42	48%
Highest Estimate Difference	37	
Lowest Estimate Difference	-44	
Actual Plots Needed	Number	Percent
Within 5	32	36%
Within 10	49	56%
Within 15	63	72%
Within 20	74	84%
Within 30	84	95%

Equation 3 was then used within a Microsoft Excel® spreadsheet to create printed table versions of the sample size estimator (Tables 9-11). The infinite population sample size estimation equation was chosen as it was slightly better at estimating sample sizes. It estimated 100% of the cruises within 30 plots (compared to 99% using finite populations) as well as having a smaller difference between the highest and lowest estimates (29 and -24 versus 26 and -31 for the finite populations, see Tables 5-8). Values were created for all three variance classes, in one-inch diameter groupings and five TPA stocking levels.

21

Table 9   Number of 1/10 acre plots needed in a low variance stand.

DBH	TPA				
	75	150	225	300	450
6	203	110	69	46	21
7	161	80	46	27	10
8	129	58	29	15	
9	103	41	18	10	
10	82	29	10		
11	66	19			
12	52	12			
13	41	10			
14	32				
15	25				
16	19				
17	14				
18	10				
19					
20					

Table 10   Number of 1/10 acre plots needed in an average variance stand.

DBH	TPA				
	75	150	225	300	450
6	248	144	96	68	37
7	201	109	68	45	20
8	165	83	48	29	10
9	136	63	33	17	
10	112	47	22	10	
11	93	35	14		
12	76	25	10		
13	63	18			
14	52	12			
15	42	10			
16	34				
17	27				
18	22				
19	17				
20	13				

Table 11   Number of 1/10 acre plots needed in a high variance stand.

DBH	TPA				
	75	150	225	300	450
6	298	183	128	96	58
7	246	143	95	68	36
8	206	113	71	47	22
9	173	89	52	32	12
10	146	70	38	21	10
11	124	55	27	13	
12	105	42	19	10	
13	89	33	12		
14	76	25	10		
15	64	18			
16	54	13			
17	45	10			
18	38				
19	31				
20	26				

Similarly, a table was created for the case where no variance levels were estimated by the cruiser (Table 12). The errors associated with Table 12 are somewhat higher (see Tables 5 and 7), but the cruiser does not have to make field estimates of variance.

23

Table 12   Number of 1/10 acre plots needed without requiring an estimate of variance.

DBH	TPA				
	75	150	225	300	450
6	173	96	61	41	20
7	148	77	47	29	12
8	128	63	35	21	10
9	111	51	27	14	
10	97	42	20	10	
11	85	34	15		
12	75	28	11		
13	66	23	10		
14	58	18			
15	52	15			
16	46	12			
17	41	10			
18	36				
19	32				
20	28				

CHAPTER IV

DISCUSSION

Regression Equation 3 for CV (using variance) estimated 100% of the 88 data samples (residuals) within 15 of the actual CV. This is a stronger model than expected; however, the cruiser must make an estimate of the variability of the stand. Equation 4 (without variance) estimated 94% of the 88 samples within 15 of the actual CV which is still considered acceptable. The cruiser only makes estimates of TPA and DBH in this instance, reducing judgment calls and erroneous estimates. Although error estimates are higher using Equation 4 rather than Equation 3, Equation 4 may be selected for use as it works well and has fewer inputs by field personnel.

In stands greater than 30 acres, the infinite population equation (Equation 1) is appropriate as the acreage component becomes less influential compared to the finite sample size equation (which incorporates acreage into the calculation). The average acreage for a timber sale in the data was 110 acres, with the smallest sample at 28 acres. The samples were for all practical purposes infinite populations. If Equation 1 for estimating the required sample size of an infinite population is used for calculating the required number of plots, the only variable is CV at the fixed confidence and error levels, reducing potential errors. The differences in the results of using finite or infinite population estimation equations were minimal, as can be seen by comparing Tables 5 versus 6 and Tables 7 versus 8.

25

While examining estimates of the number of plots required, the largest plot prediction errors (differences from one category class to another) were in stands containing smaller diameters trees and lower numbers of trees per acre, regardless of the estimated variance. The general conclusion is that sample size estimates are predicted with less error (when misclassification occurs) in stands of larger diameter trees and higher number of trees per acre. Also, stands with larger DBH's and higher numbers of TPA have lower variability in volumes, meaning a lower CV for tonnage and fewer plots are required to achieve the desired precision goals. It is further recommended that at least ten plots should be taken for any cruise.

The estimation of CV using the model that includes stand variance (Equation 3) is an important one as it can alter the number of estimated plots by an amount that can make cruising inefficient. Field personnel may find it hard to provide pre-cruise field estimates of variance. For descriptive purposes, a low variability stand has a consistent number of trees per plot and diameter measurements of tallied trees should be tightly grouped. Product classification, species and merchantable heights should also be consistent among plots. The expected tonnage standard deviation should be less than 24.9 tons per acre to be considered low. Low variability stands comprised 27% of the stands sampled. Average variability stands should have a standard deviation range of 24.6-39.9. These represented about 56% of all stands sampled. High variability stands should vary at least 40 tons per acre and have inconsistent numbers of trees per plot and inconsistent diameter measurements between plots (larger ranges). These stands may have scattered groups of merchantable trees or tree species, highly variable merchantable heights, or the stand may not be stratified correctly (which could reduce variability). Highly variable stands composed 17% of the stands sampled.

26

Consistency among plots can be used as a rule of thumb for classifying variability. If the plots are very consistent in volume totaled per plot, it is considered low variability. If the individual plots are highly inconsistent in the amount of total volume per plot, the stand is considered highly variable. Average variability estimates would be all cases between high and low conditions. If one is unsure of the classification, the higher of the two choices (high versus average) for the initial estimate should be chosen or model Equation 4 that does not contain variability should be employed. Cruisers should plan for more plots than may be necessary at the outset rather than underestimate the number of plots needed.

Perhaps, the best use of the sample size prediction models by field personnel is to gather a range of possible plots required from the lowest and highest estimates. For example, if a cruise planner has a stand that is 130 acres in size and estimates the average DBH at 9" and the TPA at 125, one could use the average variance table (Table 10) to estimate the least (63) and the most (136) number of plots needed. Using random sampling techniques, it would be possible to design a sample of 166 plots (the maximum +30) using plot allocator software and take random samples (if the cruiser is willing to visit plots randomly) until precision goals had been met. Thirty additional plots would be added because the model resulted in 100% of all estimates falling within this range (Table 5). The cruiser would now know the potential time it would take to cruise the stand and also have a starting point at which to begin cruise design. The key to finding the actual sample size needed is to examine data as it is collected (on a daily basis) using software such as T-Cruise®. If the normal procedure used by the cruiser in this example was a 10% cruise, 130 plots would have been taken. It is possible that approximately 63

27

plots were sufficient to meet precision goals. As a cruiser becomes more familiar with random sampling inventory designs, time and money can surely be saved.

The first decision to make prior to using these models for estimating CV and the number of samples plots is the appropriate plot size. The variability of the stand should be captured without using a plot size so large that more time is spent taking measurements than needed or so small that the number of plots required becomes cost prohibitive. If the CV, diameter and spatial distribution of the trees were known ahead of time, the optimum plot size could be chosen at the outset of an inventory. However, these are not known and why estimates must be made to arrive at the expected optimal plot size for each stand.

A general rule of thumb for determining plot size to use is one which measures between seven and fifteen trees per plot (Matney, T. 2011. Personal communication. Professor of Forestry, Mississippi State University. Starkville, MS. February 4). Using this guideline, one should choose plot size based on the merchantable trees per acre present in the stand. If there are a significant number of trees per acre (>200 TPA) a smaller plot size such as 1/20 acre should be used. This type of cruise would be ideal for planted and natural stands that have never been thinned. If a stand has between 80-200 TPA, a 1/10 acre plot size should be used. This standard covers most intermediate and final cruising instances (second thin and final harvest). If the TPA drops below 80 such as in an older aged or heavily thinned stand, 1/5 acre plots should be used.   The TPA ranges address optimization as well as accounting for variability within in the data.

If every area of a stand has the same diameter and spatial distribution, it would look identical across the entire stand. All plot sizes would account for the same CV. If this were the case, any chosen plot size should yield the same estimate of the required

28

number of samples. Yet in most stands, especially after a thinning, the spatial distribution of trees tends to be clumped, and this relationship would no longer be valid. Considering this point, one should be careful in using the models developed here on inventories with plot sizes other than 1/10 acre. Results from preliminary testing on alternate sample sizes (from other sales) are shown in Table 13:

Table 13   Preliminary estimates of the number of plots required using the 1/10 acre (no variance estimate) model on different plot sizes.

Sample size = 32		
	Number	Percent
# Underestimated	26	81%
# overestimated	3	9%
Average underestimated by	-8	
Average overestimated by	6	
Estimated within 5	18	56%
Estimated within 10	25	78%
Estimated within 15	30	94%
Estimated within 20	30	94%
Estimated within 30	32	100%
	Avg. # plot	
Sample Size	difference	# Samples
1/20 acre	-7	12
1/5 acre	4	3
Point	-7	17

Examination of Table 13 shows that using the 1/10 acre sample plot estimation model on smaller sized plots or with point sampling tends to underestimate the number of plots needed. Using larger plot sizes, such as 1/5 acre, resulted in overestimation of the required number of plots. These relationships were to be expected as previously

29

discussed. Smaller plot sizes tend to have higher CV measurements and larger plot sizes tend to have lower CV measurements. Therefore, if Table 13 is to be used on other (not 1/10 acre) plot size cruises, one must understand what to expect regarding sample size tendencies before use of either model.

30

CHAPTER V

CONCLUSION

The estimation of CV and sample size is often neglected at the outset of an inventory for a timber sale, particularly by untrained field personnel. The currently available options for sample size estimation in forestry are to either take a few preliminary plots to determine the estimated sample size, or to simply guess at a CV and sample size and adjust the sample size as predicted by calculations later in the cruise process. The models constructed in this study allow sample sizes to be estimated through prediction of the stand CV prior to the inventory. This is done by estimating the average DBH, average TPA and the predicted variability of the volume among plots (Equation 3) or by only using TPA and DBH (Equation 4). Once a CV estimate has been made, one can either use the tables provided here or use the estimated CV in equations unique to a specific company or agency. This process provides a consistent starting point for cruise planning and gives the cruiser an estimate of the time and effort that can be expected for particular timber sale inventories without detailed pre-cruise measurements. Had statistical requirements been examined more closely and plot estimation been made more accurately in the 88 sales examined, as many as 2,415 plots would not have been implemented during FY 2010. Ignoring or overestimating plot numbers and statistical precision costs money and time that could be invested elsewhere.

31

REFERENCES

Avery, T. E., and H.E. Burkhart. 2002. Forest Measurements: 5th edition. McGraw-Hill, New York. 456 pp.

Borders, B.E., W.M. Harrison, M.L. Clutter, B.D. Shiver and R.A. Souter. 2008. The value of timber inventory information for management planning. Canadian Journal of Forest Research. 38:2287-2294.

Clark, E. 2007. 16th Section school trust lands: past, present and future. Tree Talk. Winter:8.

Cochran, W. 1977. Sampling Techniques, 3rd ed. John Wiley and Sons, New York. 428 pp.

Evans, T. and O.V. Viengkham. 2001. Inventory time-cost and statistical power: a case study of a Lao rattan. Forest Ecology and Management. 150:313-322.

Frayer, W.E. and G.M. Furnival. 1999. Forest survey sampling designs, a history. Journal of Forestry. 97(12):4-10.

Freese, F. 1962. Elementary forest sampling. USDA Forest Service: Agriculture Handbook No. 232. 91pp.

Hamilton, D. A. 1979. Setting precision for resource inventories: the manager and the mensurationist. Journal of Forestry. 77(10):667-670.

Henderson, J.E., I.A. Munn, G.Perez-Verdin and D.L. Grebner. 2008. Forestry in Mississippi: the impact of the forest products industry on the post-Katrina Mississippi economy – an output analysis. Forest and Wildlife Research Center, Research Bulletin FO374, Mississippi State University. 31pp.

Lynch, A. 2003. Comparison of fixed area plot designs for estimating stand characteristics and western spruce budworm damage in southwestern U.S.A. forests. Canadian Journal of Forest Research. 33:1245-1255.

Mississippi State University, Cooperative Extension Service. 2009. 2009 harvest of forest products, forest economics. Report MTN-23C, February 2010. 8 pp. Also available at http://www.msucares.com/forestry/economics/reports.

Oswalt, S, T.G. Johnson, J.W. Coulston and C.M. Oswalt. 2009. Mississippi's forests, 2006. Resource Bulletin, SRS-147, USDA Forest Service, Knoxville, TN. 78 pp.

Parker, R.C., P.A. Glass, H.A. Londo, D.L. Evans, K.L. Belli, T.G. Matney and E.B. Schultz. 2005. Mississippi's forest inventory pilot program: Use of computer and spatial technologies in large area inventories. Forest and Wildlife Research Center, Bulletin FO 274, Mississippi State University. 43 pp.

Skidmore, J. 2010. Forest management manual of the Mississippi Forestry Commission: 2010 edition. Internal Document. 139 pp.

Stauffer, H. 1982. A sample size table for forest sampling. Forest Science. 28 (4):777-784.

USDA. 2010. Forest Inventory and Analysis Program: FIA Library. http://www.fia.fs.fed/us/library. [Date accessed: September 11, 2010].

USDA Forest Service Southern Region. 1986. Service Forester's Handbook. Miscellaneous Report, R8-MR 11, USDA Forest Service, Atlanta, GA. 130 pp.

Xiao, X., G. Gertner, G. Wang and A.B. Anderson. 2004. Optimal sampling scheme for estimation landscape mapping of vegetation cover. Landscape Ecology. 20:375-387.

Zeide, B. 1980. Plot size optimization. Forest Science. 26 (2):251-257.

APPENDIX A

TIMBER SALE DATA, SAS OUTPUT AND REGRESSION ANALYSIS
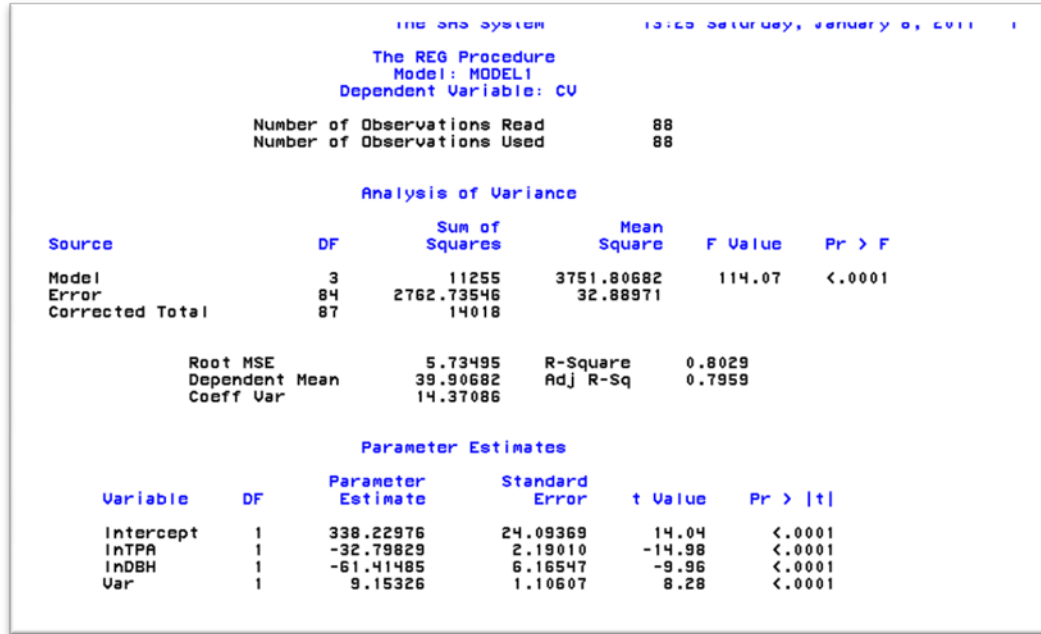
Figure 3   SAS output of the regression for Equation 3 (with VAR)

Figure 4   Residuals of the regression for Equation 3 (with VAR)

35

Figure 5   Diagnostics of the regression for Equation 3 (with VAR)

The REG Procedure
Model: MODEL2
Dependent Variable: CV

Number of Observations Read   88
Number of Observations Used   88

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	9003.01162	4501.50581	76.29	<.0001
Error	85	5015.14428	59.00170		
Corrected Total	87	14018			

Root MSE	7.68126	R-Square	0.6422
Dependent Mean	39.90682	Adj R-Sq	0.6338
Coeff Var	19.24798		

Parameter Estimates

| Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	278.79004	30.80318	9.05	<.0001
lnTPA	1	-29.56239	2.88623	-10.24	<.0001
lnDBH	1	-39.67178	7.47051	-5.31	<.0001

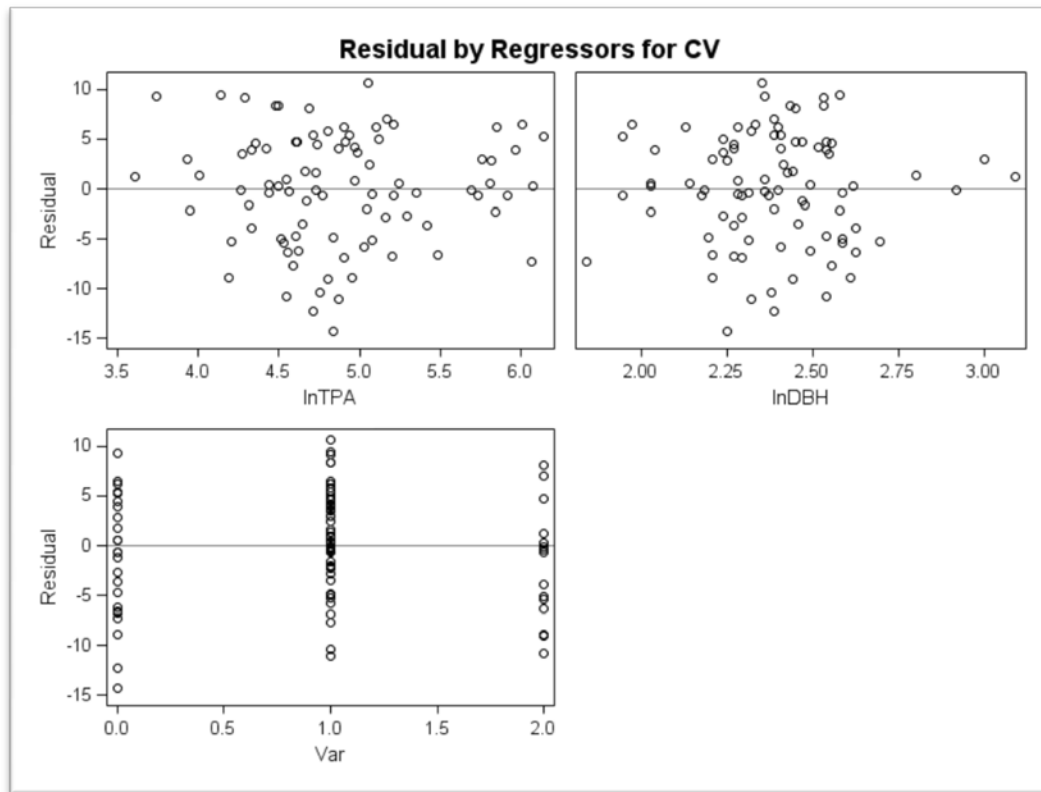Figure 6   SAS output of the regression for Equation 4 (without VAR)

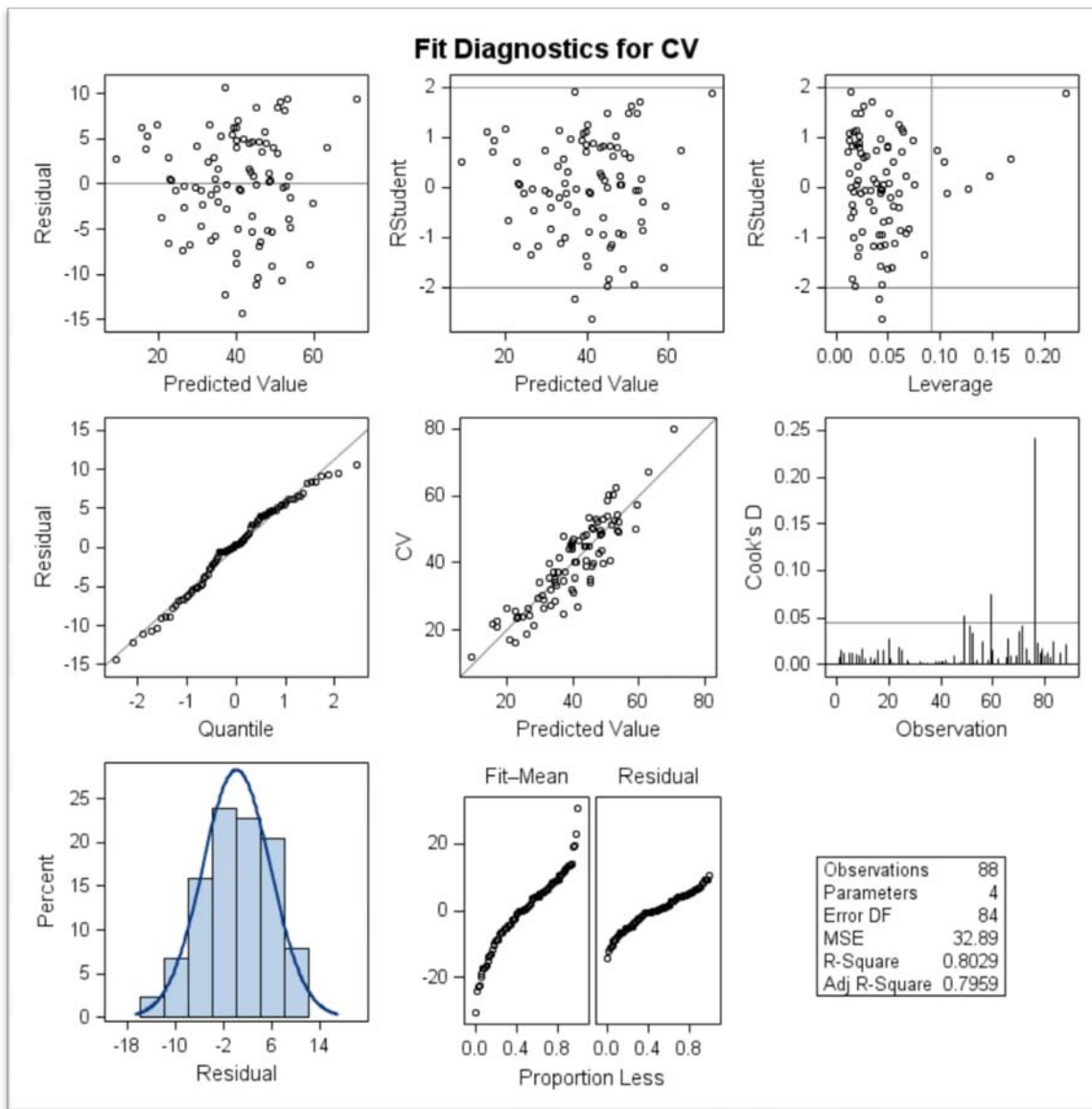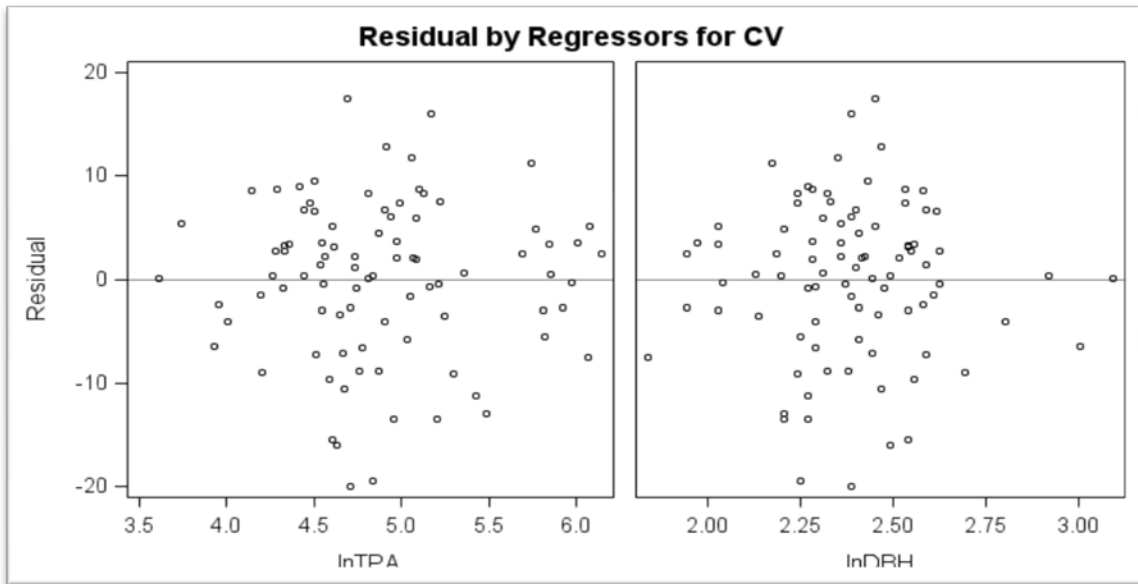Figure 7   Residuals of the regression for Equation 4 (without VAR)
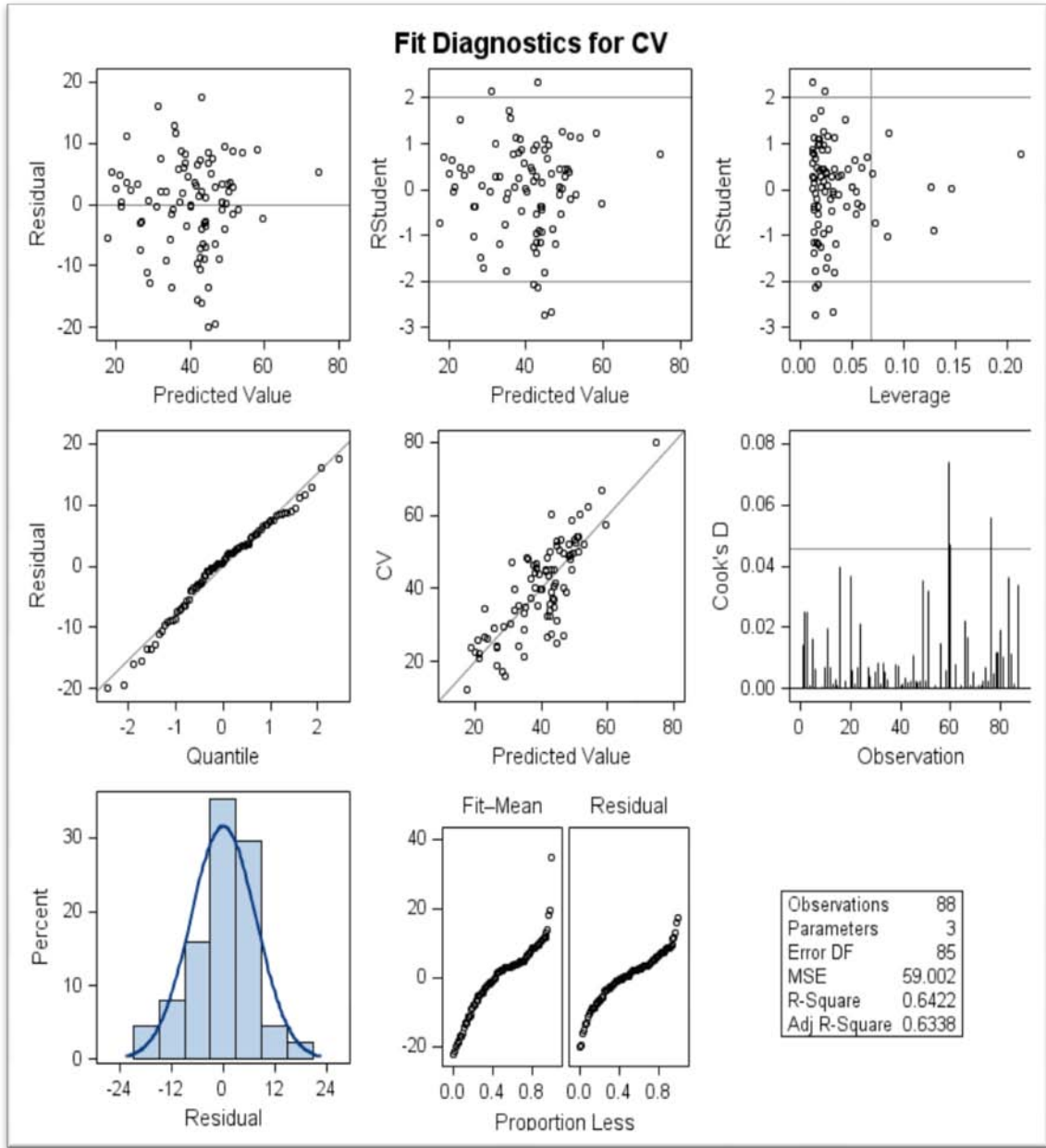
37

Figure 8   Diagnostics of the regression for Equation 4 (without VAR)

Table 14 Data used from MFC timber sales FY 2010 and FY 2011

Cover Type	Stand acres	Taken	Needed	STD Dev	Ton/ac	CV	SQRT_CV	1/CV	DBH	lnDBH	1/DBH	TPA	lnTPA	1/TPA	Var
Mixed	142	100	94	48.6	81	60.3	7.765307	0.016584	11.6	2.451005	0.086207	109	4.691348	0.009174	2
Mixed	205	69	60	58.1	123	47.2	6.870226	0.021186	10.9	2.388763	0.091743	176	5.170484	0.005682	2
Mixed	192	193	62	54.4	112	48.5	6.964194	0.020619	11.8	2.4681	0.084746	136	4.912655	0.007353	2
Mixed	197	188	61	37.8	79	47.8	6.913754	0.020921	10.5	2.351375	0.095238	157	5.056246	0.006369	1
Pine	291	59	32	40.5	119	34.2	5.848077	0.02924	8.8	2.174752	0.113636	310	5.736572	0.003226	2
Pine	163	163	89	28.9	49	58.7	7.661593	0.017036	11.4	2.433613	0.087719	90	4.49981	0.011111	1
Hard	120	113	112	28	43	67	8.185353	0.014925	9.7	2.272126	0.103093	83	4.418841	0.012048	1
Mixed	179	159	94	33	55	60.2	7.758866	0.016611	12.6	2.533697	0.079365	73	4.290459	0.013699	1
Mixed	119	121	56	33.2	72	46.2	6.797058	0.021645	9.8	2.282382	0.102041	164	5.099866	0.006098	1
Pine	112	117	98	36.1	58	62.5	7.905694	0.016	13.2	2.580217	0.075758	63	4.143135	0.015873	1
Pine	129	126	73	35.6	67	53	7.28011	0.018868	10.2	2.322388	0.098039	122	4.804021	0.008197	1
Pine	161	171	57	36.3	78	46.7	6.83374	0.021413	9.4	2.24071	0.106383	168	5.123964	0.005952	1
Mixed	68	73	41	38.9	98	39.6	6.292853	0.025253	10.3	2.332144	0.097087	184	5.214936	0.005435	1
Pine	143	130	74	35.6	67	53.3	7.300685	0.018762	12.6	2.533697	0.079365	88	4.477337	0.011364	1
Pine	83	65	64	29.3	59	49.9	7.063993	0.02004	9.4	2.24071	0.106383	146	4.983607	0.006849	1
Mixed	60	63	52	32.9	73	45.4	6.737952	0.022026	11	2.397895	0.090909	135	4.905275	0.007407	1
Pine	76	80	67	42.3	82	51.5	7.17635	0.019417	13.3	2.587764	0.075188	85	4.442651	0.011765	2
Hard	70	63	60	42	87	48.5	6.964194	0.020619	13.7	2.617396	0.072993	90	4.49981	0.011111	2
Hard	100	100	51	38.6	88	44.2	6.648308	0.022624	10.9	2.388763	0.091743	139	4.934474	0.007194	1
Mixed	62	62	47	44.8	105	42.7	6.534524	0.023419	10.1	2.312535	0.09901	161	5.081404	0.006211	2
Pine	162	161	158	22	28	80	8.944272	0.0125	10.6	2.360854	0.09434	42	3.73767	0.02381	0
Pine	218	30	16	32.3	135	23.9	4.888763	0.041841	7.6	2.028148	0.131579	435	6.075346	0.002299	1
Mixed	90	92	65	37.7	75	50.5	7.106335	0.019802	11.6	2.451005	0.086207	100	4.60517	0.01	1
Pine	81	43	18	31.1	121	25.7	5.069517	0.038911	9.1	2.208274	0.10989	318	5.762051	0.003145	1
Mixed	70	80	50	32.9	75	43.9	6.625708	0.022779	11.1	2.406945	0.09009	130	4.867534	0.007692	1
Mixed	154	154	54	32	70	45	6.708204	0.022222	9.8	2.282382	0.102041	144	4.969813	0.006944	1
Pine	163	20	21	18.2	69	26.4	5.138093	0.037879	7.2	1.974081	0.138889	407	6.008813	0.002457	0
Mixed	91	88	75	28.8	53	54.3	7.368853	0.018416	10.6	2.360854	0.09434	94	4.543295	0.010638	1
Mixed	77	73	68	30.9	59	52	7.211103	0.019231	12.9	2.557227	0.077519	78	4.356709	0.012821	1
Pine	80	40	23	26	88	29	5.385165	0.034483	7.6	2.028148	0.131579	344.0	5.840642	0.002907	1
Mixed	87	90	72	35	66	53.2	7.293833	0.018797	12.7	2.541602	0.07874	76	4.330733	0.013158	1
Mixed	83	83	52	38.3	86	44.7	6.685806	0.022371	12.7	2.541602	0.07874	101	4.615121	0.009901	1
Pine	143	143	76	34.3	63	54	7.348469	0.018519	12.8	2.549445	0.078125	72	4.276666	0.013889	1

Table 14 (Continued)

Cover Type	Stand acres	Taken	Needed	STD Dev	Ton/ac	CV	SQRT_CV	1/CV	DBH	lnDBH	1/DBH	TPA	lnTPA	1/TPA	Var
Pine	109	96	63	44.9	91	49.4	7.028513	0.020243	13.8	2.624669	0.072464	76	4.330733	0.013158	2
Pine	158	42	14	17.7	79	22.5	4.743416	0.044444	7	1.94591	0.142857	465	6.142037	0.002151	0
Pine	263	64	19	27.9	106	26.3	5.128353	0.038023	8.9	2.186051	0.11236	296	5.690359	0.003378	1
Mixed	137	127	71	29.3	56	52.4	7.238784	0.019084	10.6	2.360854	0.09434	96	4.564348	0.010417	1
Hard	80	96	52	33	73	45	6.708204	0.022222	11.3	2.424803	0.088496	113	4.727388	0.00885	1
Pine	74	37	36	39.9	113	35.4	5.94979	0.028249	11.2	2.415914	0.089286	158	5.062595	0.006329	1
Hard	60	54	31	34.9	102	34	5.830952	0.029412	12.4	2.517696	0.080645	144	4.969813	0.006944	1
Pine	130.5	57	42	33	83	40	6.324555	0.025	9.8	2.282382	0.102041	161	5.081404	0.006211	1
Mixed	47	48	48	44.3	102	43.6	6.60303	0.022936	13.3	2.587764	0.075188	93	4.532599	0.010753	2
Mixed	73	64	51	28	62	45	6.708204	0.022222	11	2.397895	0.090909	113	4.727388	0.00885	1
Pine	112	56	24	26.9	92	29.3	5.412947	0.03413	10.1	2.312535	0.09901	212	5.356586	0.004717	1
Pine	400	95	13	22.3	102	21.9	4.679744	0.045662	8.4	2.128232	0.119048	347	5.849325	0.002882	0
Hard	60	50	37	47.6	127	37.4	6.115554	0.026738	18.5	2.917771	0.054054	71	4.26268	0.014085	2
Mixed	65	64	60	35.7	73	48.9	6.992853	0.02045	12.1	2.493205	0.082645	85	4.442651	0.011765	1
Pine	290	83	64	26	54	49	7	0.020408	9	2.197225	0.111111	126	4.836282	0.007937	1
Hard	108	92	64	48.2	97.3	49.5	7.035624	0.020202	22	3.091042	0.045455	37	3.610918	0.027027	2
Pine	108	103	42	46.1	116	39.9	6.316645	0.025063	11.5	2.442347	0.086957	122	4.804021	0.008197	1
Pine	202	22	12	24	117	21	4.582576	0.047619	7.7	2.04122	0.12987	391	5.968708	0.002558	0
Pine	72	67	41	47.8	121	39.6	6.292853	0.025253	13.8	2.624669	0.072464	95	4.553877	0.010526	2
Pine	80	25	26	35.9	118	30.3	5.504544	0.033003	10.7	2.370244	0.093458	183	5.209486	0.005464	1
Mixed	47	34	32	33.6	97	34.6	5.882176	0.028902	9.9	2.292535	0.10101	174	5.159055	0.005747	1
Mixed	122	123	70	30.7	59	52.1	7.218033	0.019194	11.9	2.476538	0.084034	75	4.317488	0.013333	1
Mixed	142	142	60	21	44	47.8	6.913754	0.020921	9.7	2.272126	0.103093	114	4.736198	0.008772	0
Pine	146	148	65	43	86	49.9	7.063993	0.02004	13.6	2.61007	0.073529	66	4.189655	0.015152	2
Mixed	116	116	30	29.7	89	33.3	5.770615	0.03003	10.9	2.388763	0.091743	155	5.043425	0.006452	1
Pine	100	100	83	30.4	53	57.2	7.563068	0.017483	13.2	2.580217	0.075758	52	3.951244	0.019231	1
Pine	162	36	17	22	89	24	4.898979	0.041667	7	1.94591	0.142857	371	5.916202	0.002695	0
Hard	52	58	44	21.7	53	41.3	6.426508	0.024213	11.1	2.406945	0.09009	111	4.70953	0.009009	0
Pine	96	15	17	20.4	86	23.7	4.868265	0.042194	7.6	2.028148	0.131579	333	5.808142	0.003003	0
Pine	151	53	45	45.2	111	40.7	6.379655	0.02457	12.7	2.541602	0.07874	94	4.543295	0.010638	2
Pine	40	40	42	30.6	76	40.5	6.363961	0.024691	11.7	2.459589	0.08547	104	4.644391	0.009615	1
Pine	107	56	34	24.2	69	35.2	5.932959	0.028409	8.5	2.140066	0.117647	190	5.247024	0.005263	0
Pine	79	75	53	33.9	75	45.1	6.715653	0.022173	16.5	2.80336	0.060606	55	4.007333	0.018182	1

Table 14 (Continued)

Cover Type	Stand acres	Taken	Needed	STD Dev	Ton/ac	CV	SQRT_CV	1/CV	DBH	lnDBH	1/DBH	TPA	lnTPA	1/TPA	Var
Mixed	57	41	40	27.6	71	38.8	6.228965	0.025773	9.9	2.292535	0.10101	135	4.905275	0.007407	1
Pine	28	10	5	15	124	12.1	3.478505	0.082645	9.5	2.251292	0.105263	335	5.814131	0.002985	0
Mixed	88	40	23	26.5	92	28.8	5.366563	0.034722	11.1	2.406945	0.09009	153	5.030438	0.006536	1
Hard	60	60	36	38.6	104	37.1	6.090977	0.026954	20.1	3.00072	0.049751	51	3.931826	0.019608	1
Mixed	56	41	43	23.9	59	40.3	6.348228	0.024814	9.9	2.292535	0.10101	118	4.770685	0.008475	0
Mixed	74	71	36	23.9	65	37	6.082763	0.027027	11.5	2.442347	0.086957	106	4.663439	0.009434	0
Pine	73	59	34	36.3	102	35.5	5.958188	0.028169	13.3	2.587764	0.075188	91	4.51086	0.010989	1
Pine	108	10	12	13.7	72	18.9	4.347413	0.05291	6.3	1.84055	0.15873	431	6.066108	0.00232	0
Pine	55	30	31	25.5	76	34	5.830952	0.029412	10.2	2.322388	0.098039	130	4.867534	0.007692	1
Pine	44	46	31	27	79	35	5.91608	0.028571	10.8	2.379546	0.092593	116	4.75359	0.008621	1
Pine	143	40	41	33.3	86	38.7	6.220932	0.02584	14.8	2.694627	0.067568	67	4.204693	0.014925	1
Pine	79	37	16	20.1	83	24.2	4.91935	0.041322	9.4	2.24071	0.106383	200	5.298317	0.005	0
Pine	92	33	26	32.9	104	32.2	5.674504	0.031056	12.9	2.557227	0.077519	98	4.584967	0.010204	1
Hard	77	32	29	23	72	32.2	5.674504	0.031056	11.8	2.4681	0.084746	107	4.672829	0.009346	0
Pine	56	14	9	15.8	92	17.2	4.147288	0.05814	9.7	2.272126	0.103093	226	5.420535	0.004425	0
Pine	35	10	8	15.2	95	16.1	4.012481	0.062112	9.1	2.208274	0.10989	241	5.484797	0.004149	0
Mixed	67	37	27	19.1	61	31.2	5.585696	0.032051	9.1	2.208274	0.10989	142	4.955827	0.007042	0
Pine	44	28	13	23.8	112	21.3	4.615192	0.046948	9.7	2.272126	0.103093	182	5.204007	0.005495	0
Hard	40	26	19	20.4	76	26.4	5.138093	0.037879	12.7	2.541602	0.07874	100	4.60517	0.01	0
Pine	72	76	20	23.4	86	27.2	5.215362	0.036765	12.1	2.493205	0.082645	102	4.624973	0.009804	0
Pine	120	30	21	12.8	47	27	5.196152	0.037037	9.5	2.251292	0.105263	126	4.836282	0.007937	0
Pine	102	26	18	15.1	60.8	24.8	4.97996	0.040323	10.9	2.388763	0.091743	111	4.70953	0.009009	0

41