Modeling Green Weight of Loblolly Pine

(*Pinus taeda* L.)

by

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(ABSTRACT)

Green weight and green weight per unit volume relationships for loblolly pine trees have not been studied extensively and models for predicting weights across broad geographic areas are not readily available. In this regard three basic interrelated issues were addressed in this study: 1) an examination of weight per unit volume relationships, 2) an assessment of how tree, stand, and geographic characteristics affect weight per unit volume relationships, 3) a derivation of models of weight per unit volume for predicting total bole weight and merchantable weight, 4) a derivation of models for predicting green weight directly, and 5) a comparison of objectives 3) and 4). This study showed that green weight per unit volume varies somewhat within stems, but the variation is large. There is no discernable trend by stand characteristics, and the geographic trends were inconclusive. Data from four data sets were combined and region-wide prediction models for total green weight, green weight to any upper merchantable diameter, and green weight to any upper merchantable height were developed for loblolly pine trees.

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Table of Contents

List of Tables

List of Figures

List of Appendices

APPENDIX TITLE PAGE

1. Introduction

1.1 JUSTIFICATION

Timber is commonly bought and sold on a weight basis. Consequently, forest inventories are frequently computed in terms of weight. Hence there is a need for tree weight equations. However, green weight relationships have not been studied extensively and models for predicting weight across broad geographic areas are not readily available. This study aims at predicting green weight for loblolly pine (*Pinus taeda* L.) over various geographical regions. Different methods were compared. In one approach, green weight per unit volume conversions were examined for predicting green weight. A second approach involved direct prediction of tree green weight. The results of this study should be of interest to woodlands managers in the loblolly pine region.

1.2 OBJECTIVES

Following the methods described herein, the investigation has been carried out so that the work was consistent with requirements for the Master of Science degree. The specific objectives for this study were to develop estimates of green weight in any specified portion of loblolly pine tree stems. In order to develop these prediction equations, different approaches will be examined. Thus leading to the secondary or more specific objectives:

1. To examine weight per unit volume relationships of loblolly pine.

2. To ascertain how tree, stand, and geographic characteristics affect weight per unit volume relationships.

3. To model weight per unit volume for predicting total bole weight and merchantable weight.

4. To model green weight directly from the data.

5. To compare the direct estimation of weight (4) with estimation utilizing a green weight per unit volume conversion (3).

1.3 BACKGROUND

Total and partial tree volume estimation has been used within the forestry community for a long time. The use of tree weight as a measure of productivity and value has also been in use since weight scaling became common practice. To achieve more efficient utilization of our timber resources we need to understand both volume and weight relationships of trees (Myers et al., 1980). Furthermore, reliable conversions from volume to weight or from weight to volume are desirable. Such conversions can be achieved by using a green weight per unit volume conversion factor. The conversion factor needs to be applicable throughout the stem, the stand, and the various geographical areas of the tree species. For loblolly pine, much work has been done on individual tree volume equations and wood densities. Burkhart et al. (1972) developed per-tree and per-acre volume, green, and dry weight yields for various units for natural stands of loblolly pine. Others have also done similar work with green and dry weight equations (see Baldwin, 1987 and Myers et al., 1980). Yet the applicability of a green weight per unit volume constant has not been extensively researched for loblolly pine.

Specific gravity is defined as the ratio of the density of a material to the corresponding density of water. Specific gravity is unitless because it is a relative value (Haygreen and Bowyer, 1996). Specific gravity of loblolly pine is known to be a important measure of wood quality that can vary significantly by geographic region (Jett et al., 1991). Specific gravity has been shown not to have a strong correlation with growth or form characteristics in loblolly pine (Stonecypher et al., 1973; Talbert and Jett, 1981), but varies when the ratio of latewood to earlywood is altered. Estimates obtained from samples can be used as a representation of the population in a geographical region. Some assert that all biomass estimates should be derived from locally derived or tested equations (Clark, 1983). However, regional variability on a green weight basis has not been thoroughly examined. Forest managers need to estimate green weight per unit volume with a comprehensively good fit throughout the region of interest.

Moisture content has a direct relationship with the green weight per unit volume. It has been shown for various species in certain geographic areas that moisture content varies by season. For example, Yerkes (1967) found a seasonal change of approximately 25 percent in the moisture content of ponderosa pine sapwood. If the specific gravity is taken to be constant over the period of time of interest, moisture content is responsible for any seasonal variation in green weight per unit volume. Schroeder and Phillips (1972) showed that there was no indication of seasonal variation in tree moisture content or green weight per cubic foot of loblolly pine. This allows for constant weight scaling factors to be used throughout the year, with no adjustment for seasonal variation.

There are various ways that green weight per unit volume can be determined. Clark et al. (1980) calculated green weight per cubic foot of wood and bark from specific gravity and moisture content obtained from disks. The formula used was:

$$\text{Green weight per cubic foot} = (1 + MC/100) \times (SG) \times (C) \qquad \textbf{(1)}$$

where MC = weighted moisture content in percent

SG = weighted specific gravity

C = 62.4 pounds per cubic foot (weight of water per cubic foot)

This formula was then used to determine cubic-foot volumes from the component weight analysis. Weights can be computed for inside bark, outside bark, and bark alone. Taras and Clark (1977) also derived green weight per cubic foot for longleaf pine trees by Equation 1. The results showed that the average green weight per cubic foot did not differ greatly between tree components, where the components are total tree, saw log, pulpwood, main stem, and branches. As could be expected, the bark had a much lower green weight per cubic foot than the wood.

Density is defined as the mass or weight per unit of volume, usually expressed as pounds per cubic foot. Sample disks cut from the bole of the tree can also be used to estimate the density of the tree. Measurements taken on the sample disk allow for both inside and outside bark estimates of either green and/or dry weights. The specific gravity derived from a sample increment core has a high correlation with whole tree specific gravity (Szymanski and Tauer, 1991). This implies that the specific gravity derived from a sample disk would also be a good estimator of whole tree specific gravity. If there is bolt sectional data available up the stem, then the integration of all of the densities up the stem from the various disks would also be a good estimator of whole tree specific gravity.

Water displacement has long been accepted as a way obtaining the 'true' volume of a log. Archimedes' principle states that the force buoying up a body immersed in a liquid is equal to the weight of the liquid displaced by the body. There is also an equal force downward by the body on the liquid.

Phillips and Taras (1987) tested volume determination of seven volume equations. They found that volume determined by a density method of dividing green weight by green weight per cubic foot was poor in accuracy (upward bias +6.7%) but good with precision (Standard Error = $\pm$ 0.16 $ft.^3$; correlation coefficient to displaced volume, r = 0.999) when compared to volume determined by a displacement method. This lack of accuracy was determined to be due to disk moisture content (MC) and specific gravity (SG) not being an accurate representation of the corresponding values of the entire log MC and SG. Hence caution was given for using a log density method for determining log cubic volumes.

Fourteen tree volume equations were tested against assumed actual tree volume determined by a displacement method for 243 eastern hardwoods logs (Martin 1984). This study allowed one to view the precision and accuracy of each volume equation in estimating actual tree volume for the individual log and for the merchantable tree volume. The results showed that no single equation predicts volume best for all types of volume estimation. A density method was not among the equations tested in Martin's study, but the results help to describe the difficulty in choosing a method for volume determination.

Baldwin (1987) developed equations for predicting green and dry weight of boles to any top diameter for loblolly pine trees in the West Gulf Region. Use of these equations in conjunction with the green weight per unit volume constant for this geographical region could yield tree volume estimates. Clark (1983) states that "A tree's weight is more difficult to predict than its volume because its weight per unit volume can vary with geographic location, age, size, growth rate, moisture content, specific gravity, and species." In the research reported here the green weight per unit volume for the various geographic locations of loblolly pine will be tested using regression and visual techniques to see if any one or combination of these factors are significantly influential. The visual techniques used are scatter plots, residual plots and line graphs. These forms of graphical analysis shall aid in determining any trends the data may show.

Weight scaling of sawlogs is common practice in forestry for estimating timber value as it is brought to the mill. Markstrom & King (1993) discuss cubic foot/weight scaling of ponderosa pine and white spruce sawtimber. Their approach consists of weighing truckloads of timber and obtaining a volume based off the weight and the number of stems. Multiple linear regression equations were used to estimate truckload volumes, with weight of wood and number of stems having the best fit. This application of cubic foot/weight scaling required less than half the number of truckloads to be scaled when compared to Scribner board-foot/weight scaling. This reduction in scaling time results in reduced costs. The green weight per unit volume conversion factor could be used in conjunction with weight scaling to obtain reasonable estimates of volume.

The scales and units of measure that are used in forestry vary widely by the location and average size of the log. Board foot, cubic foot, and cubic meter are all common units used for volume. The International, Scribner, and Doyle board-foot log rules are all still in use for estimating log volume. These different log rules each have their advantages and disadvantages in the way of consistency, over and underscaling (see Avery and Burkhart, 1994). The notion of having a green weight per unit volume conversion factor that could be used for reliably switching from weight to volume or from volume to weight, would be of great utility to woodlands managers and wood buyers.

2. MATERIALS, METHODS, AND INITIAL RESULTS

2.1 DATA COLLECTION

Members of the Virginia Tech Loblolly Pine Growth and Yield Research Cooperative and other research groups supplied the data for this project. All of the data were from loblolly pine trees located throughout the Southeast. The data were separated into categories based on geographical region. Regions represented by the data are Central Louisiana, Eastern Texas, the piedmont of Georgia, and the piedmont and coastal plain of Virginia.[1]

Large data sets from across the South were used in this analysis. Because one of the study objectives was to test for geographic differences in weight per unit volume, the sample size from any geographic area represented must be reasonably large. Hence the number of data sets potentially available was limited. However, with a good distribution in areas represented, reliable inferences about geographic variability should be possible.

The data consisted of two different formats. The first and most informative was a bolt sectional data format. In this format the loblolly pine trees were felled, delimbed, and bucked systematically into equal length sections. The uppermost section length was determined by an upper diameter outside bark limit where the stem was cut and from

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[1] Data were also furnished by Champion International Corp., Mead Corp., and Boise Cascade Corp. The data sets were located near Pensacola Florida (western panhandle), Georgia Piedmont, and Zwolle and Natchitoches area in Eastern Louisiana, respectively. The data sets were omitted because of varying sample collection techniques and small sample sizes.

which the distance to the tip (uppermost point of the stem) would be measured. The sections were weighed using a scale, and diameters and lengths were taken up the stem for each bolt. Section volumes were calculated by Smalian's formula (see Avery and Burkhart, 1994).

The second data format included whole tree information only. Each tree in this format was felled and delimbed, with the upper portion of the stem being removed at a set upper diameter outside bark limit. Various height and diameter measurements were then taken up the stem. The weights were determined one of two ways, either the tree was then raised with a hoist and weighed, or a disk determined by a random number generator was taken at a random height up the stem, measured and weighed with density being determined at the laboratory. If tree volume was determined, then numerous measurements would be taken up the stem and an established volume equation would be used for prediction. The data sets using this method tend to have a larger whole tree sample size, as it is not as labor intensive, whereas the sectional data sets contain a greater amount of information per tree.

Table 1 gives the range of the data sets by diameter at breast height and total stem height.

Table 1: Data summary for all data sets considered.

Location	Sample Size	DBH (inches)				Total Height (feet)			
		Mean	SD	Min	Max	Mean	SD	Min	Max
East Texas	101	5.25	2.58	0.80	12.3	32.2	13.94	7.5	61.5
Central Louisiana	130	10.06	4.18	1.9	20.8	64.5	17.31	18.0	94.0
Virginia	192	5.89	1.77	2.5	11.4	37.8	11.72	14.7	64.3
Georgia	608	6.45	1.36	4.6	12.2	43.2	9.34	21.0	82.5
Western Florida	49	8.61	2.95	4.4	17.5	57.7	18.65	26.2	93.0
SE Louisiana	451	9.86	3.56	4.6	19.9	60.3	16.17	30.0	118.0

2.2 INITIAL RESULTS

2.2.1 Modeling Green Weight Per Unit Volume

The first step was to ascertain whether green weight per unit volume is constant up the stem of the tree or if it changes with increased height and/or diameter outside bark. The hypothesis was that

$$\frac{GreenWeight}{UnitVolume} = f\left(dob, \tfrac{ht}{HT}\right) \tag{2}$$

Where dob = diameter outside bark

ht = height up the stem

HT = total height of the tree

is a valid function and green weight per unit volume does vary significantly as height up the stem changes. The green weight per unit volume relationship was evaluated using 101 loblolly pine trees from Eastern Texas that were sectioned and weighed. Each tree was sectioned into three-foot intervals with the tip of the tree being cut and weighed when the diameter reached approximately two inches outside bark. The outside bark volumes for each bolt were derived by fitting a cubic spline to each tree individually (see Goulding 1979 and Figueiredo-Filho et al. 1996). This method was initially used for computing volume because it was thought that the spline might approximate the tree profile better than a conventional taper function. The cubic spline method will be used later for comparison with Smalian's method of volume determination.

Cubic Spline Method:

$$CV = \left\{ \left(H_U - H_L\right) \cdot A_{H_L} + b_1 \cdot \tfrac{(H_U - H_L)^2}{2} + b_2 \cdot \tfrac{(H_U - H_L)^3}{3} + b_3 \cdot \tfrac{(H_U - H_L)^4}{4} \right\} \tag{3}$$

where CV = Cubic foot volume of bolt

H_U = Height aboveground at upper end of bolt

H_L = Height aboveground at lower end of bolt

A_{H_L} = Area of bolt at the lower height

β_i = coefficients to be estimated from the data by fitting the cross-sectional area of each section base as a function of length, i= 1,2,3

With the diameter, height, weight, and derived volume for each bolt, green weight per unit volume was calculated on a per bolt basis. Once the green weight per unit volume was calculated, graphs of the sectional data were constructed and visually analyzed for trends in the data. The green weight per unit volume was plotted against each section in the tree. The trend of the data was fairly consistent throughout the stem, except at the tip of the tree where there seemed to be a lot of variation (see Figure 1). Although the moisture content and age of the wood at the tip differ from the rest of the bole, no abrupt change in green weight per unit volume was expected at the tip; hence, the validity of the cubic spline method was questioned. Assuming that the diameter, length and weight are correct measurements, then the cubic spline may not be a good fit for the tip of the tree.

Several other volume determination methods were reviewed, with the conic method being chosen as the best fit for the tip of the tree (see Figure 2). This choice was based upon graphical analysis of the stem data and a review of literature that supports the assumption that the tip of a tree is conical in shape.

Conic Method:

$$CV = \left\{ \left(\frac{A_{H_L}}{3} \right) \cdot \left(H_U - H_L \right) \right\} \qquad \textbf{(4)}$$

where all symbols remain as defined in equation (3)

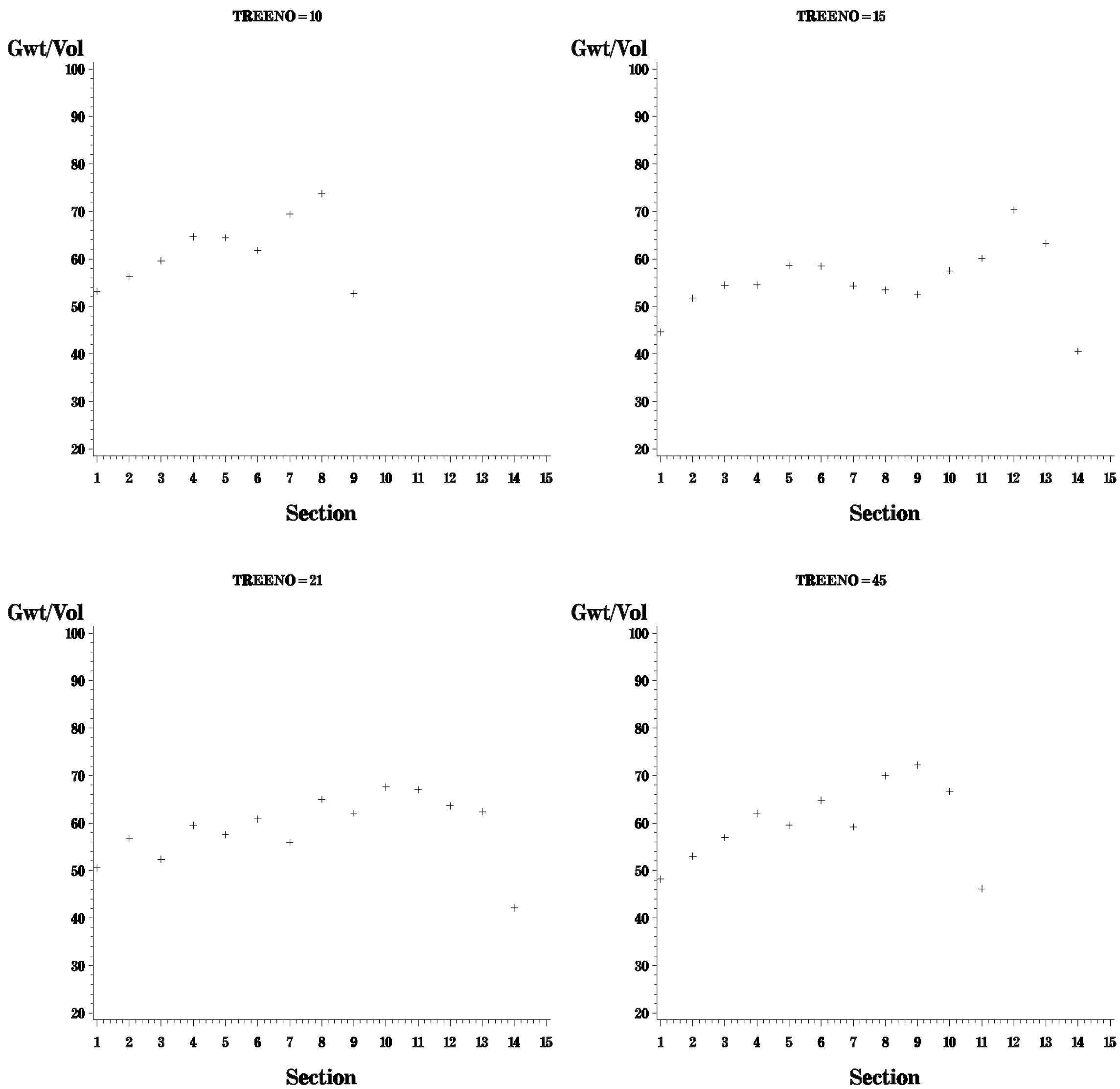


Figure 1: East Texas Green Weight Per Unit Volume By Section.

Selected trees from East Texas data to show the variation at the tip of the tree relative to the particular tree. The last section number represents the tip of the tree. There was no consistent trend for the variation in the tip. Some observations had a green weight per unit volume that was very high, and others where it was abnormally low. Volume was determined by a cubic spline.

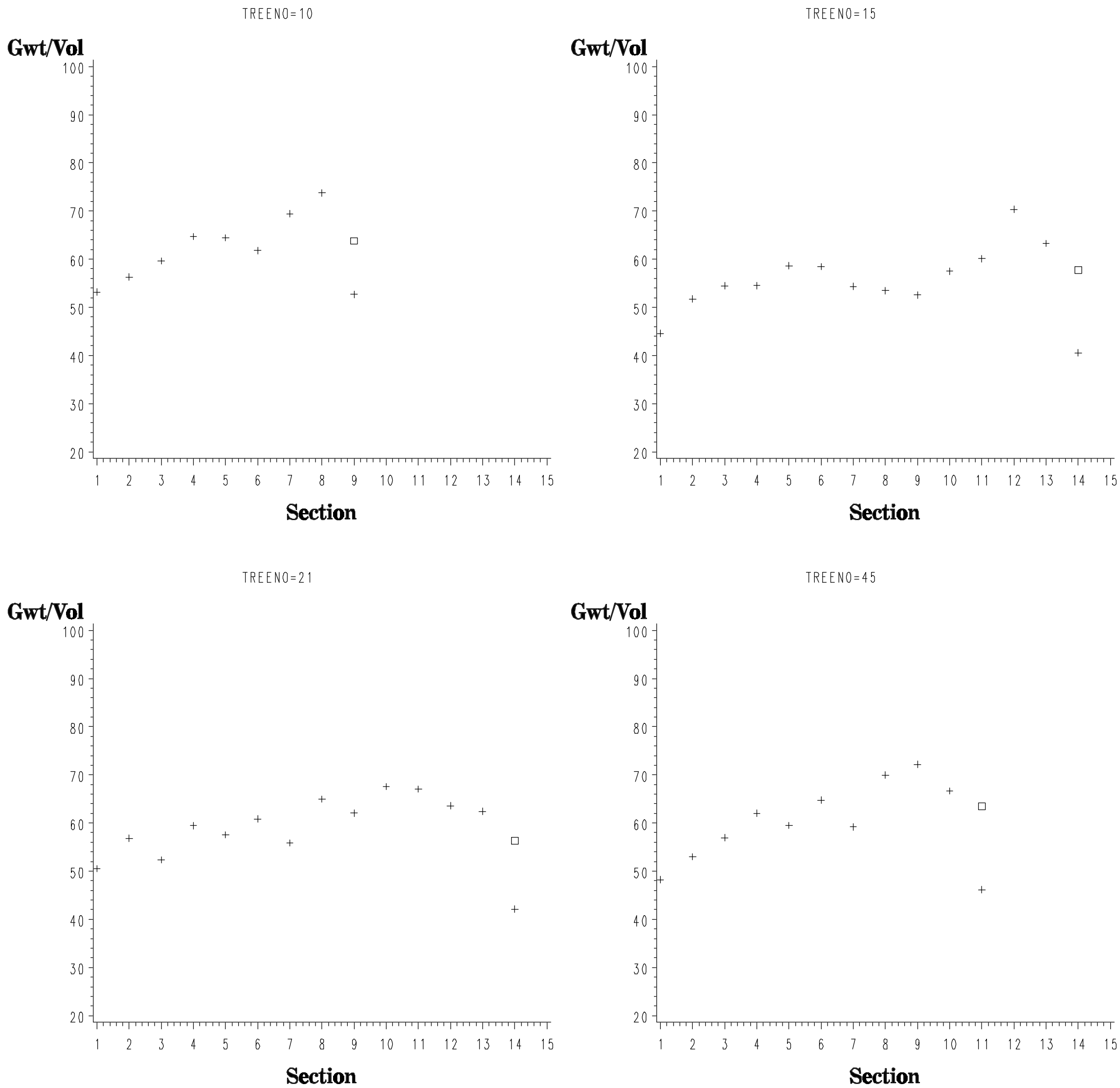


Figure 2: Comparison of Cubic Spline and Conic Volume Determination By Section.

Selected trees from East Texas data for comparison of cubic spline and conic volume determination at upper bolt (tip). The green weight per cubic foot values found using the spline method are denoted by (+). The green weight per cubic foot values found by the conic formula are denoted by a square.

After applying the conic method to compute the volume of the tips of the sample trees, green weight per unit volume values were again computed.

To examine the assumption of green weight per unit volume being consistent throughout the stem, multiple linear regression techniques were used with the data set where the tree tip volumes were computed by the conic method. Several different model formats were evaluated with respect to height up the stem, relative height, relative crown, section number and diameter outside bark. These variables may explain variation in the green weight per unit volume of the bolt on a per tree basis. None of the candidate models showed that green weight per unit volume was strongly correlated with height up the stem. Although there is a discernible trend in green weight per unit volume by stem position, the variation within this trend is very large. All models had an R-square, coefficient of determination, of less than 0.16 (see Appendix 1), meaning that less then 16% of the variation in green weight per unit volume of the bolt was explained by the height up the stem, the section number, and/or diameter outside bark. Although the results show that the F-value is statistically significant and there is a trend in the data, fitting this trend may not be better than just using the mean, due to the variance of the fitted model. The linear regression model only weakly described the variation in the response. To allow for further visualization of this trend, Figures 3-7 show green weight per unit volume graphed against the height up the stem, relative height, diameter outside bark, relative diameter outside bark and section number, respectively, for the East Texas sectional data set. The low R-square and visual interpretation obtained from the graphs further support the possibility of treating green weight per unit volume as being constant

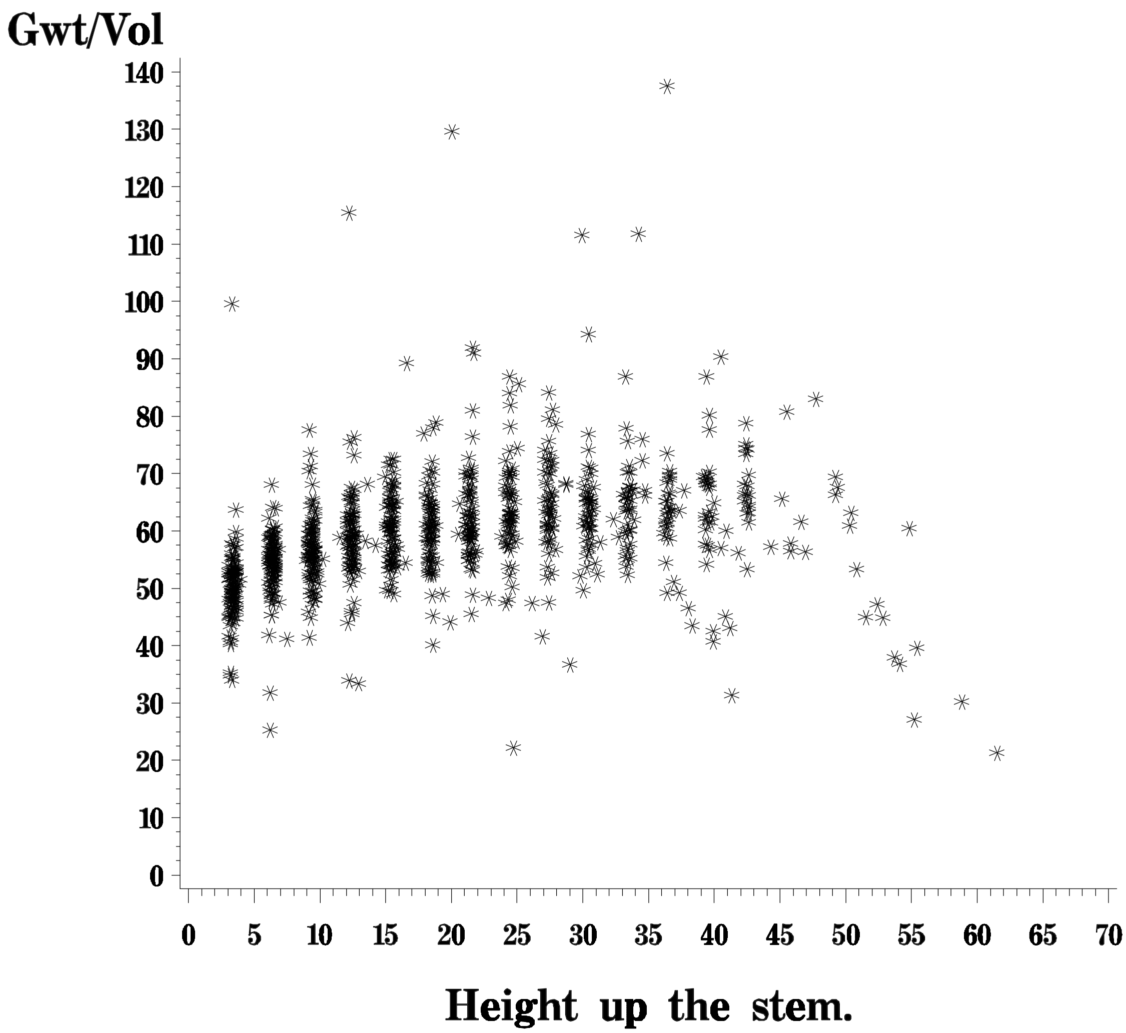


Figure 3: Green Weight Per Unit Volume By Height Up The Stem.

Green weight per unit volume (lbs./cuft.) of each bolt plotted by the height up the stem (feet) that each bolt represented.

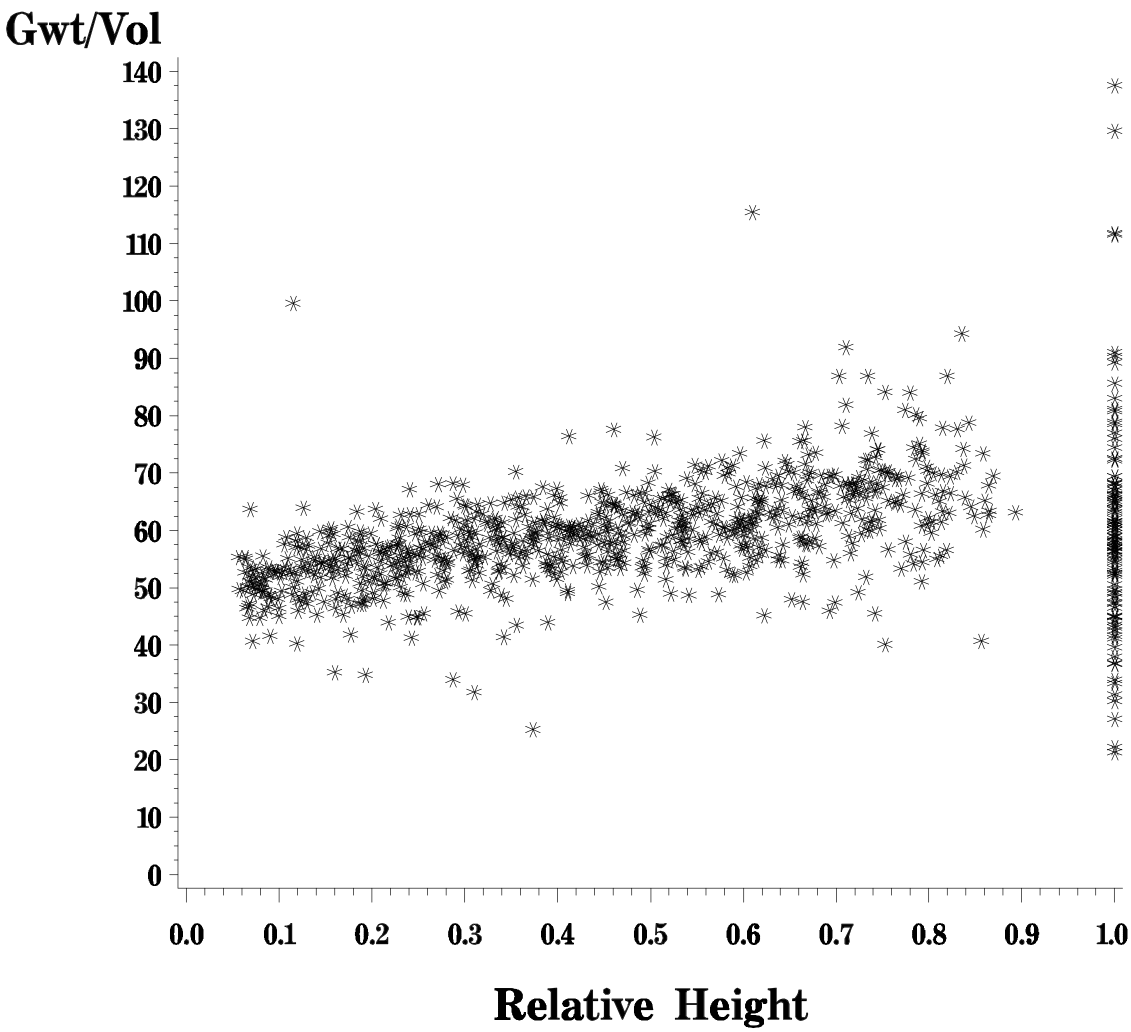


Figure 4: Green Weight Per Unit Volume By Relative Height.

Green weight per unit volume (lbs./cuft.) of each bolt plotted by the relative height of the total stem height that each bolt represented. Where relative height is computed by dividing height up the stem of each bolt by total stem height.

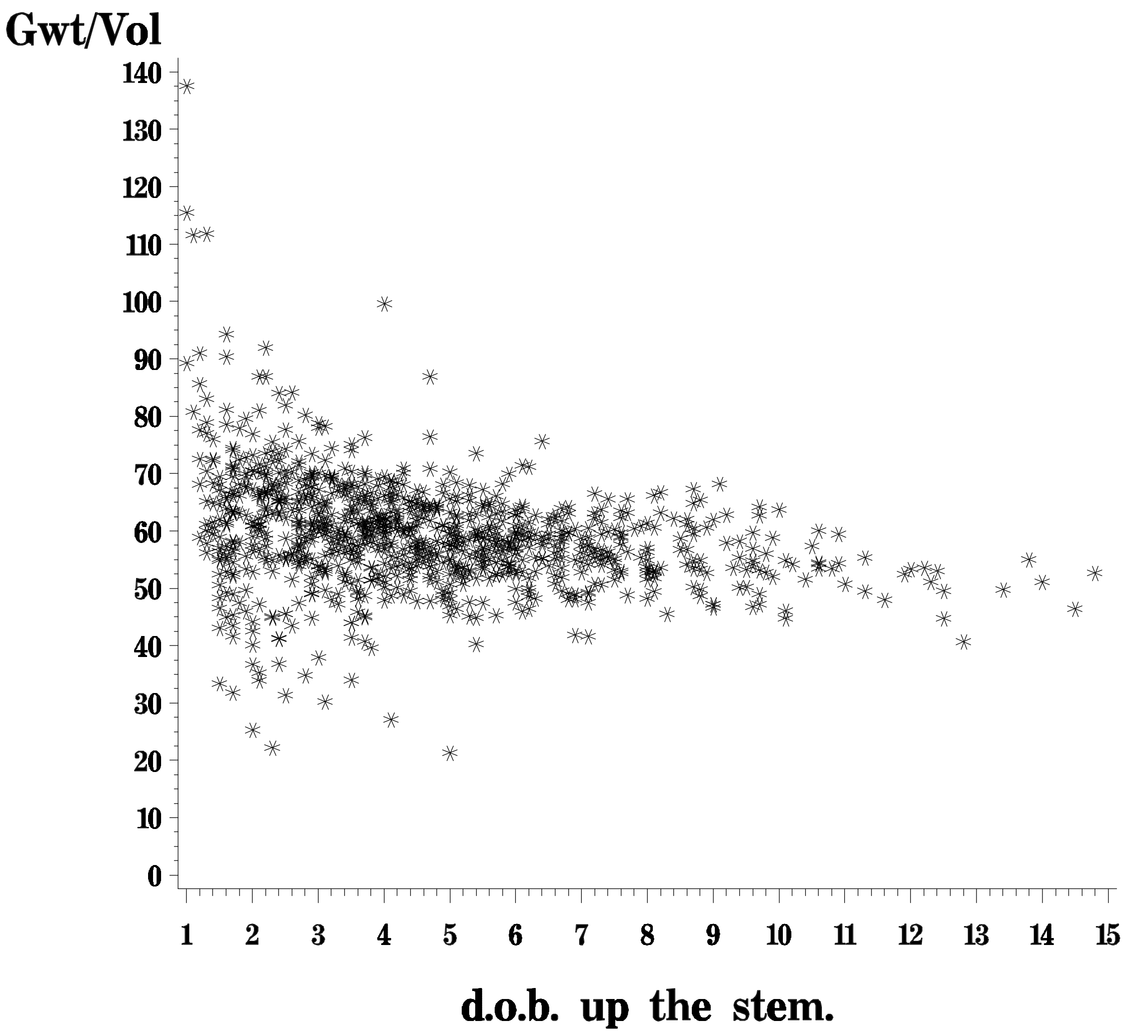


Figure 5: Green Weight Per Unit Volume By d.o.b. Up The Stem.

Green weight per unit volume (lbs./cuft.) with respect to each diameter outside bark (inches) per bolt. This graph also displays signs of heterogeneity of variance. This is due to the relative error involved in measurements. At the upper portion of the stem where the diameter is approaching zero, the accuracy of the scale (i.e. +/- 0.10 lb.) and diameter tape (i.e. +/- 0.10 in.) will have a much larger effect on the variance of the bolt weight per unit volume, when compared to the lower portion of the stem.

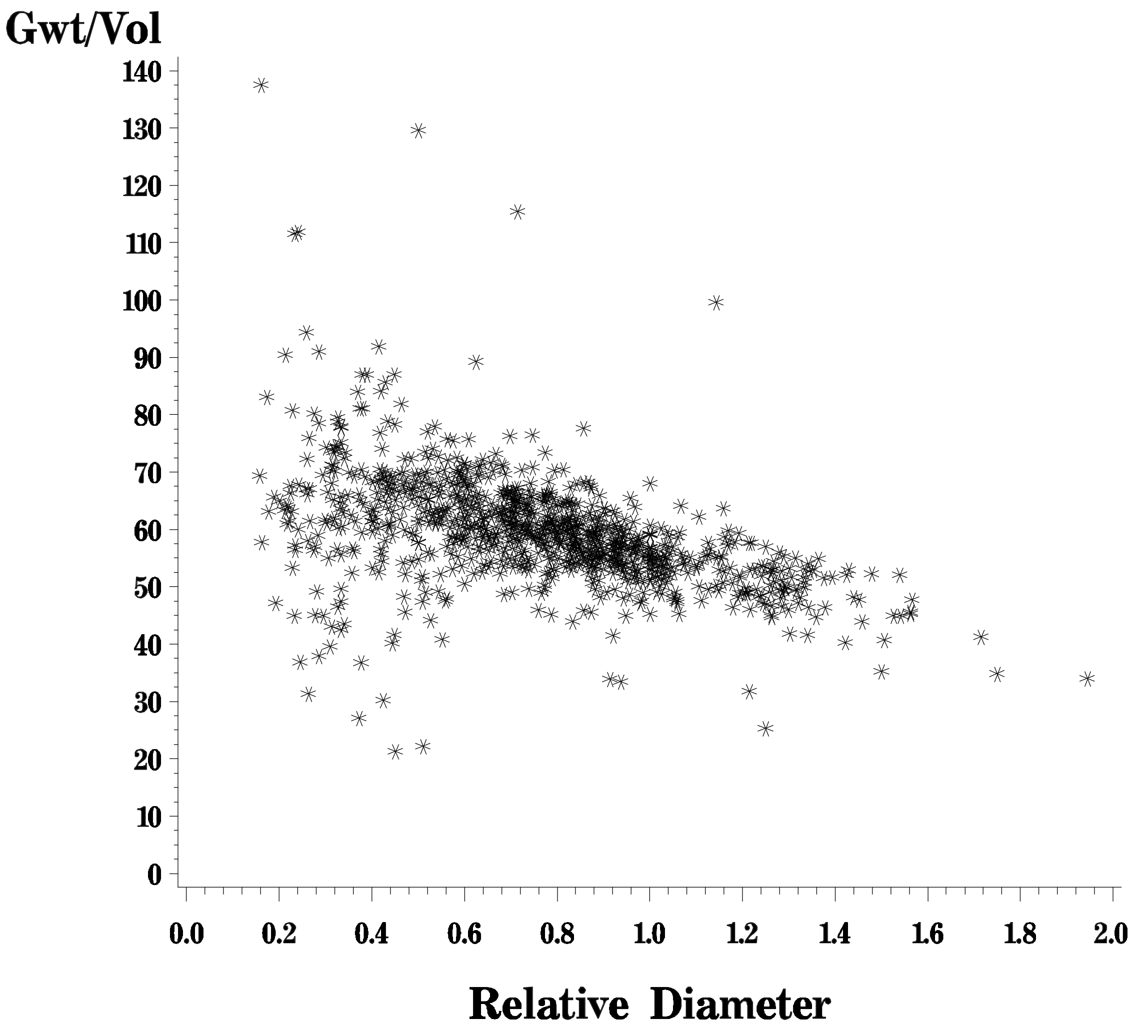


Figure 6: Green Weight Per Unit Volume By Relative Diameter.

Green weight per unit volume (lbs./cuft.) with respect to the relative diameter outside bark that each bolt represents. Where relative diameter is computed by dividing the diameter outside bark of each bolt by the diameter at breast height.

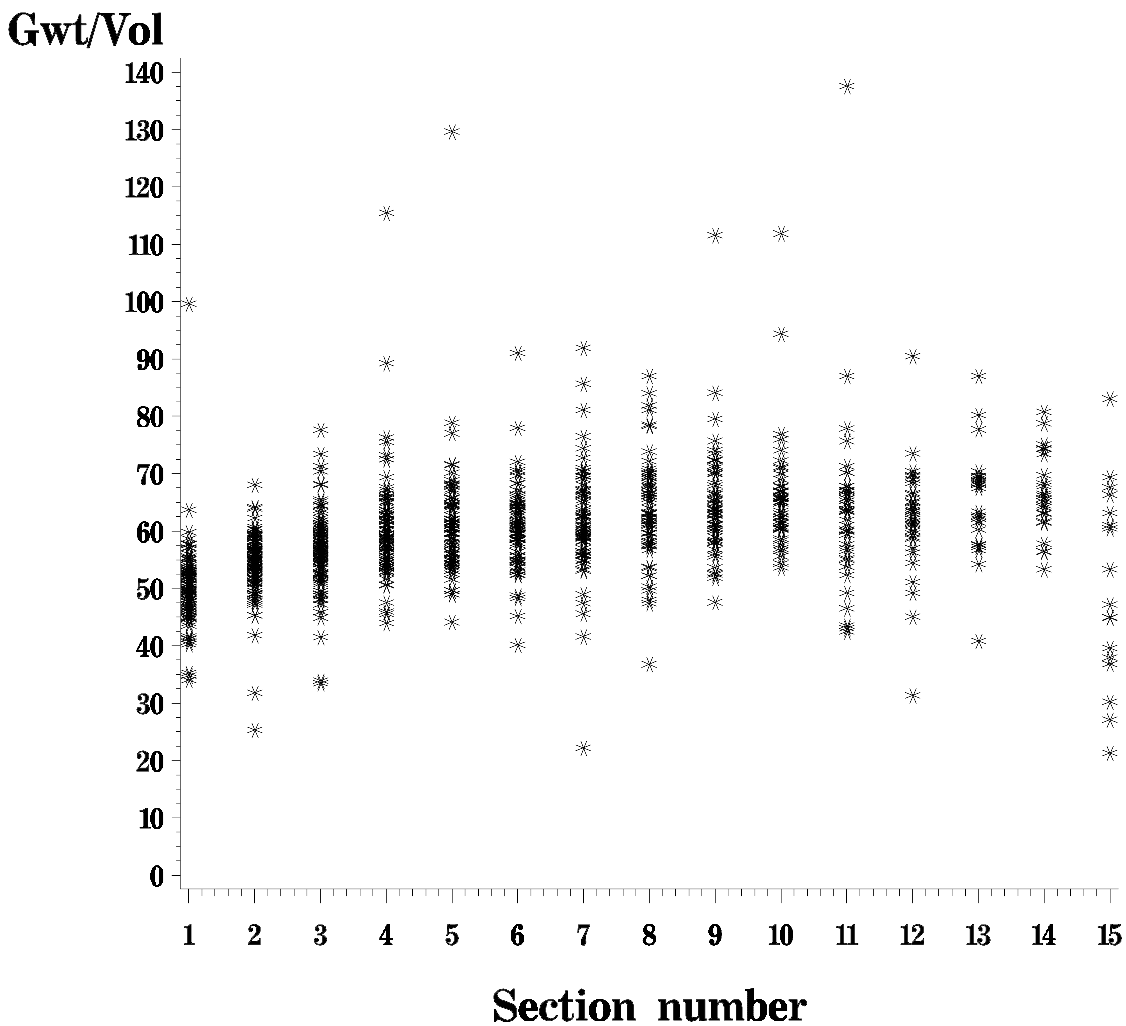


Figure 7: Green Weight Per Unit Volume By Section Number.

Green weight per unit volume (lbs./cuft.) of each bolt plotted by section number. One will note several outliers on this graph. Having checked and found no errors in these data points, it was found that most outliers occurred at the tip of the stem. The upper bolts, due to the relatively small weight and volumes, have little effect on the overall stem green weight per unit volume and were not discounted.

throughout the stem. Additional analyses, reported later in this thesis, were conducted to further elucidate the strength of weight per unit volume within the stem.

2.2.2 Further Analyses of Green Weight Per Unit Volume

The ratios of merchantable weight to total weight and merchantable volume to total volume were compared to see if there is a practical difference in the weight and volume ratio trends. The ratios for volume and weight are respectively:

$$Rvol = \frac{Mvol}{Tvol} \qquad \textbf{(5)}$$

$$Rwt = \frac{Mgwt}{Tgwt} \qquad \textbf{(6)}$$

where Rvol = Ratio of Volume

Mvol = Merchantable Volume to any upper limit

Tvol = Total Stem Volume

Rwt = Ratio of Weight

Mgwt = Merchantable Green Weight to any upper limit

Tgwt = Total Stem Green Weight

The relative volume and relative weight were graphed against relative height to aid in visualization of the general trend in the data (see Figures 8 and 9). The trend of the two ratios is similar, with the relative weight having a greater variance in the stem. Various functions were fit to the mean trend of the ratios, and showed that the two functions did not differ from one another.

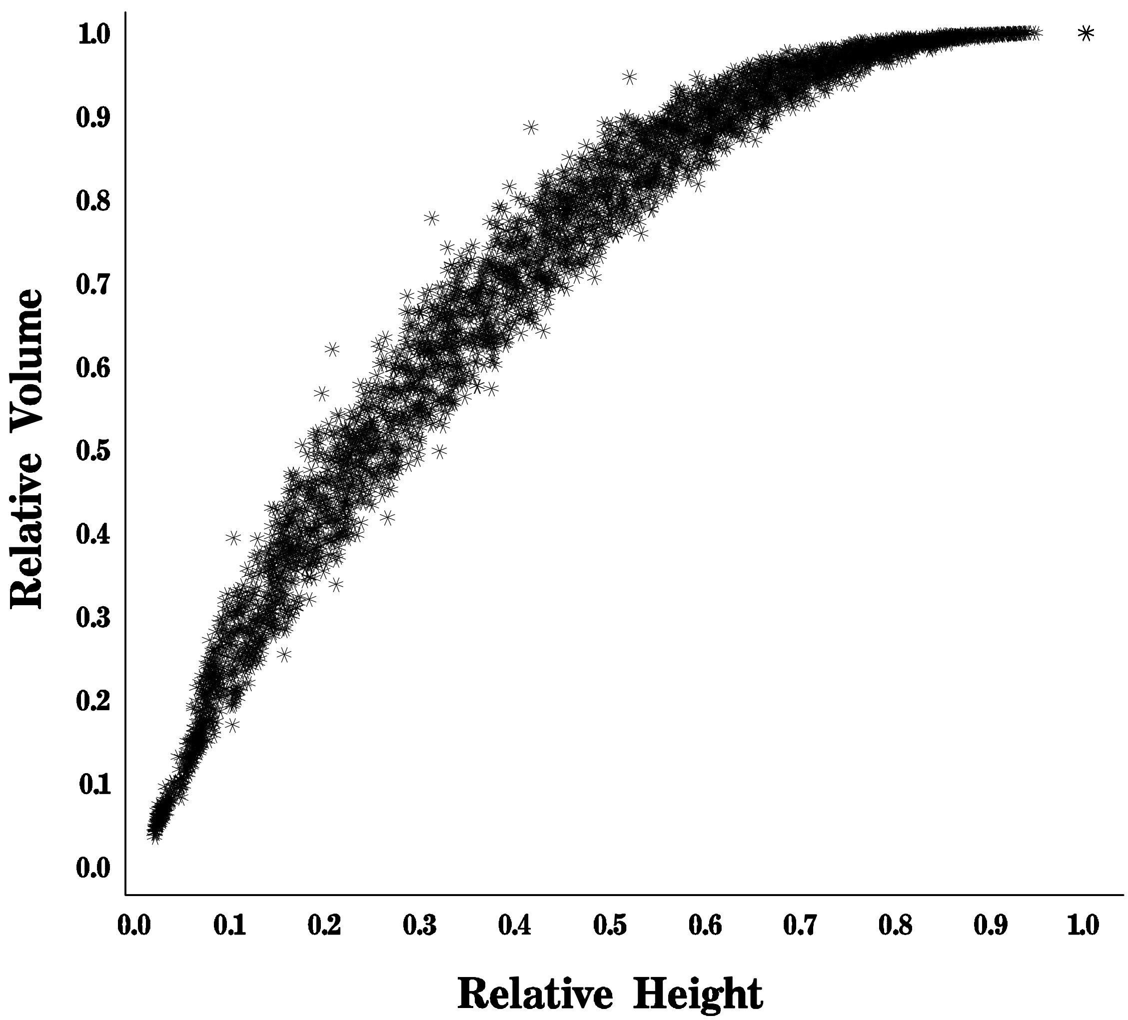


Figure 8: Relative Volume by Relative Height

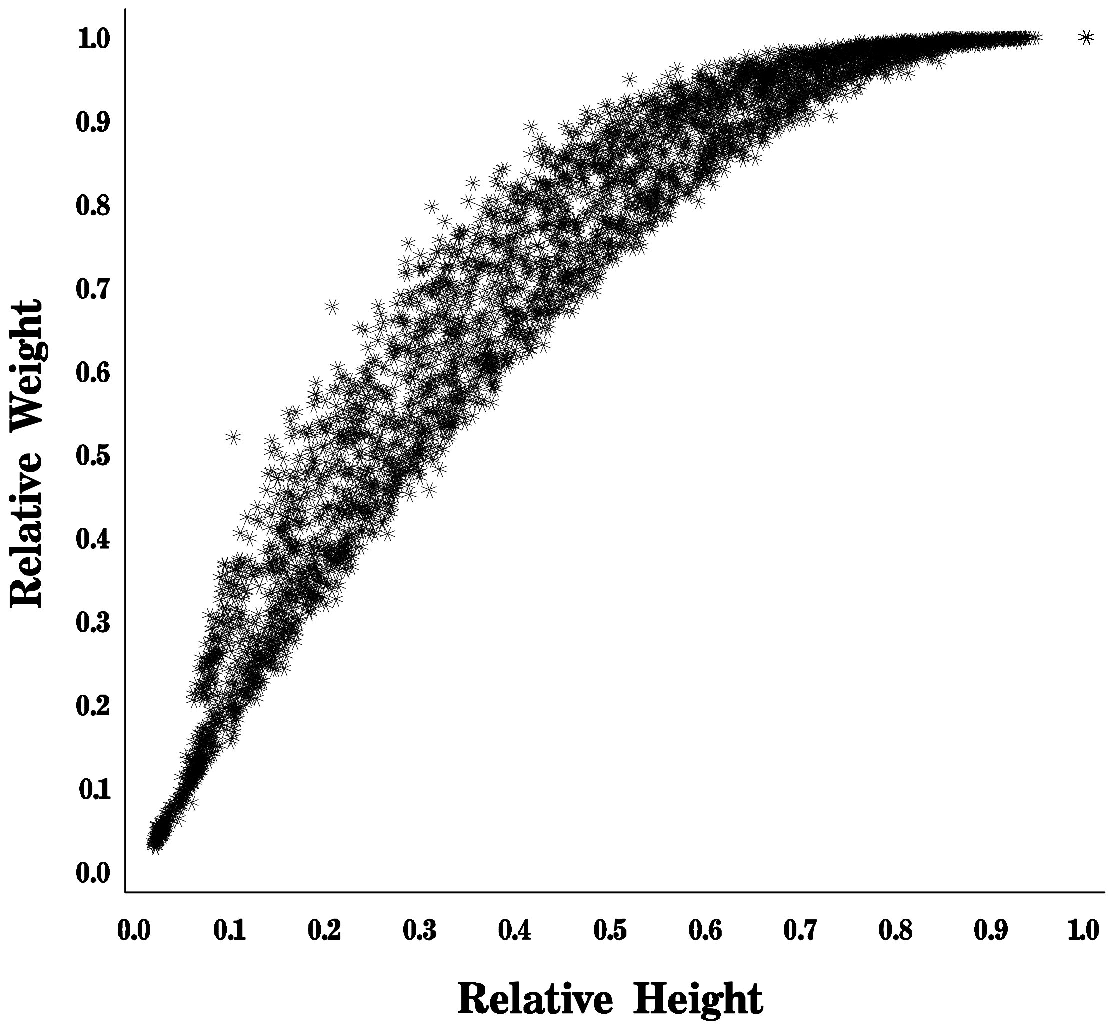


Figure 9: Relative Weight by Relative Height

The ratio (Burkhart, 1977) and exponential ratio (Van Deusen et al., 1981; Tasissa et al., 1997) forms were used to evaluate variation between the relative volumes and relative weights. Comparison was done separately for diameter up the stem and height up the stem. Nonlinear regression techniques were used to determine the coefficients for the ratio forms below.

$$Rvol = 1 + b_1\left(\frac{dob^{b_2}}{DBH^{b_3}}\right) \tag{7}$$

$$Rwt = 1 + a_1\left(\frac{dob^{a_2}}{DBH^{a_3}}\right) \tag{8}$$

$$Rvol = 1 + b_4\left(\frac{(HT-ht)^{b_5}}{HT^{b_6}}\right) \tag{9}$$

$$Rwt = 1 + a_4\left(\frac{(HT-ht)^{a_5}}{HT^{a_6}}\right) \tag{10}$$

where all symbols remain as defined above

Having fit the above equations (see Appendices 2 and 3), graphical analysis was used to determine if there was a difference in the fitted lines between relative volume and relative weight, for diameter up the stem and height up the stem separately. Figures 10 and 11 show the ratio form having essentially no difference in the relative weight and relative volume distributions for both diameter up the stem and height up the stem.

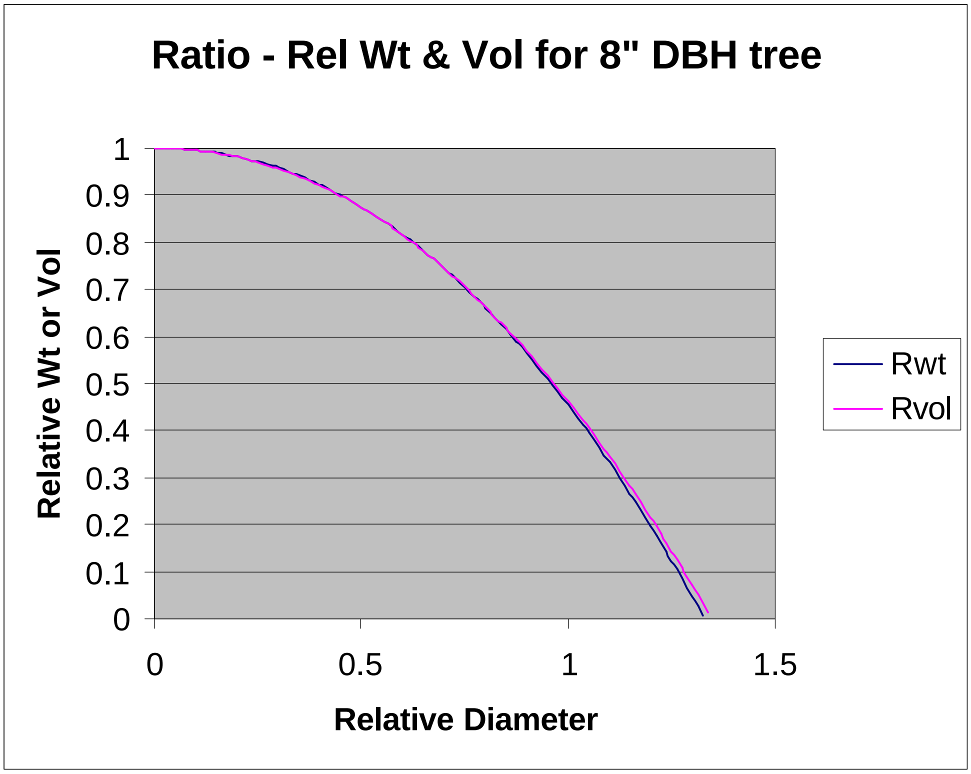


Figure 10: Relative Weight and Volume by Relative Diameter

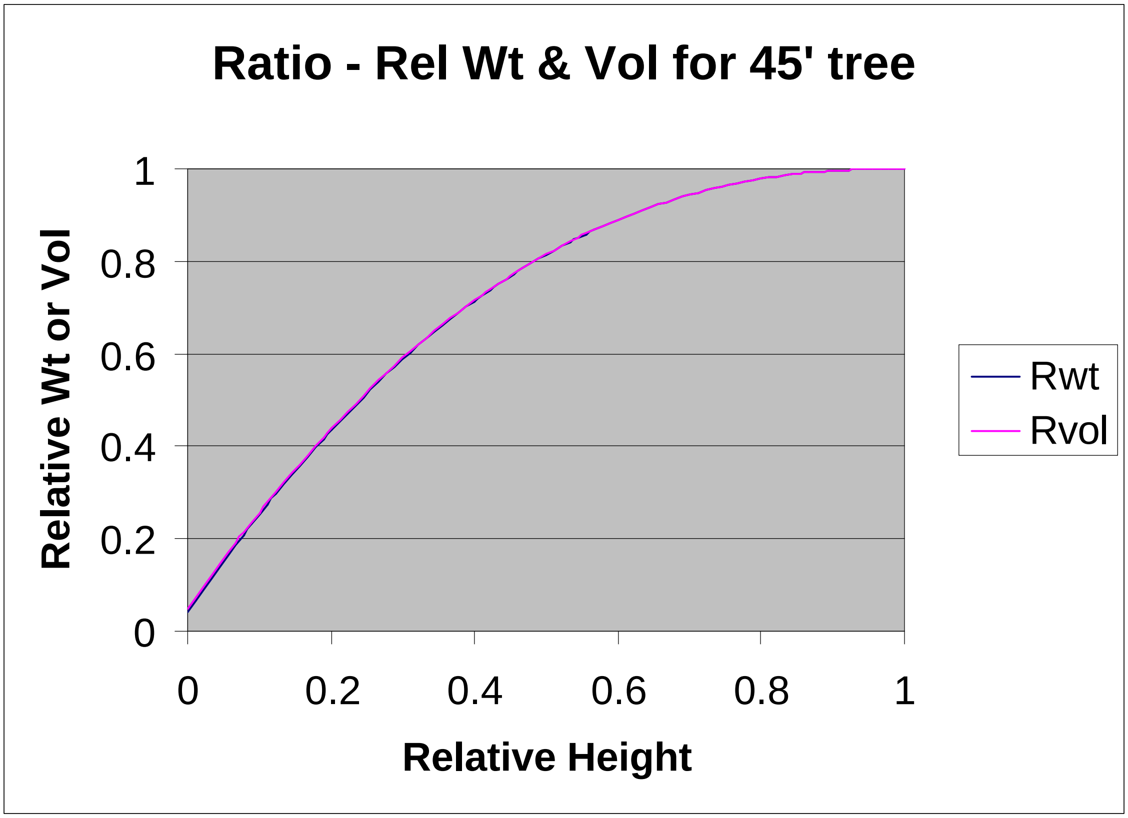


Figure 11: Relative Weight and Volume by Relative Height

Nonlinear regression techniques were used to determine the coefficients for the exponential ratio forms below.

$$Rvol = \exp\left[b_7\left(\frac{dob^{b_8}}{DBH^{b_9}}\right)\right] \quad \textbf{(11)}$$

$$Rwt = \exp\left[a_7\left(\frac{dob^{a_8}}{DBH^{a_9}}\right)\right] \quad \textbf{(12)}$$

$$Rvol = \exp\left[b_{10}\left(\frac{(HT-ht)^{b_{11}}}{HT^{b_{12}}}\right)\right] \quad \textbf{(13)}$$

$$Rwt = \exp\left[a_{10}\left(\frac{(HT-ht)^{a_{11}}}{HT^{a_{12}}}\right)\right] \quad \textbf{(14)}$$

where all symbols remain as defined above

Having fit the above equations (see Appendices 4 and 5), graphical analysis was used to determine if there was a difference in the fitted lines between relative volume and relative weight, for diameter up the stem and height up the stem separately. Figures 12 and 13 show the exponential ratio form having essentially no difference in the relative weight and relative volume distributions for both diameter up the stem and height up the stem.

The relative weight and relative volume functions are very similar in shape for both the ratio form and the exponential form. Although there is a slight trend in green weight per unit volume up the stem, it does not seem to manifest itself in these particular equation forms. This result seems consistent with those from the multiple linear regression analyses and the graphical analysis presented earlier, that green weight per unit volume is reasonably consistent throughout the stem.

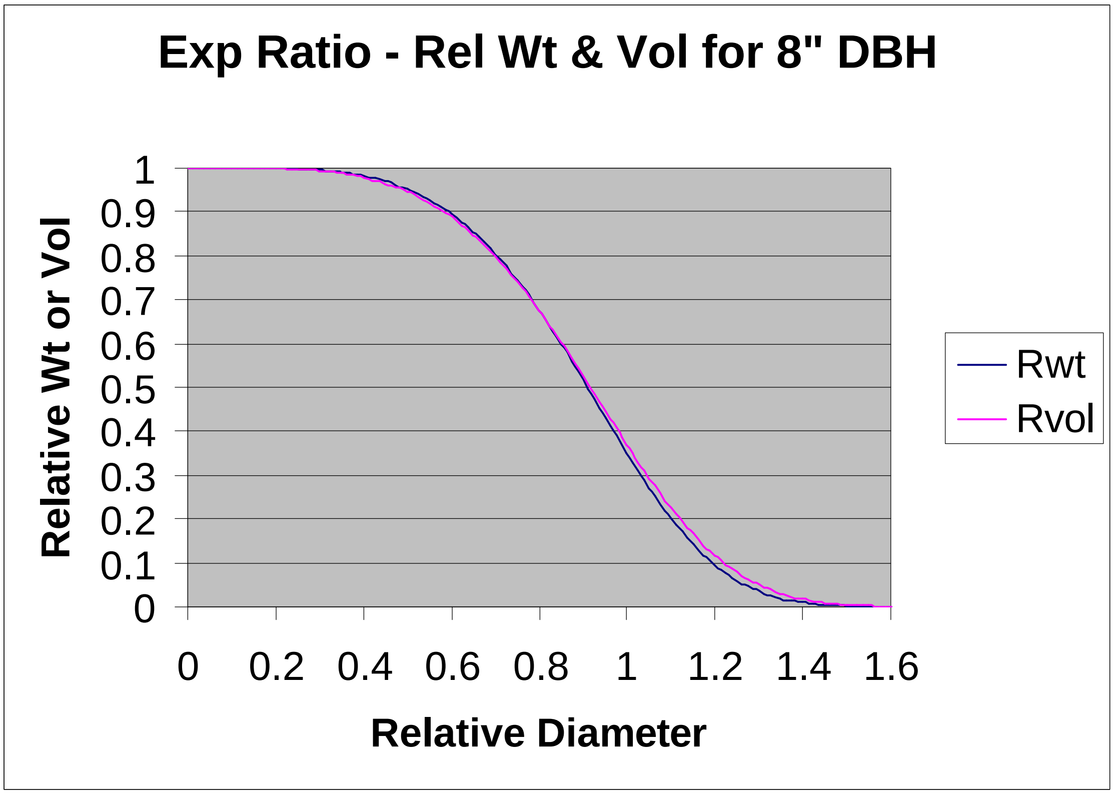


Figure 12: Relative Weight and Volume by Relative Diameter

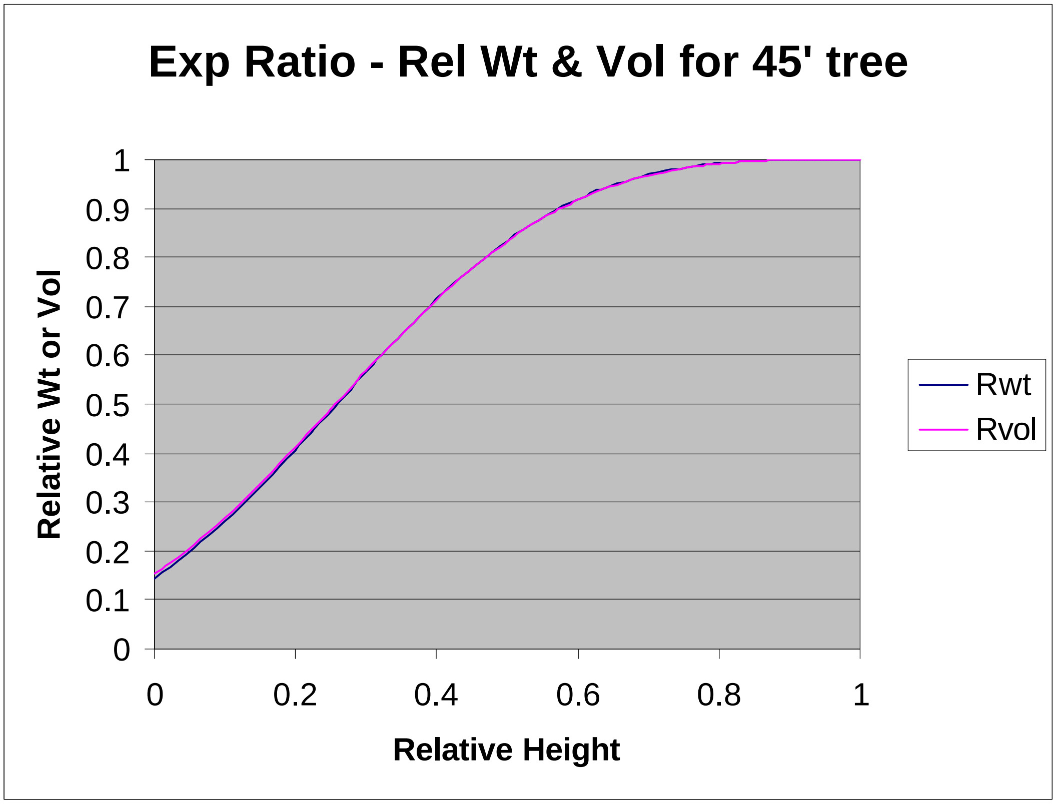


Figure 13: Relative Weight and Volume by Relative Height

2.2.3 Regional Variation in Green Weight Per Unit Volume

After the consistency of green weight per unit volume throughout the stem had been initially examined, the green weight per unit volume over the entire East Texas data set was calculated. For the sectional data two methods were considered. The first (Average Method) was the average green weight per unit volume from the sections over one whole tree, averaged over all the trees.

$$AM = \left\{ \frac{1}{N} \sum_{j=1}^{N} \left[\frac{1}{n_j} \sum_{i=1}^{n_j} \left(\frac{GreenWeight_{ji}}{UnitVolume_{ji}} \right) \right] \right\} \quad \textbf{(15)}$$

where AM = Average Method for approximation

$i = 1,2,... n_j$ the bolt number

n_j = the total number of bolts in tree j

j = 1,2,... N the tree number

N = the number of trees in the data set

This method gives each tree equal weight $\left(\frac{1}{N}\right)$ in calculating the average over the data set.

The second (Total Method) option involves totaling the volume over the whole tree and summing the weight of all the sections combined and then using the two sums to find a single green weight per unit volume constant for the tree. All of the trees values would then be summed and divided by the number of stems.

$$TM = \left\{ \frac{1}{N} \sum_{j=1}^{N} \left[\frac{\sum_{i=1}^{n_j} GreenWeight_{ji}}{\sum_{i=1}^{n_j} UnitVolume_{ji}} \right] \right\} \quad \textbf{(16)}$$

where TM = Total Method for approximation

$i = 1,2,... n_j$ the bolt number

n_j = the total number of bolts in tree j

$j = 1,2,...\ N$ the tree number

N = the number of trees in the data set

The Average Method, which takes the average green weight per unit volume over the bolts within each tree, has a mean of 58.10 pounds per cubic foot, outside bark, and a standard deviation of 5.63 for the East Texas data set. The Total Method, which totals the volume over the stem and then divides by the total weight of the stem, has a mean of 53.55 pounds per cubic foot, outside bark, and a standard deviation of 5.84 for the East Texas data set. The Average Method utilizes the within tree sectional data, and hence might be a better estimator of an individual tree green weight per unit volume. Since most of the variation occurs near the tip of the stem, any possible measurement error will have a greater influence on the individual tree mean if the average method is used. The Total Method may reduce some of the variation in the data since the very small volumes at the upper part of the stem are combined with the larger volumes of the bole. Hence the Total Method would be more appropriate for stand level green weight per unit volume. Since most of the other data sets being analyzed for this study only contain total height and total weight per tree, the Total Method was used for consistency.

The green weight per unit volume of each individual bolt was computed for the 130 loblolly pine trees from Central Louisiana. Techniques similar to those described above were used on these data. Once green weight per unit volume was ascertained from the volume outside bark and green weight of each bolt, a linear regression equation was fit to see if the height up the stem or the bolt number had any influence on the green weight per unit volume of the bolt. All models had an R-square, coefficient of determination, of less than 0.15 (see Appendix 6), showing that less then 15% of the variation in green weight per unit volume of the bolt was explained by the height up the stem, the section number, and/or diameter outside bark. This further supports the assessment made from the 101 East Texas loblolly pine trees that the green weight per unit volume is essentially consistent throughout the stem. The average green weight per unit volume for the data set was computed using the Total Method. It produced a mean green weight per unit volume of 54.77 pounds per cubic foot, outside bark, with a standard deviation of 3.37.

Data collected from Southwest Louisiana consisted of 451 loblolly pine trees. The trees were felled and sample disks were cut at random heights up the stem. The disk was then weighed and various diameter and height measurements were taken. Using the Total Method, the mean green weight per unit volume of the 451 trees in Southwestern Louisiana is 64.45 pounds per cubic foot, outside bark, with a standard deviation of 11.36. Although it has been shown that the specific gravity determined from a sample disk can be a good estimator of whole tree specific gravity, the Total Method for the Southwestern Louisiana trees shows a much higher estimate of green weight per unit volume when compared to the other data sets in the same region. This may be due to the techniques used in locating and measuring the sample disks. The average height at which a sample disk was cut from the felled tree is 28.7 feet, with a standard deviation of 19.63. The number of sample disks that were selected for laboratory testing was only one in ten. Hence the specific gravity of the 451 trees was determined from only 45 disks. The very small sample size may have resulted in estimates for this stand being higher than the others in the region. An ANOVA and test for mean differences supported the difference in green weight per unit volume of the trees from Southwest Louisiana from the rest of the data sets. The data from Southwest Louisiana were not used in any further calculations.

The data collected from Western Florida near Pensacola consisted of 49 loblolly pine trees. The trees were felled and cut into five-foot bolts, with each bolt being weighed and measured. The volume was determined using Smalian's method. The Total Method was again used for determining green weight per unit volume of the data set. The mean green weight per unit volume of the 49 trees is 58.85 pounds per cubic foot, outside bark, with a standard deviation of 4.38.

The data from the upper and lower piedmont of Georgia consisted of 608 loblolly pine trees. The trees were felled and cut into bolts, with each bolt having a sample disk cut from it for specific gravity determination. The bolts were collectively weighed in the field with and without bark; both inside and outside bark diameter measurements were taken up the stem. Cubic foot volume per bolt was then estimated using Smalian's formula. Total stem measurements for green weight to a three and four inch top diameter, inside and outside bark were available. Though these summary measurements were based off the sectional information, the weight and volume per bolt were unavailable. The Total Method was used for determining green weight per unit volume of the data set, but only to a three-inch top, outside bark. This is not biased towards the lower sections of the stem due to the occlusion of the very tip. The tip of the tree as observed in the complete sectional data sets is a very small portion of the overall weight and volume of the stem. By excluding the tip, there is no (or very little) difference in the green weight per unit volume of the overall stem. This is also consistent with the assumption that green weight per unit volume is consistent throughout the stem. The mean green weight per unit volume of the 608 trees is 53.28 pounds per cubic foot, outside bark, with a standard deviation of 4.10.

The data from the piedmont and coastal plain of Virginia consisted of 192 loblolly pine trees. The trees were felled and cut into bolts, with each bolt having a sample disk being cut from the upper end. The sample disk was then weighed in the field and measurements (inside and outside bark) were taken along the bole. The disks were labeled and sent to the lab for further analysis of density, specific gravity and dry weight. The disks were submerged in a tank of water using a basket attached to a scale. The force (buoyancy) of the disk pushing up or pulling down was measured in grams. This measurement was inside bark only. To get an estimate of disk volume, it was necessary to convert the weight of an equal volume of water from grams measured into pounds and then use a conversion from weight into volume. This was done using the following formula.

$$DiskVolume\_i.b. = \left\{ (WtH2Ograms)\left(\frac{1lb}{453.59\,grams}\right)\left(\frac{1cuft}{62.4\,lbs}\right) \right\} \qquad \textbf{(17)}$$

where $DiskVolume\_i.b.$ = the cubic foot volume of the disk inside bark

$WtH2Ograms$ = the weight of the disk submerged in water, in grams

$\frac{1lb}{453.59\,grams}$ = conversion from grams to pounds

$\frac{1cuft}{62.4\,lbs}$ = weight of one cubic foot of water

The analysis of the data set is in outside bark measurements, hence the disk volume was converted to outside bark. This conversion was done using the volume ratio of outside bark to inside bark of the individual bolts. Smalian's formula was used to estimate the volume of the bolts, with a conic formula being used at the tip of the tree. The volume ratio for each bolt was used in conjunction with the disk volume inside bark to get an estimate of disk volume outside bark. The green weight outside bark of the disk was combined with the disk volume outside bark to obtain green weight per unit volume for the disk. This ratio was used to represent the bolt, with bolt weight being obtained by multiplying the green weight per unit volume by the bolt volume. The Total Method was used for determining green weight per unit volume of the data set. The mean green weight per unit volume for the Virginia data set is 54.63 pounds per cubic foot, outside bark, with a standard deviation of 15.88. Apparently, this high standard deviation is likely due to extrapolation of the green weight per unit volume from the disks, although the standard deviation is on a per tree basis. The green weight of the bolt was later used for estimation of a nonlinear regression equation for green weight to any specified upper diameter or height.

2.3 EVALUATION OF DATA SETS

Two methods of volume determination were initially used throughout the data sets, but it resulted in problems that were detected during analysis. Thus, all volumes were computed the same way using Smalian's formula. Originally a cubic spline was fit to the East Texas data with a conic formula being used at the tip of the tree. The method of volume determination for the other data sets was Smalian's formula (see Avery and Burkhart, 1994).

Smalian's: $$CubicVolume = \left[\frac{(A_L + A_U)}{2}\right] \times L \qquad \textbf{(18)}$$

where A_L = Cross-sectional area at lower end of bolt (ft.^{2})

A_U = Cross-sectional area at upper end of bolt (ft.^{2})

L = Length of log (ft.)

A comparison of the two techniques was done to verify if the cubic spline method was comparable to Smalian's method. On a per bolt basis Smalian's formula consistently overestimated volume when compared to the cubic spline method. Smalian's formula has been shown to overestimate volume when there is significant butt swell in trees.

The volume for the East Texas data set was computed using Smalian's formula for the main stem and a conic formula applied at the tip of the stem. The mean green weight per unit volume decreased to 53.55 pounds per cubic foot, outside bark, with a standard deviation of 5.84, compared with the cubic spline mean green weight per unit volume of 55.21 pounds per cubic foot, outside bark, with a standard deviation of 4.86. This 1.66 pounds per cubic foot difference is due to butt swell, which leads to an overestimation of volume in the lower bolt. For reasons of consistency, Smalian's was used for the volume calculations in the East Texas data set as well.

The green weight per unit volume in the Florida Panhandle is larger than that of the data sets retained; this may be due to specific gravity being higher at coastal locations. The methods used in data collection are similar to those of the other data sets and there are no apparent gross measurement errors involved in calculating green weight per unit volume. An ANOVA and test for mean differences were used to check for differences in green weight per unit volume for the trees from the Florida Panhandle (see Appendix 7). The significant difference in green weight per unit volume may be an anomaly of the sample. The Florida Panhandle data set contained only 49 trees, whereas all the other data sets had at least twice as many trees sampled. Yet this smaller sample size would require a larger statistic to reject any difference in mean green weight per unit volume. The age distribution of the Florida Panhandle data set was heavily weighted with older stems, and thought to be a possible reason for the difference in mean green weight per unit volume. Whereas the Virginia and Georgia data sets contained mostly younger stems, the Central Louisiana data is distributed similar to the Florida data set. The difference being due to age distribution was then questionable.

Given that the Florida Panhandle data set did not seem to come from the same population as the other data sets and no satisfactory explanation for why it might differ was determined, it was omitted. The region of applicability of the results was limited to the part of the loblolly pine growing region excluding the Florida area. Any further calculations and inferences shall be limited to the geographic area covered by the four data sets retained for modeling (see Figure 14). Further data collection from coastal locations is required to validate any regional differences in the Florida area.

The various data set formats were made compatible and then combined. This combination enabled comparisons of green weight per unit volume and allowed modeling for predicting total bole weight and merchantable weight (see Table 2).

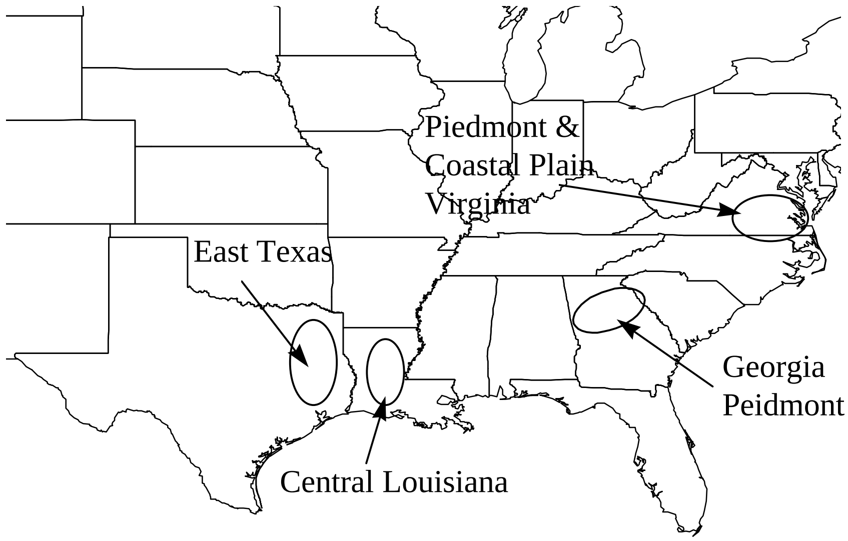


Figure 14: Data Map.

Map showing area of data collection used in green weight per unit volume estimation and for predicting green weight to any upper diameter or height limit.

Table 2: Mean Green Weight Per Unit Volume By Data Set.

Location	Sample Size	Mean Green Weight Per Unit Volume (lbs./cuft.)	Standard Deviation
East Texas	**101**	53.55	5.84
Central Louisiana	**130**	54.77	3.37
Virginia	**192**	54.63	15.88
Georgia	**608**	53.28	4.10

2.4 Regional Comparisons

An analysis of variance was computed on the four data sets to test the null hypothesis that all of the means are the same (H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4$) versus the alternative that there is a significant difference in at least one of the means. This was done using an ANOVA function in SAS.[2] If the F-Value for the observed is greater then the F-Value from the table, then the null hypothesis shall be rejected. For a 0.05 alpha level the table value is; $\mathbf{F_{table, .05}} = 2.60$ and the observed value for this test was; $\mathbf{F_{obs}} = 2.30$ (see Appendix 8).

The null hypothesis that there is no difference in any of the means, was not rejected at an alpha level of 0.05. Statistically, there is no difference in any of the mean green weight per unit volume estimates within the merged data sets. Pair-wise comparison analysis on the means is not warranted due to the lack of rejection.

2.5 Predicting Green Weight From Weight Per Unit Volume Relationships

Modeling on the slight but discernable trend in green weight per unit volume up stem was performed with various linear and non-linear models. No model adequately described this trend. Due to the inability to describe any trend, as stated previously, green weight per unit volume was assumed to be constant throughout the stem. This allowed the volume ratio models derived previously to be utilized for obtaining green weight to an upper merchantable diameter. Using a combined variable equation of the following form:

$$T = b_o + b_1 \times \left(DBH^2 \cdot HT\right) \qquad \mathbf{(19)}$$

where T= Total stem weight or total stem volume

[2] Statistical Analysis System, SAS Institute, Cary, NC, USA

total stem green weight (see Appendix 23) and total stem volume (see Appendix 9) were derived. Multiplying the green weight per unit volume constant by the derived relative volume ratio form and predicted total volume yields an estimate of green weight to the upper diameter limit specified in the relative volume ratio prediction model. This estimate was compared with green weight derived from a model form used by Tasissa et al. (1997). Nonlinear regression techniques were used to fit the Tasissa et al. model using all of the data (see Appendix 19). Table 3 shows three example trees, representative of the data, which were used to compare the methods of deriving green weight to any upper diameter limit.

Table 3 shows considerable variation between the predictions from directly modeling green weight distribution and computing green weight distribution from volume distribution and assuming a constant weight per unit volume. One would expect the direct prediction of green weight to be more accurate than derived values from volume and weight per unit volume relationships. Thus, given the relatively large discrepancy between the two predictions, it was decided to conduct a detailed investigation of green weight estimation using a weight-ratios modeling approach.

Table 3: Utilizing The Volume Ratio Function For Green Weight Prediction

Tree Diameter and Total Height	**10 inch diameter 70 feet total height**			**8 inch diameter 55 feet total height**			**6.5 inch diameter 40 feet total height**	
Upper Diameter Limit	8” dob	6” dob	4” dob	8” dob	6” dob	4” dob	6” dob	4” dob
Total Volume (cuft.)	18.6	18.6	18.6	9.1	9.1	9.1	4.1	4.1
Total Green Weight (lbs.)	1054	1054	1054	514	514	514	230	230
Tasissa et al. Form Green Weight (lbs.)	714	985	1048	114	395	502	91	212
Constant×Relative Volume×Total Volume (lbs.)	650	880	979	180	363	464	115	196

3. Results From Modeling Green Weight

For all of the following comparisons, tests of hypothesis and analyses, an alpha level of 0.05, which is commonly used in biological research, was chosen. This alpha level was found to be a reasonable balance between type I and type II error rates. All output is listed in the appendices with the computed F-ratios for those who choose to compute the exact significance level.

3.1 Predicting Green Weight Using A Ratio Form

3.1.1 Predicting and Modeling To Any Upper Diameter Limit

A number of prediction equations for green weight of the stem of loblolly pine have been derived (see Baldwin, 1987). However, the ability to reliably predict green weight to any top diameter has not been adequately investigated. To predict green weight for any specified upper diameter, the following ratio was defined:

$$R = \frac{GWT_{dob}}{GWT_{Tot}} \qquad \textbf{(20)}$$

where GWT_{dob} = Green weight, o.b., to any upper diameter ob.

GWT_{Tot} = Total green weight, o.b.

The mathematical expression to relate the ratio to tree characteristics is conditioned so that as the upper diameter goes to zero, the green weight at the upper diameter goes to the total green weight and the ratio goes to one. By simple rearrangement of the terms, this equation is equivalent to:

$$GWT_{dob} = \left(GWT_{Tot}\right) \cdot \left(R\right) \qquad \textbf{(21)}$$

With this form, a nonlinear ratio equation developed by Burkhart (1977) was used for the ratio (R). This nonlinear model is conditioned such that when the upper diameter equals zero, the ratio equals one. The ratio model is of the form:

$$R = \left[1 + b_1 \cdot \left(\frac{dob^{b_2}}{DBH^{b_3}} \right) \right] \tag{22}$$

where DBH = Diameter at breast height

dob = upper limit diameter, to which green weight is desired

β_i = coefficients to be estimated from the data, i= 1,2,3

Nonlinear regression techniques (SAS) were used to determine the coefficients for the combined equation below. This equation enables one to predict green weight to any top diameter limit by knowing the desired upper limit, DBH, and predicted total green weight.

$$GWT_{dob} = \left(GWT_{Tot} \right) \cdot \left[1 + b_1 \cdot \left(\frac{dob^{b_2}}{DBH^{b_3}} \right) \right] \tag{23}$$

where all symbols remain as defined above

The results of a nonlinear regression analysis for the entire East Texas data set gave parameter estimates that had a low standard error, and the confidence intervals did not include zero. These parameter estimates were obtained by minimizing the residual sum of squares between the green weight to the upper diameter limit and the predicted green weight to the same upper diameter limit.

$$RSS = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} \left(y_i - \hat{y}_i \right)^2 \tag{24}$$

where RSS = Residual Sum of Squares

y_i = green weight to a upper diameter limit

$\hat{y}_i$ = predicted green weight to a upper diameter limit

There were no extremely high correlations (maximum absolute value 0.71) between any two coefficients (see Appendix 10). For comparison and validation of the parameter estimates from the entire data set, a random bolt from each tree was selected and parameters of the nonlinear regression were re-estimated. This was done to see if the results differed when only one observation per tree was used, as opposed to using the full data set with multiple observations per tree. The results were similar to using the entire data set (see Appendix 11).

The above nonlinear regression analysis was repeated using the Central Louisiana data set, and gave similar results (see Appendix 12). The analysis was also repeated using the Virginia data set, with the results differing slightly (see Appendix 13). The three data sets were then merged and the nonlinear regression analysis was performed. The results of this regression analysis are shown in the prediction equation below with the parameter estimates from the combined data sets (see Appendix 14).

$$GWT_{dob} = \left(GWT_{Tot}\right) \cdot \left[1 - 0.4578 \cdot \left(\frac{dob^{2.5226}}{DBH^{2.4050}}\right)\right] \qquad \textbf{(25)}$$

where all symbols remain as defined above

3.1.2 Predicting and Modeling To Any Upper Height Limit

In addition to the equation utilizing the upper diameter and DBH, another form will also be considered using total height of the tree and an upper height limit. The form and use are similar to that of the above equation, but differ as follows (see Cao and Burkhart, 1980):

$$GWT_{ht} = \left(GWT_{Tot}\right) \cdot \left[1 + a_1 \cdot \left(\frac{\left(HT - ht\right)^{a_2}}{HT^{a_3}}\right)\right] \qquad \textbf{(26)}$$

where GWT_{ht} = green weight of tree to specified height

GWT_{Tot} = total green weight of tree

HT = total height of the tree

ht = specified height up the stem to which green weight is desired

α_i = coefficients to be estimated from the data, i= 1,2,3

Nonlinear regression techniques were used to evaluate this model using the East Texas data and the results give parameter estimates that had a low standard error, and the confidence intervals did not include zero. These parameter estimates were obtained by minimizing the residual sum of squares between the green weight to the upper height limit and the predicted green weight to the same upper height limit. The correlation matrix did not show extraordinarily high correlation (maximum absolute value 0.82) between any two coefficients (see Appendix 15).

The above nonlinear regression analysis for predicting green weight to any upper height limit was repeated using the Central Louisiana data set, and gave similar results (see Appendix 16). The analysis was also repeated using the Virginia data set, with the results differing slightly (see Appendix 17). The three data sets were then merged and the nonlinear regression analysis was performed. The results of this regression analysis are shown in equation 27, with the parameter estimates from the combined data sets (see Appendix 18).

$$GWT_{ht} = \left(GWT_{Tot}\right) \cdot \left[1 - 0.3383 \cdot \left(\frac{\left(HT - ht\right)^{2.0263}}{HT^{1.7785}}\right)\right] \qquad \textbf{(27)}$$

where the variables remain as defined above in (26)

3.2 Predicting Green Weight Using An Exponential Ratio Form.

3.2.1 Predicting and Modeling To Any Upper Diameter Limit

The preceding equations are commonly used for predicting volume ratios. Another form that has been applied was originally published by Van Deusen et al. (1987) and used in modified form by Tasissa et al. (1997). This model, called the exponential model, has the following form:

$$GWT_{dob} = \left\{ Gwt_{Tot} \cdot \left[\exp\left(b_1 \cdot \left(\frac{dob^{b_2}}{DBH^{b_3}} \right) \right) \right] \right\} \qquad \textbf{(28)}$$

where exp = is the base of the natural logarithm

and all other variables and symbols remain as defined above

The exponential ratio model was fitted for completeness and comparison to the ratio equation. Nonlinear regression techniques were used to evaluate this model using all of the data and the results gave parameter estimates with low standard errors, and confidence intervals that did not include zero. The parameter estimates were obtained by minimizing the residual sum of squares between the green weight to the upper diameter limit and the predicted green weight to the same upper diameter limit. The correlation matrix showed a maximum absolute value of 0.91 correlation between the β_2 and β_3 coefficients (see Appendix 19). This high correlation did not, however, inhibit convergence.

$$GWT_{dob} = \left\{ Gwt_{Tot} \cdot \left[\exp\left(-1.5219 \cdot \left(\frac{dob^{6.0481}}{DBH^{6.0532}} \right) \right) \right] \right\} \qquad \textbf{(29)}$$

where all variables and symbols remain as defined above

3.2.2 Predicting and Modeling To Any Upper Height Limit

The exponential ratio model is of the following form for predicting green weight to any upper height limit:

$$GWT_{ht} = \left\{ Gwt_{Tot} \cdot \left[\exp\left(a_1 \cdot \left(\frac{(HT - ht)^{a_2}}{HT^{a_3}} \right) \right) \right] \right\} \qquad \textbf{(30)}$$

where all variables and symbols remain as defined above

Nonlinear regression techniques were used to evaluate this model using all of the data and the results gave parameter estimates that had a low standard error, and whose confidence interval did not contain zero. These parameter estimates were obtained by minimizing the residual sum of squares between the green weight to the upper height limit and the predicted green weight to the same upper height limit. The correlation matrix did not show extremely high correlation (maximum absolute value 0.84) between any two coefficients (see Appendix 20).

$$GWT_{ht} = \left\{ Gwt_{Tot} \cdot \left[\exp\left(-0.1933 \cdot \left(\frac{(HT - ht)^{3.1350}}{HT^{2.5734}} \right) \right) \right] \right\} \tag{31}$$

where all variables and symbols remain as defined above

3.3 Comparison Of The Ratio and Exponential Ratio Prediction Equations

3.3.1 Residual Sum Of Squares Comparison

In comparing the ratio and exponential ratio form of predicting green weight to any upper diameter limit, the residual sum of squares (RSS) was used as a method of determining the best prediction equation. For predicting green weight to any upper diameter limit, the RSS for the ratio form was 103,461,142 and the RSS for the exponential ratio form was 21,269,585 (see Appendices 14 and 19). Since the RSS for the exponential ratio form is approximately one-fifth the size of the RSS for the ratio form, the exponential ratio from was chosen (Equation 29) for predicting green weight to any upper diameter limit. For predicting green weight to any upper height limit, the RSS for the ratio form was 4,867,448 and the RSS for the exponential ratio form was 10,545,209 (see Appendices 18 and 20). Since the RSS for the ratio form is less then half the size of the RSS for the exponential ratio form, based on this criterion, the ratio form was chosen (Equation 27) for predicting green weight to any upper height limit.

Thus, based on RSS, there was no clear-cut choice of one model form over the other. Consequently, additional evaluation criteria were desired. It may be that there is no ‘best’ form, and that a combination of models may be required.

3.3.2 Implicit Taper Functions Comparison

It is possible to compare the implicit taper functions of both the ratio and exponential ratio forms. This allows one to examine how well each form performs. Implicit taper functions for the ratio model were presented in Amateis and Burkhart (1987) and for the exponential ratio model in Tasissa et al. (1997).

By equating and rearranging equations (23) and (26) or equations (28) and (30), the following implicit taper functions are derived for both the ratio and exponential ratio form:

$$dob = \left\{ \left(\frac{a_1}{b_1} \right)^{\frac{1}{b_2}} \cdot DBH^{\frac{b_3}{b_2}} \cdot \left[\frac{(HT - ht)^{\frac{a_2}{b_2}}}{HT^{\frac{a_3}{b_2}}} \right] \right\} \quad \textbf{(32)}$$

$$ht = H - \left\{ \left(\frac{b_1}{a_1} \right)^{\frac{1}{a_2}} \cdot \left(HT^{\frac{a_3}{a_2}} \right) \cdot \left(\frac{dob^{\frac{b_2}{a_2}}}{DBH^{\frac{b_3}{a_2}}} \right) \right\} \quad \textbf{(33)}$$

where β_i = parameter estimates from the original ratio forms, i= 1,2,3

α_i = parameter estimates from the original ratio forms, i= 1,2,3

and all other symbols remain as defined above

The α_i's and β_i's are obtained from the modeled prediction equations given in equations (25) and (27) or equations (29) and (31) for the ratio and exponential ratio model forms, respectively.

Substituting in the estimated parameter values from the overall data set gives the final implicit taper functions for the ratio form as:

$$dob = \left\{ (0.8870) \cdot DBH^{(0.9534)} \cdot \left[\frac{(HT - ht)^{(0.8033)}}{HT^{(0.7050)}} \right] \right\}, \quad \textbf{(34)}$$

$$ht = H - \left\{ (1.1610) \cdot \left(HT^{(0.8777)} \right) \cdot \left(\frac{dob^{(1.2449)}}{DBH^{(1.1869)}} \right) \right\}, \quad \textbf{(35)}$$

and for the exponential ratio form as:

$$dob = \left\{ (0.7109) \cdot DBH^{(1.0008)} \cdot \left[\frac{(HT - ht)^{(0.5183)}}{HT^{(0.4255)}} \right] \right\}, \qquad \textbf{(36)}$$

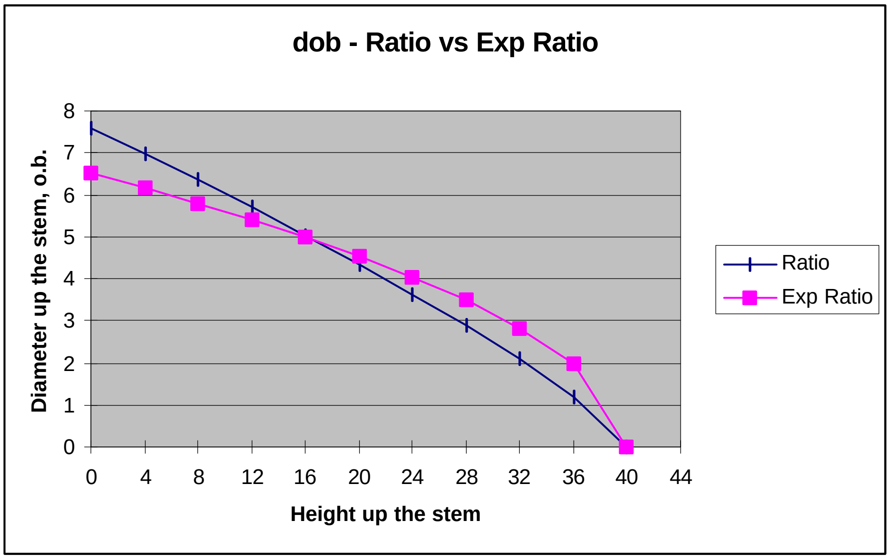
$$ht = H - \left\{ (1.9313) \cdot \left(HT^{(0.8209)} \right) \cdot \left(\frac{dob^{(1.9292)}}{DBH^{(1.9308)}} \right) \right\}. \qquad \textbf{(37)}$$

Graphs of the predicted diameter up the stem, outside bark, from both the ratio (34) and exponential ratio (36) forms are presented for comparison in Figure 15. Three trees with average, low, and high diameter at breast height and total height values are presented. They are graph a) 6.5 inch DBH and 40 feet total height, b) 4 inch DBH and 30 feet total height, and c) 10 inch DBH and 70 feet total height (see Figure 15). The increments of height up the stem are in tenths of the total height; this allows for common visualization between graphs.

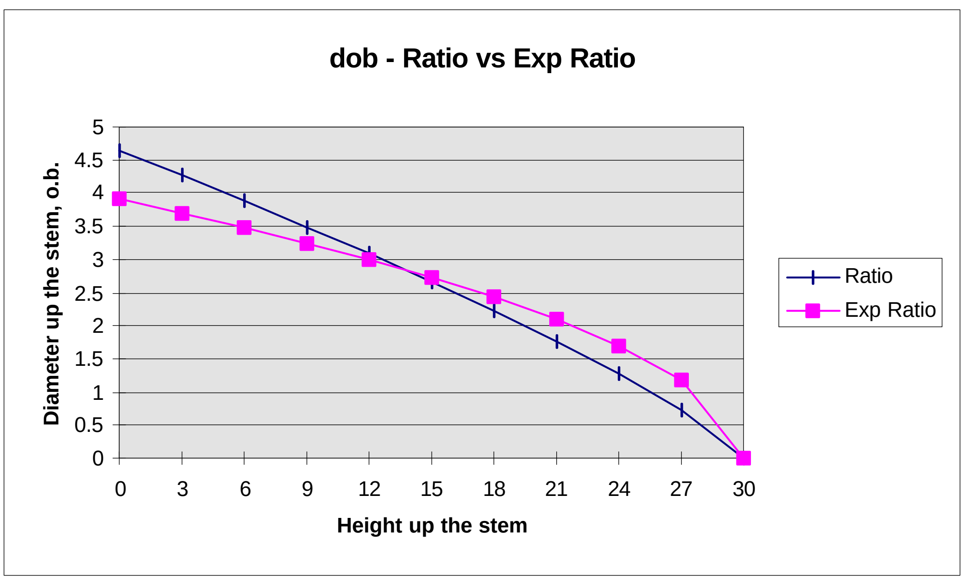
These graphs show varying predictions when comparing the two model forms. Using measurement data from 422 trees with sectional information and a total of 3873 sections, residuals were computed for the actual upper stem outside bark diameter (obs_{dob}), minus either the ratio or exponential ratio form predicted upper stem outside bark diameter ($pred_{dob}$). The residuals (obs_{dob} - $pred_{dob}$), squared residuals $(obs_{dob} - pred_{dob})^2$, and absolute residuals ($|obs_{dob} - pred_{dob}|$) for the ratio and exponential ratio forms were compared over the whole data set (i.e. all sections), and by section number, so

Figure 15: a), b), and c)

a) 6.5 inch DBH and 40 feet total height



b) 4 inch DBH and 30 feet total height



c) 10 inch DBH and 70 feet total height

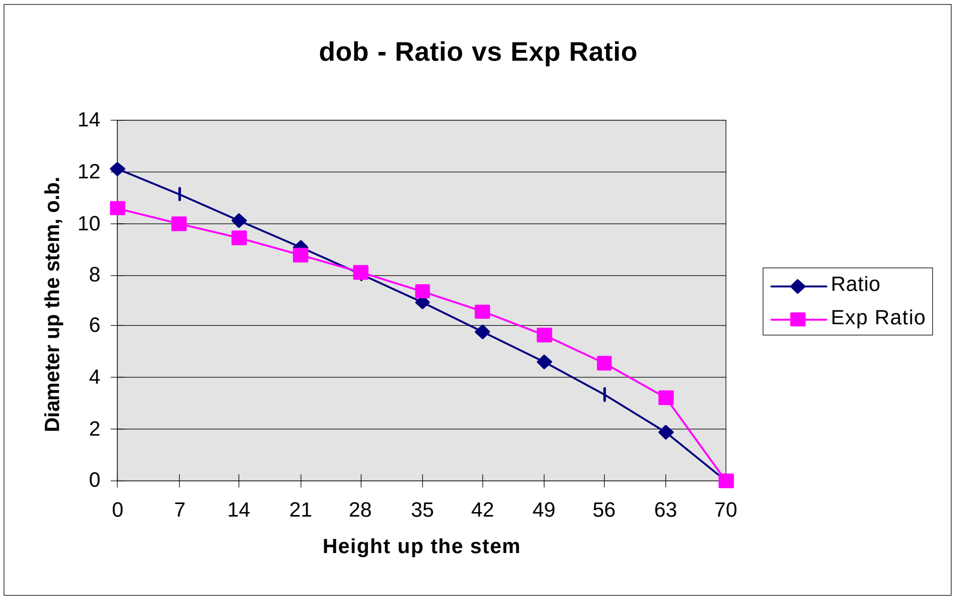


Figure 15: Graphs Of Predicted Diameter Up The Stem, Outside Bark

as to see how each form predicts diameter outside bark overall and by location along the stem (see Appendix 21).

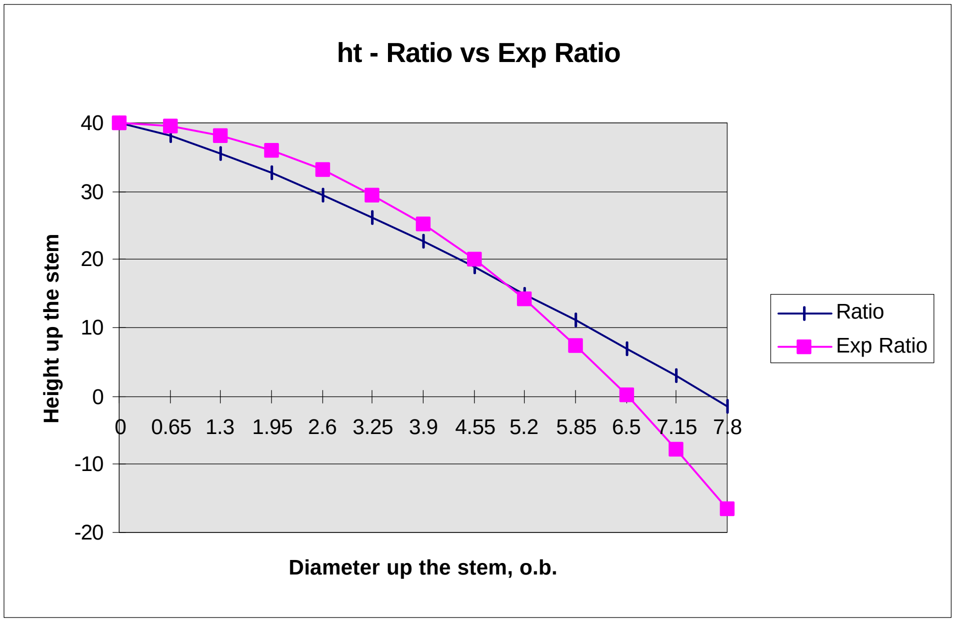
In sections one, six, seven and eight of the tree, the ratio form had a lower absolute, squared and standard residual value. This shows that the ratio form did a better job of predicting diameter outside bark up the stem in these portions of the tree. In sections two, three, four, five, and all of the upper bolts, the exponential ratio form had lower absolute, squared and standard residual value. This shows that the exponential form was a better predictor of diameter outside bark in these portions of the tree. The ratio form consistently under predicted diameter outside bark in the upper portions of the stem. The results of the residual analysis support the residual sum of squares comparison, which identified the exponential ratio form as the model which best predicted green weight to any upper diameter limit. Using the point of intersection on the graphs presented for reference, the ratio form generally predicts best for the lower portions of the stem, and the exponential form predicts best for the upper portions.

Graphs of the predicted height up the stem from both the ratio (35) and exponential ratio (37) forms for the same three example trees are presented for comparison (see Figure 16). The increments of diameter up the stem are in tenths of the diameter at breast height; this allows for common visualization between graphs.

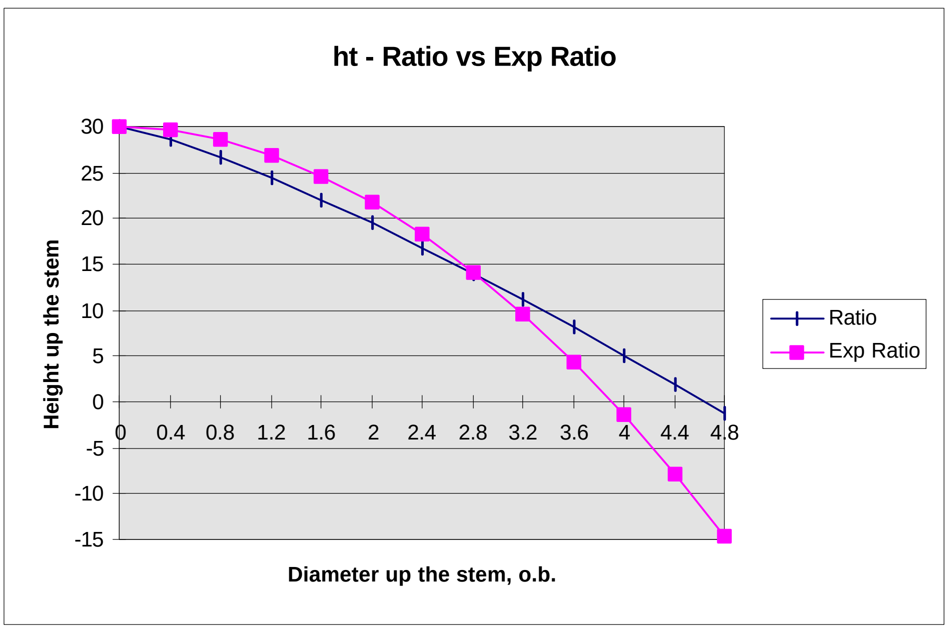
These graphs show inconsistent prediction abilities when comparing the two model forms. Again, using the measurement data from the 422 trees with sectional information (total of 3681 sections), residuals (obs_{dob} - $pred_{dob}$), squared residuals $(obs_{dob} - pred_{dob})^2$, and absolute residuals ($|obs_{dob} - pred_{dob}|$) were computed for the actual height up the stem, minus either the ratio or exponential ratio form predicted height up the stem.

Figure 16: a), b), and c)

a) 6.5 inch DBH and 40 feet total height



b) 4 inch DBH and 30 feet total height



c) 10 inch DBH and 70 feet total height

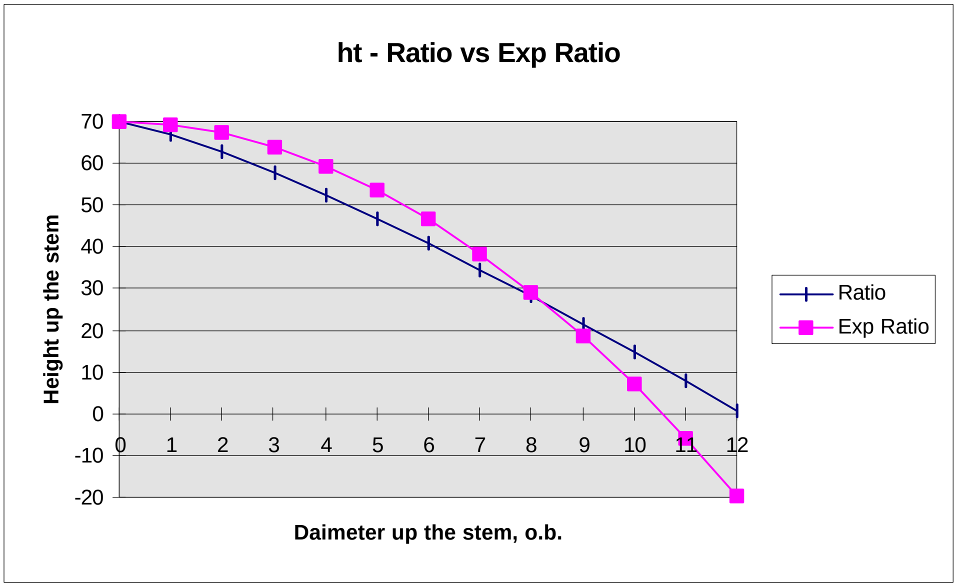


Figure 16: Graphs Of Predicted Height Up The Stem, Outside Bark

The residuals for the ratio and exponential ratio forms were compared over the whole data set (e.g. all sections), and by section number, in order to see how each form predicts height up the stem overall and by location along the stem (see Appendix 22).

In sections one through seven of the tree, the ratio form had a lower absolute and squared residual value. This shows that the ratio form did a better job of predicting height up the stem in these portions of the tree. Overall and in the upper sections, the exponential ratio form had lower absolute, squared and standard residual value. This shows that the exponential form is a better predictor of height up the stem in these portions of the tree. The ratio form consistently under predicted height up the stem in the upper portions of the tree. These results are not consistent with the residual sum of squares comparison results, which indicated that the ratio model is a better fit to green weight to any upper height limit than the exponential ratio form. Using the point of intersection on the graphs presented for reference, the ratio form predicts best for the lower portions of the stem, and the exponential form predicts best for the upper portions.

Overall, neither ratio form predicts best over the whole stem for diameter outside bark or height up the stem. For consistency, the same taper function should probably be used for both model forms. Since the exponential ratio form performs best over most of the stem for predicting both diameter outside bark and height up the stem, it is recommended.

A mixed taper form containing the ratio and exponential ratio taper models was also derived from equations fitted to the data. Residual analysis showed that the prediction ability for both diameter outside bark and height up the stem was inadequate. Hence, the mixed taper form was discarded from further analysis.

3.4 Predicting Total Green Weight

For both the ratio and exponential ratio nonlinear regression equations, an estimate of total stem green weight is required for prediction of merchantable weights. Total weight can be estimated using a combined variable equation where total stem green weight is modeled as a function of diameter at breast height and total height of the tree.

$$GWT_{Tot} = f\left(DBH, HT\right) \quad \textbf{(38)}$$

The model is of the following form:

$$GWT_{Tot} = b_o + b_1 \times \left(DBH^2 \cdot HT\right) \quad \textbf{(39)}$$

where all symbols remain as defined above

The range of DBH, total height, green weight per unit volume, total stem volume, and total stem green weight of the final merged data set used for prediction is presented in Table 4. Equation (39) was fit over this merged data set and had an R-square value of 0.98 (see Appendix 23), meaning 98% of the variation in total stem green weight is explained by the diameter at breast height and total tree height. With a highly significant F-value and high R-square, the combined variable equation (39) shows a good fit for prediction of total stem green weight. The prediction equation with the parameter estimates is as follows:

$$GWT_{Tot} = -32.6772 + 0.1553 \cdot \left(DBH^2 \cdot HT\right) \quad \textbf{(40)}$$

where all symbols remain as defined above

In estimating green weight to an upper diameter limit, the following variables are needed: DBH, dob (the upper diameter limit), and predicted total stem green weight. For estimating green weight to an upper height limit, the following variables are needed: THT, ht (the upper height limit), and predicted total stem green weight. Total stem green weight is required for both types of upper limit green weight estimation. The presented prediction equation (40), will aid in assembling the necessary variables for predicting either type of upper limit green weight.

Table 4: Summary Table For Merged Data Set

Variable	N	Mean	Standard Deviation	Minimum	Maximum
DBH (inches)	1031	6.68	2.51	0.80	20.80
Total Height (feet)	1031	43.83	14.39	7.50	94.00
GWT/VOL (lbs./cuft.)	1031	53.74	7.86	27.41	104.46
Total Volume (cuft.)	1031	7.03	11.31	0.07	115.33
Total Green Weight (lbs.)	1031	395.59	644.56	3.10	6519.10

4. Summary, Discussion and Conclusions

Using data from 1031 loblolly pine trees from throughout the Southeast, this research showed green weight per unit volume varies somewhat within the stem, but the variation is large and there is no discernable trend by stand characteristics. It was necessary to omit some data sets from the analysis due to incompatible data collection techniques or uncharacteristic values. In the data judged suitable for analysis, the mean green weight per unit volume was not significantly different in any of the data sets considered. The mean green weight per unit volume of loblolly pine derived from the combined data sets is 53.74 pounds per cubic foot, outside bark, with a standard deviation of 7.86.

Because of variation in data collection methods, it is difficult to legitimately combine different samples. Although various data sets may all contain similar variables, there is usually a lack of commonality within collection and measurement techniques. This adds to the difficulty of justifying the merging of data sets collected by different persons working for different employers in different regions. The data sets analyzed as part of the final merged data set in this research all use the same method for determining volume of the stem and green weight per unit volume. The weight data were collected in a similar manner for all data sets, with the exception of the Virginia data set where is was necessary to extrapolate the weights from the green weight per unit volume of the disks.

Unfortunately, there are confounding effects between measurement methods and geographic area, so a completely legitimate test can not be done. Some data sets however seem to be different from the main body and from published data. While there is no strong evidence that geographic variation is significant, one can not say with certainty.

There could still be measurement error in the form of 1) rounding error when initially measuring heights or diameters, 2) differences in the type and graduation of scales used for weight data, 3) the method of diameter and height measurement (i.e. d-tape, ruler, or caliper), and 4) any error involved in volume estimation from improper diameters or lengths. These factors make it very difficult to combine data sets across broad ranges of data collection techniques. However, it is assumed that there were no systematic measurement differences in the data, which enables one to combine data sets.

Prediction equations were developed using nonlinear regression analysis. The criterion used for parameter estimation and model refinement was to minimize the residual sum of squares. An equation for predicting stem green weight to any upper diameter limit (equation 29) of an exponential ratio form was developed. This form has a much lower residual sum of squares than the ratio form model. Also, an equation for predicting stem green weight to any upper height limit was developed. Equation (31) is of an exponential ratio form. Overall and in the upper sections, equation (31) has lower residual values than the ratio form. This conflicts with the SAS derived RSS, where the ratio form had a lower overall RSS. But, for consistency, the same form should probably be used for both prediction equations.

Implicit taper function relationships were used to develop models to predict diameter up the stem, outside bark, and height up the stem. To help distinguish between models and to identify where each model performed best, residuals and graphical analyses of predicted values were performed. For predicting diameter up the stem, outside bark, the ratio model presented (34) performs best at the lower end of the tree stem, whereas the exponential ratio model presented (36) performs best at the upper part of the stem. Note that no model performed best across the whole range of the stem. For predicting height up the stem, the exponential ratio model presented (37) performs better overall, with the ratio model only performing better in the lower part of the stem.

A combined variable equation was used for predicting total stem green weight. The model (40) has a good fit over the range of the data, and will aid in the estimation of green weight to any upper diameter or height limit.

Any of the models presented should not be used outside of the range of the data regions (see Figure 14), and caution is given for predicting green weights of stems outside the range of the data used for parameter estimation.

The equations presented here allow forest managers to predict green weight for any portion of loblolly pine tree boles. These prediction equations should prove valuable across a reasonably wide range of conditions. However, definitive answers to questions regarding regional variability must await the acquisition of a sufficiently large sample collected by consistent means over broad areas. Furthermore, if weight per unit volume trends within the stem are important, then adequate data with sufficient measurement precision throughout the stem must be obtained.

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Appendix

Appendix 1: Regression Procedures

Green Weight Per Unit Volume, By Bolt Data For East Texas.

Model: MODEL1

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	11957.69428	11957.69428	124.119	0.0001
Error	916	88248.25906	96.34089		
C Total	917	100205.95334			

Root MSE	9.81534	R-square	0.1193
Dep Mean	59.00647	Adj R-sq	0.1184
C.V.	16.63435		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	53.352283	0.60209748	88.611	0.0001
HT	1	0.297560	0.02670889	11.141	0.0001

Green Weight Per Unit Volume, By Bolt Data For East Texas.

Model: MODEL2

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	8737.42412	8737.42412	87.500	0.0001
Error	916	91468.52921	99.85647		
C Total	917	100205.95334			

Root MSE	9.99282	R-square	0.0872
Dep Mean	59.00647	Adj R-sq	0.0862
C.V.	16.93513		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	64.808098	0.70245989	92.259	0.0001
DOB	1	-1.252032	0.13384801	-9.354	0.0001

Green Weight Per Unit Volume, By Bolt Data For East Texas.

Model: MODEL3

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	14986.26454	7493.13227	80.453	0.0001
Error	915	85219.68880	93.13627		
C Total	917	100205.95334			

Root MSE	9.65071	R-square	0.1496
Dep Mean	59.00647	Adj R-sq	0.1477
C.V.	16.35535		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	58.276397	1.04695594	55.663	0.0001
DOB	1	-0.801172	0.14049677	-5.702	0.0001
HT	1	0.233794	0.02854257	8.191	0.0001

Green Weight Per Unit Volume, By Bolt Data For East Texas.

Model: MODEL4

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	13709.29213	13709.29213	145.181	0.0001
Error	916	86496.66121	94.42867		
C Total	917	100205.95334			

Root MSE	9.71744	R-square	0.1368

Dep Mean	59.00647	Adj R-sq	0.1359
C.V.	16.46843		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	52.921055	0.59828022	88.455	0.0001
SECTION	1	1.009471	0.08377957	12.049	0.0001

Green Weight Per Unit Volume, By Bolt Data For East Texas.

Model: MODEL5

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	27.30551	27.30551	0.243	0.6223
Error	916	102993.23995	112.43803		
C Total	917	103020.54545			

Root MSE	10.60368	R-square	0.0003
Dep Mean	56.75864	Adj R-sq	-0.0008
C.V.	18.68206		

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	57.073684	0.72882320	78.309	0.0001
RELHT	1	-0.629991	1.27839766	-0.493	0.6223

Model: MODEL6

Dependent Variable: GWTSMAL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	3	5749.10356	1916.36785	18.007	0.0001
Error	914	97271.44189	106.42390		
C Total	917	103020.54545			

Root MSE	10.31620	R-square	0.0558
Dep Mean	56.75864	Adj R-sq	0.0527
C.V.	18.17555		

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	61.266391	1.71698065	35.683	0.0001
RELHT	1	-0.393748	1.82450591	-0.216	0.8292
DOB	1	-0.571438	0.19962474	-2.863	0.0043
RELCRN	1	-0.854392	0.12100835	-7.061	0.0001

Variable	N	Mean	Std Dev	Minimum	Maximum	
GWTVOL	918	59.4228261	10.5673542	21.1909948	153.9580470	**cubic spline**
GWTSMAL	918	59.0064694	10.4535089	21.1909948	153.9580470	**Smalian's**

Appendix 2: Ratio Form Predicted Relative Volume and Weight by Diameter

```
Fit over whole data set with mult obs/tree,Raito DIAMETER -> VOLUME.

                 Non-Linear Least Squares Iterative Phase
              Dependent Variable RVOL   Method: Gauss-Newton
     Iter        B1             B2             B3        Sum of Squares
        0       1.000000       3.000000       3.000000    6470.448944
        1      -0.320414       3.309883       3.421483     428.593349
        2      -0.340729       2.319679       1.941324     162.669326
        3      -0.239464       2.098608       1.711666      57.134751
        4      -0.242312       2.092274       1.709728      57.127648
        5      -0.241998       2.093067       1.709887      57.127578
        6      -0.242048       2.093000       1.709917      57.127577
        7      -0.242039       2.092990       1.709889      57.127576
NOTE: Convergence criterion met.


  Non-Linear Least Squares Summary Statistics     Dependent Variable RVOL

      Source                DF Sum of Squares     Mean Square

      Regression             3   2273.0816096     757.6938699
      Residual            4101     57.1275765       0.0139302
      Uncorrected Total   4104   2330.2091860

      (Corrected Total)   4103    313.6173708


      Parameter      Estimate     Asymptotic             Asymptotic 95 %
                                  Std. Error          Confidence Interval
                                                      Lower          Upper
      B1          -0.242039042 0.00471313398 -0.2512795085 -0.2327985755
      B2           2.092990272 0.01921560646  2.0553165776  2.1306639656
      B3           1.709889031 0.01874725981  1.6731335675  1.7466444953

                    Asymptotic Correlation Matrix
```

Corr	B1	B2	B3
B1	1	0.2860064742	-0.164071515
B2	0.2860064742	1	0.8919215238
B3	-0.164071515	0.8919215238	1

Fit over whole data set with mult obs/tree,Ratio DIAMETER -> WEIGHT.

Non-Linear Least Squares Iterative Phase

Dependent Variable RWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	6536.724460
1	-0.311806	3.299095	3.419194	437.352413
2	-0.328090	2.329931	1.890900	228.626967
3	-0.237749	2.153780	1.741301	57.716971
4	-0.238592	2.125605	1.727722	57.121957
5	-0.237815	2.130605	1.731446	57.121047
6	-0.237831	2.129125	1.729985	57.120993
7	-0.237865	2.129690	1.730621	57.120984
8	-0.237844	2.129447	1.730334	57.120983
9	-0.237855	2.129556	1.730465	57.120982

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RWT

Source	DF	Sum of Squares	Mean Square
Regression	3	2275.9378497	758.6459499
Residual	4101	57.1209822	0.0139285
Uncorrected Total	4104	2333.0588319	
(Corrected Total)	4103	329.7544825	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.237854507	0.00457583414	-0.2468257864	-0.2288832275
B2	2.129556227	0.01900382506	2.0922977471	2.1668147072
B3	1.730464671	0.01852637102	1.6941422763	1.7667870648

Appendix 3: Ratio Form Predicted Relative Volume and Weight by Height

Fit over whole data set with mult obs/tree,Ratio HEIGHT -> VOLUME

Non-Linear Least Squares Iterative Phase

Dependent Variable RVOL Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-0.500000	2.000000	2.000000	140.472126
1	-0.504862	2.627441	2.392646	52.139252
2	-0.549246	2.400621	2.249341	3.378167
3	-0.575867	2.362200	2.230413	2.957466
4	-0.577394	2.363251	2.231870	2.956961
5	-0.577447	2.363269	2.231909	2.956961
6	-0.577449	2.363270	2.231911	2.956961

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RVOL

Source	DF	Sum of Squares	Mean Square
Regression	3	2096.2643218	698.7547739
Residual	3870	2.9569609	0.0007641
Uncorrected Total	3873	2099.2212827	
(Corrected Total)	3872	291.7348282	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.577448921	0.00688700151	-0.5909516615	-0.5639461798
B2	2.363269900	0.00626795682	2.3509808661	2.3755589344
B3	2.231910533	0.00742432255	2.2173543137	2.2464667521

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.295577619	-0.638344445
B2	-0.295577619	1	0.923241598
B3	-0.638344445	0.923241598	1

Fit over whole data set with mult obs/tree,Ratio HEIGHT -> WEIGHT.

Non-Linear Least Squares Iterative Phase

Dependent Variable RWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	2530.155795
1	-0.311191	3.750126	3.917197	536.563764
2	-0.126370	2.212881	2.077518	424.191435
3	-0.510921	2.908330	2.644223	104.872492
4	-0.494866	2.462652	2.274169	10.631290
5	-0.513302	2.369232	2.205006	8.985504
6	-0.514852	2.370248	2.206841	8.985296
7	-0.514969	2.370310	2.206956	8.985296
8	-0.514976	2.370314	2.206964	8.985296

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RWT

Source	DF	Sum of Squares	Mean Square
Regression	3	2093.0735358	697.6911786
Residual	3870	8.9852961	0.0023218
Uncorrected Total	3873	2102.0588319	
(Corrected Total)	3872	307.5281777	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.514976332	0.01070146398	-0.5359577551	-0.4939949082

B2	2.370314315	0.01082839916	2.3490840213	2.3915446095
B3	2.206963853	0.01283940638	2.1817907535	2.2321369533

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.292733294	-0.638091942
B2	-0.292733294	1	0.9222345807
B3	-0.638091942	0.9222345807	1

Appendix 4: Exponential Ratio Form Predicted Rel. Vol. and Wt. by Diameter

Fit over whole data set with mult obs/tree,EXP Raito DIAMETER -> VOLUME.

Non-Linear Least Squares Iterative Phase

Dependent Variable RVOL Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-1.000000	3.000000	3.000000	55.353322
1	-0.603287	3.449355	3.262269	36.741345
2	-0.349500	4.052282	3.614913	34.339074
3	-0.380140	4.088960	3.631547	31.079667
4	-0.393630	4.167032	3.721134	31.019662
5	-0.396306	4.181366	3.737002	31.016805
6	-0.396928	4.184536	3.740622	31.016689
7	-0.397050	4.185180	3.741350	31.016684
8	-0.397074	4.185310	3.741498	31.016684

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RVOL

Source	DF	Sum of Squares	Mean Square
Regression	3	2299.1925018	766.3975006
Residual	4101	31.0166842	0.0075632
Uncorrected Total	4104	2330.2091860	
(Corrected Total)	4103	313.6173708	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.397074324	0.01046753028	-0.4175967325	-0.3765519147
B2	4.185310357	0.03838180841	4.1100598303	4.2605608835
B3	3.741497579	0.03754476332	3.6678881443	3.8151070133

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.0804678119	-0.246066953
B2	0.0804678119	1	0.9433709096
B3	-0.246066953	0.9433709096	1

Fit over whole data set with mult obs/tree,EXP Ratio DIAMETER -> WEIGHT.

Non-Linear Least Squares Iterative Phase

Dependent Variable RWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-1.000000	3.000000	3.000000	55.523903
1	-0.583186	3.519835	3.313737	35.568057
2	-0.325638	4.236360	3.751808	32.074164
3	-0.357793	4.304753	3.795107	27.830932
4	-0.371223	4.401562	3.902817	27.751204
5	-0.374328	4.418674	3.921966	27.747539
6	-0.375012	4.422304	3.926125	27.747395
7	-0.375146	4.423024	3.926947	27.747390
8	-0.375172	4.423166	3.927109	27.747389

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RWT

Source	DF	Sum of Squares	Mean Square
Regression	3	2305.3114425	768.4371475
Residual	4101	27.7473894	0.0067660
Uncorrected Total	4104	2333.0588319	
(Corrected Total)	4103	329.7544825	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.375172334	0.00950364798	-0.3938049761	-0.3565396911

B2	4.423165995	0.03841873649	4.3478430679	4.4984889219
B3	3.927108971	0.03723246499	3.8541118220	4.0001061205

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.0964847782	-0.219623204
B2	0.0964847782	1	0.9471347032
B3	-0.219623204	0.9471347032	1

Appendix 5: Exponential Ratio Form Predicted Rel. Vol. and Wt. by Height

Fit over whole data set with mult obs/tree,EXP Ratio HEIGHT -> VOLUME

Non-Linear Least Squares Iterative Phase

Dependent Variable RVOL Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-0.500000	3.000000	3.000000	253.894754
1	-0.529519	2.609661	2.183327	105.723363
2	-0.600791	2.669451	2.431543	9.691974
3	-0.617916	3.268142	2.981425	4.914028
4	-0.641100	3.354684	3.072868	4.835804
5	-0.645726	3.363491	3.082896	4.835099
6	-0.646166	3.364149	3.083693	4.835095
7	-0.646200	3.364210	3.083764	4.835095

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RVOL

Source	DF	Sum of Squares	Mean Square
Regression	3	2094.3861881	698.1287294
Residual	3870	4.8350945	0.0012494
Uncorrected Total	3873	2099.2212827	
(Corrected Total)	3872	291.7348282	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.646200123	0.01572603800	-0.6770327890	-0.6153674575
B2	3.364210388	0.01261975490	3.3394679393	3.3889528362
B3	3.083764205	0.01415425901	3.0560131883	3.1115152209

Asymptotic Correlation Matrix

Corr	B1	B2	B3

ffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff

B1	1	-0.169890872	-0.577220942
B2	-0.169890872	1	0.9016487744
B3	-0.577220942	0.9016487744	1

Fit over whole data set with mult obs/tree,EXP Ratio HEIGHT -> WEIGHT.

Non-Linear Least Squares Iterative Phase

Dependent Variable RWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-0.500000	3.000000	3.000000	269.767594
1	-0.385684	2.651174	2.141268	105.123007
2	-0.490458	2.729262	2.436773	15.876714
3	-0.504560	3.332166	2.984798	10.703708
4	-0.521784	3.408399	3.065629	10.643879
5	-0.525612	3.415938	3.074511	10.643340
6	-0.526036	3.416522	3.075268	10.643336
7	-0.526072	3.416579	3.075339	10.643336

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable RWT

Source	DF	Sum of Squares	Mean Square
Regression	3	2091.4154963	697.1384988
Residual	3870	10.6433356	0.0027502
Uncorrected Total	3873	2102.0588319	
(Corrected Total)	3872	307.5281777	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.526072121	0.01916573439	-0.5636486985	-0.4884955439
B2	3.416578680	0.01893040547	3.3794634912	3.4536938681
B3	3.075339381	0.02104790644	3.0340725933	3.1166061678

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.148979158	-0.56376486
B2	-0.148979158	1	0.8995769848
B3	-0.56376486	0.8995769848	1

Appendix 6: Regression Procedures

Green Weight Per Unit Volume, by Bolt data.

Model: MODEL1

Dependent Variable: GWTVOL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	80655.83843	80655.83843	284.122	0.0001
Error	1753	497637.59557	283.87769		
C Total	1754	578293.43400			

Root MSE	16.84867	R-square	0.1395
Dep Mean	58.45811	Adj R-sq	0.1390
C.V.	28.82178		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	46.863813	0.79679870	58.815	0.0001
BOLT_NO	1	1.508265	0.08947986	16.856	0.0001

Green Weight Per Unit Volume, by Bolt data.

Model: MODEL2

Dependent Variable: GWTVOL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	79566.93525	79566.93525	279.674	0.0001
Error	1753	498726.49875	284.49886		
C Total	1754	578293.43400			

Root MSE	16.86709	R-square	0.1376
Dep Mean	58.45811	Adj R-sq	0.1371
C.V.	28.85330		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	48.496043	0.71899902	67.449	0.0001
HTOP	1	0.298822	0.01786842	16.723	0.0001

Green Weight Per Unit Volume, by Bolt data.

Model: MODEL3

Dependent Variable: GWTVOL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	81694.01512	40847.00756	144.108	0.0001
Error	1752	496599.41888	283.44716		
C Total	1754	578293.43400			

Root MSE	16.83589	R-square	0.1413
Dep Mean	58.45811	Adj R-sq	0.1403
C.V.	28.79992		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	43.279996	2.03484072	21.269	0.0001
BOLT_NO	1	4.990659	1.82180576	2.739	0.0062
HTOP	1	-0.695485	0.36340289	-1.914	0.0558

Appendix 7: ANOVA and Test for Mean Differences, Florida Data

Merged data, 1=East Texas 2=Central Louisiana 3=Georgia 4=Virginia 5=Florida

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
LOC	5	1 2 3 4 5

Number of observations in data set = 1080

Dependent Variable: TGWTVOL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1645.1752087	411.2938022	6.89	0.0001
Error	1075	64138.3630482	59.6635935		
Corrected Total	1079	65783.5382568			

R-Square	C.V.	Root MSE	TGWTVOL Mean
0.025009	14.31037	7.7242212	53.976408

T Confidence Intervals for variable: TGWTVOL

Alpha= 0.05 Confidence= 0.95 df= 1075 MSE= 59.66359

Critical Value of T= 1.96

LOC	N	Lower Confidence Limit	Mean	Upper Confidence Limit
5	49	56.6868	58.8520	61.0172
2	130	53.4421	54.7714	56.1007
4	192	53.5382	54.6320	55.7258
1	101	52.0453	53.5534	55.0615
3	608	52.6621	53.2767	53.8914

T tests (LSD) for variable: TGWTVOL

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 1075 MSE= 59.66359

Critical Value of T= 1.96

Least Significant Difference= 2.0301

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	LOC
A	58.852	49	5
B	54.771	130	2
B	54.632	192	4
B	53.553	101	1
B	53.277	608	3

Appendix 8: ANOVA and Test for Mean Differences, Retained Data Sets

Merged data, 1=East Texas 2=Central Louisiana 3=Georgia 4=Virginia

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
LOC	4	1 2 3 4

Number of observations in data set = 1031

Analysis of Variance Procedure

Dependent Variable: TGWTVOL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	425.02766887	141.67588962	2.30	0.0757
Error	1027	63217.14676817	61.55515752		
Corrected Total	1030	63642.17443704			

R-Square	C.V.	Root MSE	TGWTVOL Mean
0.006678	14.59811	7.8457095	53.744688

Analysis of Variance Procedure

T Confidence Intervals for variable: TGWTVOL

Alpha= 0.05 Confidence= 0.95 df= 1027 MSE= 61.55516

Critical Value of T= 1.96

LOC	N	Lower Confidence Limit	Mean	Upper Confidence Limit
2	130	53.4211	54.7714	56.1216
4	192	53.5209	54.6320	55.7431
1	101	52.0215	53.5534	55.0853
3	608	52.6524	53.2767	53.9011

T tests (LSD) for variable: TGWTVOL

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 1027 MSE= 61.55516

Critical Value of T= 1.96

Least Significant Difference= 1.7021

Means with the same letter are not significantly different.

T Grouping	Mean	N	LOC
A	54.7714	130	2
A			
A	54.6320	192	4
A			
A	53.5534	101	1
A			
A	53.2767	608	3

Appendix 9: Predicted Total Volume

Predicted total volume, using a combined variable equation

Model: MODEL1

Dependent Variable: TVOL

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	130438.18013	130438.18013	109622.721	0.0001
Error	1029	1224.38931	1.18988		
C Total	1030	131662.56944			

Root MSE	1.09082	**R-square**	**0.9907**
Dep Mean	7.02822	Adj R-sq	0.9907
C.V.	15.52054		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-0.525465	0.04092189	-12.841	0.0001
D2H	1	0.002739	0.00000827	331.093	0.0001

Appendix 10: Predicted Green Weight To Upper Diameter Limit

Fit over whole data set with multiple obs per tree, Texas Data

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	195319992
1	-0.430914	3.502788	3.565369	4426514
2	-0.461372	2.392041	2.356901	1584458
3	-0.410927	2.251133	2.114911	1309466
4	-0.419957	2.305100	2.179202	1306669
5	-0.419726	2.290968	2.164653	1306491
6	-0.419776	2.294704	2.168471	1306479
7	-0.419762	2.293721	2.167466	1306478
8	-0.419766	2.293980	2.167731	1306478
9	-0.419765	2.293912	2.167661	1306478

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	83054224.809	27684741.603
Residual	915	1306478.011	1427.845
Uncorrected Total	918	84360702.820	
(Corrected Total)	917	44299740.920	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.419764611	0.03522206937	-0.4888911963	-0.3506380265
B2	2.293911826	0.03444489520	2.2263105175	2.3615131342
B3	2.167661246	0.04926363969	2.0709767741	2.2643457177

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.0547124588	-0.707814693

B2	0.0547124588	1	0.6632412178
B3	-0.707814693	0.6632412178	1

Appendix 11: Predicted Green Weight To Upper Diameter Limit

Randomly chosen section to fit equation, Texas Data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-1.000000	3.000000	3.000000	1198132
1	-0.376936	2.758207	2.675966	104962
2	-0.392611	2.577470	2.410752	46705.276928
3	-0.407365	2.645817	2.506253	45509.961284
4	-0.403271	2.634546	2.490276	45502.013662
5	-0.404026	2.636757	2.493318	45501.724282
6	-0.403887	2.636332	2.492737	45501.713815
7	-0.403913	2.636414	2.492848	45501.713431

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	6081052.1666	2027017.3889
Residual	98	45501.7134	464.3032
Uncorrected Total	101	6126553.8800	
(Corrected Total)	100	3941633.4143	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.403913389	0.05607952098	-0.5152020197	-0.2926247574
B2	2.636413720	0.08772951773	2.4623163348	2.8105111044
B3	2.492847846	0.11144537841	2.2716868343	2.7140088584

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.081042261	-0.595362818
B2	-0.081042261	1	0.8465508549
B3	-0.595362818	0.8465508549	1

Appendix 12: Predicted Green Weight To Upper Diameter Limit

Fit over whole data set with multiple obs per tree, Central Louisiana data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	12588471931
1	-0.421964	3.385535	3.464299	494597267
2	-0.424144	2.370180	2.284036	144019509
3	-0.430425	2.599807	2.455803	100210661
4	-0.433682	2.508578	2.371977	99316660
5	-0.433623	2.531843	2.395469	99288844
6	-0.433597	2.525601	2.389161	99286868
7	-0.433598	2.527287	2.390861	99286723
8	-0.433598	2.526832	2.390402	99286713
9	-0.433598	2.526955	2.390526	99286712

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	4283449893.6	1427816631.2
Residual	1753	99286712.2	56638.2
Uncorrected Total	1756	4382736605.8	
(Corrected Total)	1755	2474225391.5	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.433597797	0.03202733946	-0.4964147013	-0.3707808926
B2	2.526955021	0.02876671830	2.4705333444	2.5833766978
B3	2.390526156	0.03665597619	2.3186308634	2.4624214492

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.1236017727	-0.61785175
B2	0.1236017727	1	0.7020661044
B3	-0.61785175	0.7020661044	1

Appendix 13: Predicted Green Weight To Upper Diameter Limit

Fit over whole data set with multiple obs per tree, Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	247468449
1	-0.261746	2.590037	2.823504	26867793
2	-0.098278	4.581076	3.637376	2222226
3	-0.135463	4.251148	3.481817	1968675
4	-0.175708	4.023631	3.384338	1772520
5	-0.253642	3.720757	3.266415	1667755
6	-0.369993	3.511010	3.210647	1164482
7	-0.379237	3.564704	3.239547	958467
8	-0.380083	3.556236	3.233540	958183
9	-0.380011	3.556987	3.234172	958182
10	-0.380018	3.556921	3.234117	958182

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	226109898.69	75369966.23
Residual	1427	958182.38	671.47
Uncorrected Total	1430	227068081.07	
(Corrected Total)	1429	111163696.54	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.380018061	0.01793332066	-0.4151971715	-0.3448389506
B2	3.556921446	0.03121319607	3.4956917105	3.6181511806
B3	3.234117333	0.03694952589	3.1616348584	3.3065998069

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.005020049	-0.587480302
B2	-0.005020049	1	0.8107033562
B3	-0.587480302	0.8107033562	1

Appendix 14: Predicted Green Weight To Upper Diameter Limit

Fit over MERGED data sets (dob), Texas, Louisiana, and Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	13031260372
1	-0.444591	3.388242	3.459148	446632946
2	-0.444294	1.494964	1.281274	420984941
3	-0.484279	2.365586	2.252456	109353056
4	-0.460537	2.554362	2.439054	103556182
5	-0.457489	2.513879	2.396031	103468198
6	-0.457853	2.524936	2.407457	103461656
7	-0.457739	2.521950	2.404360	103461180
8	-0.457769	2.522759	2.405198	103461145
9	-0.457760	2.522540	2.404971	103461142
10	-0.457763	2.522599	2.405033	103461142

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	4590704247.5	1530234749.2
Residual	4101	103461142.2	25228.3
Uncorrected Total	4104	4694165389.7	
(Corrected Total)	4103	3255877124.5	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.457762632	0.01966446439	-0.4963163475	-0.4192089175
B2	2.522599032	0.01867713145	2.4859810603	2.5592170039
B3	2.405032870	0.02337535169	2.3592036708	2.4508620682

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.0765638214	-0.594806884
B2	0.0765638214	1	0.7540390057
B3	-0.594806884	0.7540390057	1

Appendix 15: Predicted Green Weight To Upper Height Limit

Fit over whole data set with multiple obs per tree (ht), East Texas data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWTH Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	88713420
1	-0.954221	3.665298	3.680075	2763450
2	-0.821888	1.643016	1.604547	1297368
3	-0.943343	2.287896	2.275422	98512.847957
4	-0.994627	2.481900	2.473500	69267.974890
5	-0.992952	2.480733	2.471753	69248.533045
6	-0.993014	2.480787	2.471820	69248.531037
7	-0.993012	2.480785	2.471817	69248.531033

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWTH

Source	DF	Sum of Squares	Mean Square
Regression	3	73841744.679	24613914.893
Residual	814	69248.531	85.072
Uncorrected Total	817	73910993.210	
(Corrected Total)	816	38154822.089	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.993011741	0.05662114151	-1.1041542375	-0.8818692439
B2	2.480784591	0.01106902424	2.4590570360	2.5025121468
B3	2.471816830	0.01845757595	2.4355861745	2.5080474856

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.077440042	-0.823662818
B2	-0.077440042	1	0.6286050395
B3	-0.823662818	0.6286050395	1

Appendix 16: Predicted Green Weight To Upper Height Limit

Fit over whole data set with multiple obs per tree (ht), Louisiana data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWTH Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	6581385562
1	-0.581281	4.420647	4.511715	1056361748
2	-0.424884	1.572836	1.528151	397117881
3	-0.633716	2.286271	2.138035	51010748
4	-0.668185	2.010867	1.913942	2237696
5	-0.668706	1.996499	1.902303	2069810
6	-0.668040	1.996917	1.902490	2069793
7	-0.668057	1.996902	1.902481	2069793

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWTH

Source	DF	Sum of Squares	Mean Square
Regression	3	3901484499.5	1300494833.2
Residual	1623	2069793.1	1275.3
Uncorrected Total	1626	3903554292.6	
(Corrected Total)	1625	2216357065.2	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.668057367	0.02410133225	-0.7153311897	-0.6207835440
B2	1.996901828	0.00418238165	1.9886982499	2.0051054068
B3	1.902480617	0.00909989912	1.8846315202	1.9203297144

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.01438855	-0.897221589
B2	-0.01438855	1	0.4539905783
B3	-0.897221589	0.4539905783	1

Appendix 17: Predicted Green Weight To Upper Height Limit

Fit over MERGED data sets (ht), Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWTH Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	1.000000	3.000000	3.000000	179495362
1	-0.403552	3.140124	3.279347	26401085
2	-0.064868	2.503438	2.039552	13108856
3	-0.098424	2.596207	2.220715	12074245
4	-0.175348	2.729998	2.476666	10630728
5	-0.501254	2.985492	2.949400	7658154
6	-0.472308	2.769440	2.554270	1695400
7	-0.523526	2.848078	2.694858	233402
8	-0.543734	2.862297	2.720026	230485
9	-0.544291	2.862206	2.720023	230464
10	-0.544285	2.862210	2.720024	230464

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics Dependent Variable SGWTH

Source	DF	Sum of Squares	Mean Square
Regression	3	226837617.54	75612539.18
Residual	1427	230463.53	161.50
Uncorrected Total	1430	227068081.07	
(Corrected Total)	1429	111163696.54	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.544284960	0.03289489981	-0.6088136291	-0.4797562910
B2	2.862209732	0.01302598008	2.8366571642	2.8877622998
B3	2.720023563	0.02038921114	2.6800268255	2.7600202996

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.084400993	-0.794940509
B2	-0.084400993	1	0.6711603831
B3	-0.794940509	0.6711603831	1

Appendix 18: Predicted Green Weight To Upper Height Limit

Fit over MERGED data sets (ht), Texas, Louisiana, and Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWTH   Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-0.600000	1.500000	1.500000	258709411
1	-0.281326	1.863253	1.666999	209249834
2	-0.319281	2.102572	1.821448	18137094
3	-0.339926	2.027925	1.780970	4869560
4	-0.338355	2.026233	1.778522	4867449
5	-0.338287	2.026273	1.778513	4867448
6	-0.338290	2.026271	1.778513	4867448

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics   Dependent Variable SGWTH

Source	DF	Sum of Squares	Mean Square
Regression	3	4199665918.5	1399888639.5
Residual	3870	4867448.4	1257.7
Uncorrected Total	3873	4204533366.9	
(Corrected Total)	3872	2915528262.8	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.338290464	0.00880930067	-0.3555620880	-0.3210188390
B2	2.026270817	0.00412445657	2.0181843558	2.0343572775
B3	1.778512898	0.00730250372	1.7641955188	1.7928302781

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.068164013	-0.840791988
B2	-0.068164013	1	0.5968601745
B3	-0.840791988	0.5968601745	1

Appendix 19: Predicted Green Weight To Upper Diameter Limit

Fit using EXP FUNCTION (dob), Texas, Louisiana, and Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWT   Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-1.500000	6.000000	6.000000	21295083
1	-1.523274	6.045774	6.051343	21269634
2	-1.521838	6.048007	6.053082	21269585
3	-1.521879	6.048126	6.053206	21269585

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics   Dependent Variable SGWT

Source	DF	Sum of Squares	Mean Square
Regression	3	4672895805.0	1557631935.0
Residual	4101	21269584.7	5186.4
Uncorrected Total	4104	4694165389.7	
(Corrected Total)	4103	3255877124.5	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-1.521879023	0.05953518653	-1.6386023957	-1.4051556497
B2	6.048125918	0.03110721190	5.9871378052	6.1091140317
B3	6.053206308	0.03443238947	5.9856989248	6.1207136908

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	-0.120910176	-0.509653853
B2	-0.120910176	1	0.9149791633
B3	-0.509653853	0.9149791633	1

Appendix 20: Predicted Green Weight To Upper Height Limit

Fit using EXP FUNCTION (ht), Texas, Louisiana, and Virginia data.

Non-Linear Least Squares Iterative Phase

Dependent Variable SGWTH   Method: Gauss-Newton

Iter	B1	B2	B3	Sum of Squares
0	-0.200000	3.100000	2.500000	32936241
1	-0.186572	3.001448	2.444512	11076299
2	-0.191849	3.130997	2.567554	10547042
3	-0.193208	3.134205	2.572533	10545222
4	-0.193316	3.134930	2.573329	10545209
5	-0.193325	3.134954	2.573365	10545209

NOTE: Convergence criterion met.

Non-Linear Least Squares Summary Statistics   Dependent Variable SGWTH

Source	DF	Sum of Squares	Mean Square
Regression	3	4193988157.9	1397996052.6
Residual	3870	10545209.0	2724.9
Uncorrected Total	3873	4204533366.9	
(Corrected Total)	3872	2915528262.8	

Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
B1	-0.193324645	0.01334159330	-0.2194823393	-0.1671669516
B2	3.134954311	0.01095138497	3.1134828892	3.1564257325
B3	2.573365015	0.01856931214	2.5369577901	2.6097722389

Asymptotic Correlation Matrix

Corr	B1	B2	B3
B1	1	0.0073178724	-0.836237105
B2	0.0073178724	1	0.5414632707
B3	-0.836237105	0.5414632707	1

Appendix 21: Predicted Diameter Up The Stem, Outside Bark, Residuals

Predicted dob using Ratio and Exponential Ratio forms.

Where DOB_R = actual DOB - predicted Ratio DOB

DOB_E = actual DOB - predicted Exponential Ratio DOB

SDOB_R = squared (actual DOB - predicted Ratio DOB)

SDOB_E = squared (actual DOB - predicted Exponential Ratio DOB)

ADOB_R = absolute (actual DOB - predicted Ratio DOB)

ADOB_E = absolute (actual DOB - predicted Exponential Ratio DOB)

RDOB = predicted Ratio DOB

EDOB = predicted Exponential Ratio DOB

R_E = RDOB - EDOB

Predicted dob using Ratio and Exponential Ratio forms.

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	3873	0.1846482	0.9112545	-2.2186276	5.0429937
DOB_E	3873	0.0752329	0.7973402	-2.0656416	5.4502940
SDOB_R	3873	0.8642653	1.7844339	1.7661033E-7	25.4317854
SDOB_E	3873	0.6412472	1.7024623	7.513685E-10	29.7057044
ADOB_R	3873	0.6728864	0.6415570	0.000420250	5.0429937
ADOB_E	3873	0.5568476	0.5755462	0.000027411	5.4502940
RDOB	3873	6.0813988	3.8723161	0.7702568	24.5435734
EDOB	3873	6.1908141	3.5190689	0.7636403	22.2955645
R_E	3873	-0.1094153	0.8228852	-2.9746801	2.2480089

-------------------------------- SECTION=1 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	422	0.4106889	0.9100118	-1.5097213	3.9272287
DOB_E	422	1.3147104	1.0918371	-0.4364942	5.4502940
SDOB_R	422	0.9948244	1.5685669	0.000026477	15.4231252
SDOB_E	422	2.9177467	4.2319239	3.6115943E-6	29.7057044
ADOB_R	422	0.7931941	0.6054222	0.0051456	3.9272287
ADOB_E	422	1.3198787	1.0855687	0.0019004	5.4502940
RDOB	422	7.8312543	4.3581346	0.8470482	24.5435734

EDOB	422	6.9272327	3.9217309	0.7636403	22.2955645
R_E	422	0.9040215	0.4442596	0.0834079	2.2480089

-------------------------------- SECTION=2 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	419	-0.2749656	0.6178662	-2.1504355	1.6309006
DOB_E	419	0.4221526	0.4833344	-1.1859051	2.1622005
SDOB_R	419	0.4564536	0.6876573	0.000017340	4.6243728
SDOB_E	419	0.4112674	0.5828776	4.5501579E-6	4.6751111
ADOB_R	419	0.5276768	0.4224177	0.0041642	2.1504355
ADOB_E	419	0.5106150	0.3884583	0.0021331	2.1622005
RDOB	419	7.3723403	4.3633711	0.9585271	23.9943978
EDOB	419	6.6752221	3.9187482	0.9187406	21.9723927
R_E	419	0.6971183	0.4595792	-0.0632541	2.0220050

Predicted dob using Ratio and Exponential Ratio forms.

-------------------------------- SECTION=3 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	410	-0.3746517	0.6352831	-2.2149054	1.0735870
DOB_E	410	0.0834322	0.4279879	-1.5611218	1.1921687
SDOB_R	410	0.5429641	0.7946316	0.000027116	4.9058061
SDOB_E	410	0.1896878	0.2967960	5.0428249E-8	2.4371013
ADOB_R	410	0.5821981	0.4522259	0.0052073	2.2149054
ADOB_E	410	0.3381070	0.2748740	0.000224562	1.5611218
RDOB	410	6.8675785	4.2293157	0.9563332	22.8866507
EDOB	410	6.4094947	3.8337639	0.9551877	21.3124148
R_E	410	0.4580838	0.4169366	-0.3100113	1.5742359

-------------------------------- SECTION=4 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	387	-0.3577111	0.6184993	-2.2186276	1.5757402
DOB_E	387	-0.1140965	0.4646848	-1.7854731	1.5233619

SDOB_R	387	0.5095102	0.7981506	1.7661033E-7	4.9223082
SDOB_E	387	0.2283920	0.3559666	1.7451224E-6	3.1879140
ADOB_R	387	0.5533630	0.4514712	0.000420250	2.2186276
ADOB_E	387	0.3811706	0.2886455	0.0013210	1.7854731
RDOB	387	6.5137834	4.0589181	0.7702568	21.7656100
EDOB	387	6.2701689	3.7257120	0.8069336	20.6328705
R_E	387	0.2436145	0.3632663	-0.4663493	1.1430051

-------------------------------- SECTION=5 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	353	-0.2642054	0.5485201	-2.0877183	1.0162780
DOB_E	353	-0.2100774	0.4595611	-1.6201101	1.1062811
SDOB_R	353	0.3698264	0.5829490	5.1519989E-6	4.3585678
SDOB_E	353	0.2547307	0.3952272	6.9766424E-7	2.6247568
ADOB_R	353	0.4756153	0.3795057	0.0022698	2.0877183
ADOB_E	353	0.3969016	0.3122113	0.000835263	1.6201101
RDOB	353	6.2931006	3.8646278	1.0111639	20.6302412
EDOB	353	6.2389726	3.6064552	1.3138917	19.9318572
R_E	353	0.0541280	0.3000753	-0.5409290	0.7598988

-------------------------------- SECTION=6 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	323	-0.1322255	0.4763151	-1.7492947	1.2952212
DOB_E	323	-0.2678892	0.4644542	-1.7048322	1.1103836
SDOB_R	323	0.2436573	0.3844048	3.6663669E-7	3.0600318
SDOB_E	323	0.2868144	0.4139873	1.4266379E-7	2.9064528
ADOB_R	323	0.3822129	0.3128476	0.000605505	1.7492947
ADOB_E	323	0.4197935	0.3330635	0.000377709	1.7048322
RDOB	323	6.0235567	3.6694119	0.7880360	19.4793520
EDOB	323	6.1592204	3.4874690	1.1107624	19.2071410
R_E	323	-0.1356637	0.2444434	-0.7587469	0.3835810

Predicted dob using Ratio and Exponential Ratio forms.

---------------------------------- SECTION=7 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	296	0.0435737	0.4526188	-1.2873855	1.6636340
DOB_E	296	-0.2812750	0.4932735	-1.5851492	1.0758736
SDOB_R	296	0.2060703	0.3682635	0.000015413	2.7676780
SDOB_E	296	0.3216123	0.4497583	7.513685E-10	2.5126979
ADOB_R	296	0.3426077	0.2983135	0.0039259	1.6636340
ADOB_E	296	0.4463888	0.3503771	0.000027411	1.5851492
RDOB	296	5.6817642	3.5021942	1.3711507	18.3115540
EDOB	296	6.0066128	3.3946722	1.6846352	18.4560685
R_E	296	-0.3248487	0.1993486	-0.8564263	0.1293709

---------------------------------- SECTION=8 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	264	0.2514648	0.5050866	-1.0022393	2.0803143
DOB_E	264	-0.2530832	0.5468063	-1.9273513	1.7261159
SDOB_R	264	0.3173807	0.5864194	0.000010917	4.3277075
SDOB_E	264	0.3619157	0.5486690	3.1927133E-6	3.7146831
ADOB_R	264	0.4270572	0.3681252	0.0033042	2.0803143
ADOB_E	264	0.4607490	0.3875500	0.0017868	1.9273513
RDOB	264	5.4045958	3.3231753	1.2066626	17.1252123
EDOB	264	5.9091438	3.2963276	1.5698381	17.6754477
R_E	264	-0.5045480	0.1758576	-1.0658153	-0.0141459

---------------------------------- SECTION=9 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	236	0.4341774	0.6032992	-1.0441515	2.1908885
DOB_E	236	-0.2526193	0.6135812	-2.0520088	1.3835188
SDOB_R	236	0.5509378	0.8357928	8.0159289E-6	4.7999922
SDOB_E	236	0.4387032	0.6764111	4.5434662E-6	4.2107401
ADOB_R	236	0.5699146	0.4765473	0.0028312	2.1908885
ADOB_E	236	0.5115322	0.4216531	0.0021315	2.0520088
RDOB	236	5.0658226	3.1383695	1.2776400	15.9183758
EDOB	236	5.7526193	3.1886467	1.5670350	16.8613812

R_E	236	-0.6867967	0.1892283	-1.4128803	-0.1536437

SECTION=10

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	201	0.6768548	0.7114584	-1.0147938	2.7544479
DOB_E	201	-0.1902783	0.6697348	-2.0458671	1.7718429
SDOB_R	201	0.9617873	1.2711193	9.5902132E-6	7.5869830
SDOB_E	201	0.4825189	0.7282498	4.696426E-6	4.1855722
ADOB_R	201	0.7802375	0.5956356	0.0030968	2.7544479
ADOB_E	201	0.5384004	0.4400081	0.0021671	2.0458671
RDOB	201	4.8226477	2.9510577	1.0230493	14.6886797
EDOB	201	5.6897808	3.0776184	1.6755315	16.0090248
R_E	201	-0.8671331	0.2327700	-1.7146253	-0.2883383

Predicted dob using Ratio and Exponential Ratio forms.

SECTION=11

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	167	0.8788767	0.7928005	-0.6665750	2.7381369
DOB_E	167	-0.1795166	0.7090761	-1.8088893	1.5218475
SDOB_R	167	1.3971932	1.6101716	0.000010853	7.4973934
SDOB_E	167	0.5320044	0.7168256	0.000396908	3.2720804
ADOB_R	167	0.9695231	0.6782127	0.0032944	2.7381369
ADOB_E	167	0.5787825	0.4451989	0.0199225	1.8088893
RDOB	167	4.5887880	2.7555199	1.2305208	13.5600096
EDOB	167	5.6471813	2.9415775	1.6058256	15.2041197
R_E	167	-1.0583933	0.2822552	-1.9662677	-0.3753048

SECTION=12

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	133	1.2210926	0.9219831	-0.6299024	4.0517393
DOB_E	133	-0.0195509	0.7670016	-2.0656416	2.0626153
SDOB_R	133	2.3347286	2.6531334	0.000033501	16.4165915

SDOB_E	133	0.5842505	0.8756115	1.3124376E-6	4.2668752
ADOB_R	133	1.2907932	0.8207598	0.0057880	4.0517393
ADOB_E	133	0.5884191	0.4897107	0.0011456	2.0656416
RDOB	133	4.3623661	2.5478169	1.1172264	12.1482607
EDOB	133	5.6030096	2.8078842	1.7965472	14.1629912
R_E	133	-1.2406435	0.3470807	-2.0819250	-0.5314924

------------------------------- SECTION=13 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	101	1.5202203	0.9844637	-0.6630503	4.1049760
DOB_E	101	0.1091610	0.7629578	-1.9038656	2.1652179
SDOB_R	101	3.2706430	3.3315785	0.000377167	16.8508281
SDOB_E	101	0.5882574	0.8593603	0.000163108	4.6881686
ADOB_R	101	1.5629660	0.9143620	0.0194208	4.1049760
ADOB_E	101	0.6013565	0.4784287	0.0127714	2.1652179
RDOB	101	4.1589876	2.3608723	1.1275421	10.6950240
EDOB	101	5.5700470	2.7005238	1.7330357	13.0452923
R_E	101	-1.4110594	0.4136509	-2.3502683	-0.5714554

------------------------------- SECTION=14 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	78	1.4698292	1.0952667	-0.5247225	4.3883715
DOB_E	78	-0.1344381	0.8622845	-2.0354550	2.3532247
SDOB_R	78	3.3446275	3.8148741	0.000927933	19.2578046
SDOB_E	78	0.7520757	1.0439433	0.0017811	5.5376666
ADOB_R	78	1.5287780	1.0102224	0.0304620	4.3883715
ADOB_E	78	0.6979060	0.5181163	0.0422030	2.3532247
RDOB	78	3.8686323	2.0889545	1.4697474	9.4691444
EDOB	78	5.4728996	2.4587349	2.3993515	12.0598169
R_E	78	-1.6042673	0.4444910	-2.5906725	-0.7477110

Predicted dob using Ratio and Exponential Ratio forms.

------------------------------- SECTION=15 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	38	2.1497151	0.9876982	0.3896179	5.0429937
DOB_E	38	0.1715084	0.8028702	-1.8267583	2.8247101
SDOB_R	38	5.5711503	5.1471087	0.1518021	25.4317854
SDOB_E	38	0.6570524	1.3949393	5.7645916E-6	7.9789869
ADOB_R	38	2.1497151	0.9876982	0.3896179	5.0429937
ADOB_E	38	0.6003389	0.5519630	0.0024010	2.8247101
RDOB	38	4.0660744	1.9667578	1.2775072	7.9152188
EDOB	38	6.0442811	2.3661528	2.4032832	10.7426705
R_E	38	-1.9782067	0.4339260	-2.8274517	-1.1257761

------------------------------- SECTION=16 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	23	2.4531295	0.8953914	1.2595112	4.5509261
DOB_E	23	0.2393046	0.7338567	-0.8189416	2.2098912
SDOB_R	23	6.7847124	5.0693065	1.5863684	20.7109281
SDOB_E	23	0.5723973	1.1981475	0.000580468	4.8836193
ADOB_R	23	2.4531295	0.8953914	1.2595112	4.5509261
ADOB_E	23	0.5361086	0.5458376	0.0240929	2.2098912
RDOB	23	3.8860009	1.5859124	1.8480950	6.4344941
EDOB	23	6.0998258	1.9774003	3.3314057	9.3988833
R_E	23	-2.2138249	0.4257241	-2.9643892	-1.4833107

------------------------------- SECTION=17 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	13	2.7430352	0.6811931	1.7862135	4.4320210
DOB_E	13	0.2877890	0.7790255	-0.7752807	2.0635507
SDOB_R	13	7.9525721	4.2961131	3.1905585	19.6428101
SDOB_E	13	0.6430202	1.1803791	0.000672664	4.2582416
ADOB_R	13	2.7430352	0.6811931	1.7862135	4.4320210
ADOB_E	13	0.5880976	0.5673842	0.0259358	2.0635507
RDOB	13	3.5877340	0.9368672	2.1564833	4.7006007
EDOB	13	6.0429802	1.2396078	4.2144659	7.6752807
R_E	13	-2.4552462	0.3330108	-2.9746801	-1.9067686

SECTION=18

Variable	N	Mean	Std Dev	Minimum	Maximum
DOB_R	9	1.7913027	0.7051041	1.0275943	2.9264635
DOB_E	9	-0.6072947	0.8305633	-1.7104137	0.7143012
SDOB_R	9	3.6506959	2.9099298	1.0559501	8.5641888
SDOB_E	9	0.9819938	0.8790043	0.3301283	2.9255150
ADOB_R	9	1.7913027	0.7051041	1.0275943	2.9264635
ADOB_E	9	0.9233523	0.3815642	0.5745679	1.7104137
RDOB	9	2.6086973	0.3185731	1.9190852	3.0478474
EDOB	9	5.0072947	0.5430091	3.8877873	5.7104137
R_E	9	-2.3985974	0.2419389	-2.7380080	-1.9687021

Appendix 22: Predicted Height Up The Stem, Residuals

Where HT_R = actual HT - predicted Ratio HT

HT_E = actual HT - predicted Exponential Ratio HT

SHT_R = squared (actual HT - predicted Ratio HT)

SHT_E = squared (actual HT - predicted Exponential Ratio HT)

AHT_R = absolute (actual HT - predicted Ratio HT)

AHT_E = absolute (actual HT - predicted Exponential Ratio HT)

RHT = predicted Ratio HT

EHT = predicted Exponential Ratio HT

R_EHT = RHT - EHT

Predicted ht using Ratio and Exponential Ratio forms.

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	3681	1.0629089	4.9634012	-12.7731528	23.1431594
HT_E	3681	0.2258439	4.8209243	-15.5598703	30.2301834
SHT_R	3681	25.7584346	39.7941515	2.771203E-6	535.6058286
SHT_E	3681	23.2860023	43.2810640	5.3216988E-7	913.8639865
AHT_R	3681	3.9115298	3.2343795	0.0016647	23.1431594
AHT_E	3681	3.7393351	3.0505578	0.000729500	30.2301834
RHT	3681	26.6614323	15.1703012	-5.2389367	87.2010944
EHT	3681	27.4984973	19.0645916	-24.1301834	92.0245451
R_EHT	3681	-0.8370650	4.6767237	-10.2943276	19.4412967

--------------------------------- SECTION=2 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	422	-1.7160936	4.0337285	-12.7731528	11.8156577
HT_E	422	5.2477620	6.0087134	-11.6455687	30.2301834
SHT_R	422	19.1773864	24.9471007	0.0012262	163.1534335
SHT_E	422	63.5580872	96.5634971	0.000450016	913.8639865
AHT_R	422	3.4898727	2.6485463	0.0350171	12.7731528
AHT_E	422	6.2209077	4.9917372	0.0212136	30.2301834
RHT	422	8.2793638	4.2805648	-5.2389367	20.7731528
EHT	422	1.3155081	7.0432624	-24.1301834	19.6455687
R_EHT	422	6.9638557	4.2580801	-0.4587944	19.4412967

SECTION=3

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	417	-2.2030407	4.0595517	-12.2019692	10.3882600
HT_E	417	1.3068786	4.7156476	-13.6063698	13.9037909
SHT_R	417	21.2938283	26.5311364	0.000642319	148.8880519
SHT_E	417	23.8919373	34.7919666	0.000241906	193.3154017
AHT_R	417	3.7370852	2.7102837	0.0253440	12.2019692
AHT_E	417	3.7721861	3.1121981	0.0155533	13.9037909
RHT	417	12.8474053	4.2616752	2.4247860	24.2019692
EHT	417	9.3374859	5.5241827	-2.6945951	25.6063698
R_EHT	417	3.5099193	3.0544828	-2.4660360	8.9768444

Predicted ht using Ratio and Exponential Ratio forms.

SECTION=4

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	397	-1.9591755	3.8574794	-12.6962315	8.5961697
HT_E	397	-0.5908642	4.5099131	-15.5598703	14.9514339
SHT_R	397	18.6810344	24.2425894	2.771203E-6	161.1942945
SHT_E	397	20.6372045	30.3487112	5.3216988E-7	242.1095634
AHT_R	397	3.4681098	2.5826440	0.0016647	12.6962315
AHT_E	397	3.6766016	2.6716633	0.000729500	15.5598703
RHT	397	16.7314677	4.3472850	4.6034199	28.6962315
EHT	397	15.3631563	5.3090062	-0.6925236	31.5598703
R_EHT	397	1.3683113	2.4902590	-3.1798626	9.2525628

SECTION=5

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	361	-1.4027921	3.3904649	-10.1233770	7.7882997
HT_E	361	-1.4952473	4.1105252	-13.1012910	10.6353587
SHT_R	361	13.4312349	18.1968237	0.000398194	102.4827618
SHT_E	361	19.0853776	26.5746257	0.000033139	171.6438259

AHT_R	361	2.9412208	2.1894598	0.0199548	10.1233770
AHT_E	361	3.5475565	2.5530916	0.0057566	13.1012910
RHT	361	20.2568087	4.2840619	9.1181668	29.7991486
EHT	361	20.3492639	5.0975091	5.2809668	33.1012910
R_EHT	361	-0.0924552	2.0086692	-3.4195654	6.1364250

---------------------------------- SECTION=6 ----------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	333	-0.5196704	2.9708706	-8.6822761	8.9618294
HT_E	333	-1.8058165	3.8301184	-11.3771939	10.1847716
SHT_R	333	9.0696250	13.1406020	4.0967072E-6	80.3143865
SHT_E	333	17.8867265	22.4306921	0.000098557	129.4405415
AHT_R	333	2.3665795	1.8653083	0.0020240	8.9618294
AHT_E	333	3.4671097	2.4256021	0.0099276	11.3771939
RHT	333	23.5262770	4.3478742	11.2932638	32.7803468
EHT	333	24.8124231	5.1904256	9.6557253	35.3771939
R_EHT	333	-1.2861461	1.6673691	-3.9984416	4.2056680

---------------------------------- SECTION=7 ----------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	306	0.5772319	2.8925897	-7.4876331	11.0437783
HT_E	306	-1.6515832	3.8271322	-12.2919094	8.6245344
SHT_R	306	8.6729287	16.0297219	0.000197352	121.9650396
SHT_E	306	17.3268024	21.4561158	0.000050814	151.0910368
AHT_R	306	2.1866059	1.9759663	0.0140482	11.0437783
AHT_E	306	3.4302734	2.3618333	0.0071284	12.2919094
RHT	306	26.6466243	4.3940485	14.4663072	35.4876331
EHT	306	28.8754395	5.2337924	14.2411463	40.2919094
R_EHT	306	-2.2288151	1.4007080	-4.8278004	2.8704323

Predicted ht using Ratio and Exponential Ratio forms.

---------------------------------- SECTION=8 ----------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum

HT_R	274	1.8031081	3.0382697	-5.7637839	13.4258125
HT_E	274	-1.2459452	3.9077381	-11.1505255	14.1282395
SHT_R	274	12.4485914	21.2108031	0.000312686	180.2524410
SHT_E	274	16.7670652	22.7889336	0.000202824	199.6071526
AHT_R	274	2.6795667	2.2995243	0.0176829	13.4258125
AHT_E	274	3.3008264	2.4275746	0.0142416	14.1282395
RHT	274	29.6950671	4.6076111	17.8676742	38.0185835
EHT	274	32.7441204	5.4691992	18.5097618	43.1505255
R_EHT	274	-3.0490533	1.2245843	-5.3867417	3.5296408

SECTION=9

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	250	2.8633936	3.4454086	-4.5541430	12.7903400
HT_E	250	-0.9395730	4.0051870	-10.4698159	11.0171621
SHT_R	250	20.0223798	28.0063716	0.000126648	163.5927962
SHT_E	250	16.8601543	21.1724722	0.000488699	121.3778600
AHT_R	250	3.4799157	2.8185713	0.0112538	12.7903400
AHT_E	250	3.3775862	2.3396499	0.0221065	11.0171621
RHT	250	33.1206064	4.6891289	21.1278064	42.3015978
EHT	250	36.9235730	5.4649010	23.6153810	48.5359597
R_EHT	250	-3.8029666	1.0535885	-6.2507140	0.4637288

SECTION=10

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	212	4.0589150	3.8372075	-4.3267038	13.7805366
HT_E	212	-0.4284350	4.0639285	-10.0780045	13.3253489
SHT_R	212	31.1294992	36.9226564	0.000291621	189.9031883
SHT_E	212	16.6211683	21.5726916	0.000359245	177.5649242
AHT_R	212	4.5104828	3.2918321	0.0170769	13.7805366
AHT_E	212	3.3456515	2.3352748	0.0189538	13.3253489
RHT	212	36.3835378	4.9627558	24.2261567	44.3689848
EHT	212	40.8708878	5.7140442	26.5649046	51.3791989
R_EHT	212	-4.4873500	1.0169133	-7.0102140	-0.4551876

Predicted ht using Ratio and Exponential Ratio forms.

------------------------------- SECTION=11 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	181	5.0132058	4.0781906	-3.4914433	13.6454047
HT_E	181	-0.0950596	3.9403348	-9.7659996	10.8456644
SHT_R	181	41.6719833	41.9616640	0.000164079	186.1970696
SHT_E	181	15.4494945	17.8406509	0.0162664	117.6284369
AHT_R	181	5.3961812	3.5528794	0.0128093	13.6454047
AHT_E	181	3.3005385	2.1403856	0.1275397	10.8456644
RHT	181	40.1464627	5.3638650	27.3459239	48.2953025
EHT	181	45.2547281	6.0981377	30.7246119	55.8720222
R_EHT	181	-5.1082654	1.1687309	-7.9217068	-2.0326813

------------------------------- SECTION=12 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	151	6.3479269	4.2043310	-2.5160672	17.6165110
HT_E	151	0.7393565	3.8362313	-8.4753182	14.1102441
SHT_R	151	57.8555126	55.2274613	0.000550725	310.3414588
SHT_E	151	15.1658572	23.8438013	0.000107712	199.0989880
AHT_R	151	6.6117415	3.7728844	0.0234675	17.6165110
AHT_E	151	3.1198398	2.3385194	0.0103784	14.1102441
RHT	151	43.9063777	5.9374727	30.3690306	53.7003355
EHT	151	49.5149482	6.6517426	34.4165121	59.7557801
R_EHT	151	-5.6085704	1.4114566	-8.3737997	-2.6579667

------------------------------- SECTION=13 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	119	7.6678020	4.3675168	-2.7983261	19.0804202
HT_E	119	1.4768685	3.8391787	-7.7456433	13.8726834
SHT_R	119	77.7100951	66.5687593	0.0057005	364.0624364
SHT_E	119	16.7965741	24.3831543	0.0026581	192.4513436

AHT_R	119	7.8236365	4.0792946	0.0755019	19.0804202
AHT_E	119	3.2957374	2.4464225	0.0515569	13.8726834
RHT	119	48.0204333	6.5658023	28.5673031	58.2557232
EHT	119	54.2113668	7.1736900	32.2577504	64.1472985
R_EHT	119	-6.1909335	1.4021278	-8.8085719	-3.1220291

-------------------------------- SECTION=14 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	100	6.8043351	4.4437901	-2.0108866	20.5994509
HT_E	100	0.5970385	3.6020694	-6.0568781	14.1199395
SHT_R	100	65.8487743	69.3671488	0.0140953	424.3373762
SHT_E	100	13.2016097	22.4217907	0.0327672	199.3726906
AHT_R	100	6.9813483	4.1572074	0.1187237	20.5994509
AHT_E	100	2.9819192	2.0864565	0.1810171	14.1199395
RHT	100	52.6926649	7.5276225	36.5221659	63.3151486
EHT	100	58.8999615	8.3095165	41.2842114	71.0568781
R_EHT	100	-6.2072966	1.9270457	-9.8389254	-2.5785995

Predicted ht using Ratio and Exponential Ratio forms.

-------------------------------- SECTION=15 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	75	8.7177093	3.8307797	1.3634126	23.1431594
HT_E	75	2.4334630	3.3789649	-5.1618917	15.8786315
SHT_R	75	90.4776633	84.6306766	1.8588940	535.6058286
SHT_E	75	17.1869138	36.2492717	0.000335724	252.1309390
AHT_R	75	8.7177093	3.8307797	1.3634126	23.1431594
AHT_E	75	3.1430015	2.7216205	0.0183228	15.8786315
RHT	75	57.5436241	8.4863451	39.8548180	68.6365874
EHT	75	63.8278703	9.2755604	44.6841178	75.1618917
R_EHT	75	-6.2842462	2.1526141	-9.9839537	-2.6602293

-------------------------------- SECTION=16 --------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum

HT_R	38	8.3951863	3.4303216	2.3423321	19.9918926
HT_E	38	1.5032004	2.3620024	-2.5842188	10.8207832
SHT_R	38	81.9365982	71.8805207	5.4865195	399.6757678
SHT_E	38	7.6918497	19.0075862	0.0089689	117.0893492
AHT_R	38	8.3951863	3.4303216	2.3423321	19.9918926
AHT_E	38	2.0591367	1.8828430	0.0947043	10.8207832
RHT	38	67.3811295	3.9259912	55.0081074	73.6700568
EHT	38	74.2731154	2.4270351	64.1792168	79.0842168
R_EHT	38	-6.8919859	2.4974036	-10.2943276	-1.9060632

------------------------------- SECTION=17 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	23	8.4876785	3.3424695	3.8511227	18.5326495
HT_E	23	1.5378365	2.3177139	-2.1391746	8.6640577
SHT_R	23	82.7270447	72.8604428	14.8311464	343.4590982
SHT_E	23	7.5031823	15.8929136	0.0059647	75.0658955
AHT_R	23	8.4876785	3.3424695	3.8511227	18.5326495
AHT_E	23	2.0353931	1.8743267	0.0772317	8.6640577
RHT	23	72.4688432	3.8334400	61.4673505	77.3437532
EHT	23	79.4186853	2.4863225	71.3359423	83.3119551
R_EHT	23	-6.9498420	2.5030854	-9.8987006	-2.9297936

Predicted ht using Ratio and Exponential Ratio forms.

------------------------------- SECTION=18 ------------------------------

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	13	6.2702774	2.5693556	2.9090095	11.0221550
HT_E	13	-0.1224124	2.2747114	-3.2303549	3.0384850
SHT_R	13	45.4101518	37.7437089	8.4623362	121.4879017
SHT_E	13	4.7912726	2.9069646	1.6274876	10.4351927
AHT_R	13	6.2702774	2.5693556	2.9090095	11.0221550
AHT_E	13	2.1011101	0.6387433	1.2757302	3.2303549
RHT	13	79.1912611	2.8553859	73.0229601	82.5909905
EHT	13	85.5839509	2.1870333	81.8480517	89.3671027

R_EHT	13	-6.3926898	1.5033983	-8.8935649	-3.9955748

SECTION=19

Variable	N	Mean	Std Dev	Minimum	Maximum
HT_R	9	6.3611569	1.6380330	4.6177516	9.9030122
HT_E	9	1.8553606	0.7780233	1.1315164	3.6093179
SHT_R	9	42.8493408	23.8679566	21.3236294	98.0696502
SHT_E	9	3.9804256	3.7107615	1.2803294	13.0271756
AHT_R	9	6.3611569	1.6380330	4.6177516	9.9030122
AHT_E	9	1.8553606	0.7780233	1.1315164	3.6093179
RHT	9	84.8610654	1.5777175	82.0969878	87.2010944
EHT	9	89.3668616	1.2818896	87.8684836	92.0245451
R_EHT	9	-4.5057962	0.8644910	-6.2936943	-3.4862352

Appendix 23: Predicted Total Green Weight

Predicted total green weight, using a combined variable equation.

Model: MODEL1

Dependent Variable: TGWT

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	419282521.84	419282521.84	49958.504	0.0001
Error	1029	8636001.5099	8392.6156559		
C Total	1030	427918523.35			

Root MSE	91.61122	R-square	0.9798
Dep Mean	395.58500	Adj R-sq	0.9798
C.V.	23.15842		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-32.677244	3.43678414	-9.508	0.0001
D2H	1	0.155267	0.00069467	223.514	0.0001

Vita

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