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Factors influencing basal area growth of yellow-poplar (Liriodendron tulipifera L.) in central West Virginia

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Yellow-Poplar (*Liriodendron tulipifera* L.) in Central West Virginia

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Thesis submitted to the Davis College of Agriculture, Forestry, and Consumer Sciences at West Virginia University in partial fulfillment of the requirements for the degree of

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ABSTRACT

Factors Influencing Basal Area Growth of Yellow-Poplar (*Liriodendron tulipifera* L.) in Central West Virginia

Christopher T. Crum

This paper uses data from continuous forest inventory (CFI) plots to evaluate basal area growth of yellow-poplar (*Liriodendron tulipifera* L.) as related to four topographic factors (aspect, slope position, steepness, and landform), two competition variables (basal area per acre and trees per acre) and four tree characteristics (age, diameter, total height, and crown diameter). These variables were plotted against basal area growth per year using simple linear regression on 69 yellow-poplar trees. The four tree characteristics all had a highly significant ($p < .01$) relationship with basal area growth. While the other variables did not exhibit a significant relationship, the two competition variables did have a significant ($p < .05$) relationship with each other.

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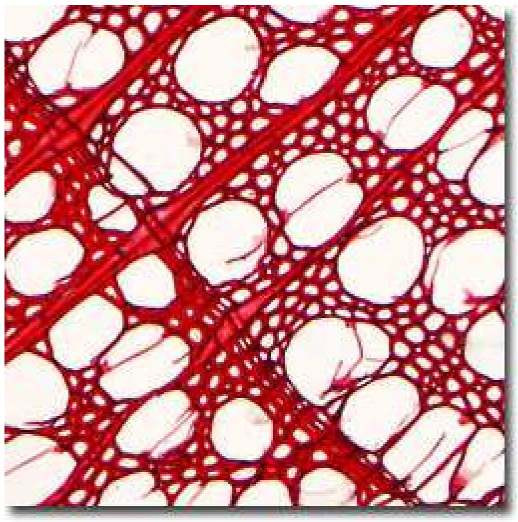
CHAPTER 1: INTRODUCTION

Project Background

Basal area growth is a function of the amount of xylem produced by the cambium layer. The quantity and size of xylem cells of a given species is directly related to the size of the crown and the amount of hormones and photosynthate produced by the foliage (Barnes et al., 1998). Photosynthate is first allocated to respiration, production of fine roots, seed production, primary growth (branch and root extension), and lastly to xylem growth and defense from insects and diseases (Oliver and Larson, 1996). Any factor that limits the production of photosynthate should, in turn, decrease the amount and/or size of the xylem cells and decrease basal area growth.

Yellow-poplar (*Liriodendron tulipifera* L.) is a fast growing, shade intolerant species. It grows in the eastern United States from central New York to Florida and west to Michigan and Louisiana. Yellow-poplar can be found on deep, rich, moist soils along streams or around swampy areas; usually mixed with other broadleaf trees or eastern hemlock (*Tsuga canadensis* (L.) Carr.) (USDA, 1965). This species is most abundant and reaches its largest size in the valleys of lower Ohio and in the mountains of North Carolina, Tennessee, Georgia, Kentucky, Virginia, and West Virginia (Olson, 1969). Yellow-poplar is a species with excellent potential for forest management. Not only is this tree abundant and fast-growing but it has good form, straight trunks, and good natural pruning ability. There are a variety of markets for yellow-poplar wood which makes this tree a very valuable timber resource in West Virginia.

Figure 1.1: A transverse section through an annual ring of yellow-poplar showing the vessels, trachieds and ray cells.



http://www.microscopy.fsu.edu/trees/pages/tulippoplar.html

Basal area growth may vary by rate and seasonal timing for different species. This can be seen when examining the xylem cells of a tree in the transverse section. Yellow-poplar is a diffuse-porous hardwood that has a fairly uniform distribution of vessels throughout the growth ring (Barnes et al., 1998). This indicates that yellow-poplar has a relatively consistent growth rate throughout the growing season. Sustained growth can also be seen in the shoots of yellow-poplar, which have continued growth late in the growing season on sites where moisture continues to be adequate. A study conducted in the lower Piedmont of North Carolina showed that yellow-poplar had a 160-day height-growth period beginning in early April and ending about the middle of September. Extension growth was fairly constant, with no peak during the growing season (Olson, 1969). Because yellow-poplar has sustained growth it is considered more site-sensitive than most ashes (*Fraxinus spp.*), oaks (*Quercus spp.*), or hickories (*Carya spp.*) (Oliver and Larson, 1996). Several studies have found that yellow-poplar trees outgrow other species on good sites, but oaks will outgrow yellow-poplar trees on poor sites (Fekedulegn et al., 2002; Carmean and Hahn, 1983). In the central Appalachians, northeast aspects are typically better sites and southwest aspects are typically poorer.

Objectives

Basal area growth for this study was on an individual tree basis and was determined from two diameter outside bark measurements taken several years apart using the following formula:

$$BAGY = (0.005454DBH_{t_2}{}^2 - 0.005454DBH_{t_1}{}^2) / years_{(t_1 - t_2)}$$

Where:

BAGY	= basal area growth per year
DBH	= the diameter at breast height (four and a half feet from the ground on the upslope side of the tree)
t_1	= the time of the first DBH measurements
t_2	= the time of the second DBH measurements
$years_{(t_1 - t_2)}$	= the interval between the two measurements

The basal area growth per year (BAGY) was then examined in relation to several tree characteristics and site characteristics.

The specific objectives of this study were:

1. The main objective of this paper was to see how certain tree characteristics, topographic variables, and competition variables relate to basal area growth. The tree characteristics examined included crown diameter, DBH, total height, and age. The competition variables included basal area per acre and trees per acre and the topographic variables were aspect, slope position, steepness, and landform.

2. A secondary objective was to determine the utility of continuous forest inventory (CFI) data for calculating basal area growth.

CHAPTER 2: LITERATURE REVIEW

Tree Characteristics

Foresters have made many comparisons between different tree characteristics. Some of these have been used to develop useful tools in forestry practice. For example, site index (a measure of site quality) is the average height of the dominant and codominant trees in the stand in relation to some index age. In West Virginia the base age for site index is normally 50 years. Not all trees follow the same height growth curve, even if they are the same species. Foresters understand that trees grow differently in different areas, but they also understand that an underlying relationship exists between age and total height.

Carmean and Hahn (1983) published a study comparing site indicies of five oak species and yellow-poplar. They used the site index of one species to predict the site index of another using linear regression. The equations accounted for from 40 to 89 percent of the variation in site index for each of the 13 species pairs.

A study by Phillips (1966) related the site index of yellow-poplar to soil and topography. He found that the depth to mottling, depth to tight subsoil, clay content of the subsoil, topographic position, and surface soil drainage were all related to site index. He derived an equation that explained approximately 67 percent of the observed variation in site index. Van Lear and Hosner (1967) were unable to find a relationship between site index of yellow-poplar and soil mapping units in southwest Virginia.

Several studies have investigated the relationship between diameter and age (Gibbs, 1963; Kenefic and Nyland, 1999; O'Brien et al., 1995; Loewenstein et al., 2000; Leak, 1985). Kenefic and Nyland (1999) develop an equation which explained 81 percent of the variation between age and diameter of sugar maple (*Acer saccharum* Marsh.) in an uneven-aged stand in New York. Loewenstein et al. (2000) used several equations to predict age from DBH in a managed uneven–aged oak forest. The resulting R^2 values ranged from 0.404 for red oak (*Quercus rubra* L.) to 0.619 for white oak (*Q. alba* L.). It was stated that accurate prediction of tree age from diameter is impossible. Leak's (1985) study, conducted in an old-growth northern hardwoods and spruce-fir (*Picea-Abies*) stand, found that age and size are fairly well correlated. The R^2 values ranged from 0.47 to 0.92. Gibbs (1963) stated that for unmanaged mountain hardwoods in Parsons, West Virginia there was extreme variability in the tree age-DBH relationship. The tree ages were placed in groups according to their DBH class. Among the species used in this study, yellow-poplar showed the least variability in age within the DBH classes. O'Brien et al. (1995) looked at eight neotropical tree species in Panama. They checked relationships between diameter, height, crown, and age. The best correlations were with total height-diameter and crown-diameter relationships.

As mentioned earlier, crown size is related to tree growth and several studies have examined crown dimensions and how they relate to diameter or basal area growth (Bragg, 2001; Dean, 2004; Smith et al., 1992; Ottorini et al., 1996; Miller, 2000; Strub et al., 1975). Dean (2004) looked at three pine (*Pinus spp.*) species. He implied that basal area growth occurs in response to the mechanical stress on the tree's trunk. Smith et al. (1992) also studied growth of three pine species. These pines were open grown and showed high correlations ($R^2 = 0.878$ to $R^2 = 0.914$) for the crown-basal area growth relationship. The other studies mentioned looked at other factors such as stand age, density (trees per unit area), average height of dominants and codominants, competition and branch arrangement.

Site Characteristics

Physiographic factors influence many other key ecosystem features, which make them a big part of forest management (Barnes et al., 1998). Physiographic factors include such things as aspect, slope position, and slope steepness. These are in turn related to the amount of solar energy and soil characteristics of the site. However, physiographic factors can be difficult to distinguish, and more research is needed before landscape features can be used in mathematical models to accurately classify ecosystems (Carmean, 1975).

One example of an influence of a physiographic factor is the effect of slope position on soil. Soil is usually shallower at upper slope positions because it is exposed to the action of wind, precipitation and gravity. Slope position also influences the amount of soil moisture and nutrient accumulation (Barnes et al., 1998). The lower the slope position the higher the soil moisture and biomass accumulation. Soil is usually shallower on steeper terrain because more erosion had occurred. Barnes et al. (1998) found that in dissected terrain, the greatest site index was on northeast aspects and the lowest was on south and west aspects. They also found that when both aspect and slope steepness are considered, a higher site index can be found with lower slope percentages and on the northeast aspects. Hicks and Frank (1984) suggest that aspect may directly or indirectly affect the properties of the upper soil horizons.

McNab (1993) conducted a study on topographic features and site index of yellow-poplar in North Carolina. One of the factors investigated was landform index.

Landforms were divided into three categories: ridge, slope, and cove. He stated that site index of yellow-poplar was weakly correlated with most conventional soil-site variables and only landform index and terrain shape index were significantly correlated with site index at each location.

In another study, McNab (1987) compared age, aspect, and shape index to total height of yellow-poplar. The shape index was derived from two different slope types: side and head. He stated that age had about the same importance on both slope types, explaining about 75 percent of the total variation. Also, surface shape was of lesser importance than aspect, but caused a uniform response to estimated site index on both slope types.

A third study by McNab (1989) related the terrain shape index (which was estimated from percent slope) and lateral shape class (concave, linear, or convex) to total height of yellow-poplar in North Carolina. All sample plots were located on middle to lower slopes. The study showed that the terrain shape index was significantly related to lateral shape class for all three areas.

Munn and Vimmerstedt (1980) compared height growth of yellow-poplar to soil and topography in southern Ohio and found that 65 percent of the variability in height could be explained by soil chemical or physical characteristics and topographic features. Auten (1945) also did a study comparing site index for yellow-poplar to soil and topography. His study included cutover areas in southeastern Ohio, southern Indiana and Illinois, Kentucky, and Tennessee. Auten (1945) indicated that the most important factor was depth to tight subsoil. It was also mentioned that site index increased by about three feet for each inch the A horizon increased in depth, between one and eight inches of total thickness. Frank et al. (1984) used weighted stepwise regression to develop a model that explained 65 percent of the variation between biomass and soil-site factors in West Virginia.

Stage (1976) recommends combining the effect of slope and aspect when relating them to tree growth. Poage and Tappeiner (2002) examined the relationship between diameter and basal area growth of old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees in western Oregon. The site factors of province, site class, slope, aspect, and elevation explained less than 8 percent of the variation when slope and aspect were combined prior to the analysis. In a study of two *Eucalyptus* species in Israel by Brunori et al. (1995), the effect of slope position and aspect with tree growth were highly significant. There was no significant difference between the species studied.

Basal Area Growth

Monserud and Sterba (1996) conducted an extensive study on even and uneven-aged forest stands in Austria. This study used remeasured trees growing on 5,416 plots. Each of the nine major species or species groups were fitted to their own model. Variables and resulting R^2 values when used individually to predict basal area growth included: DBH and crown length (0.14 to 0.47), a competition variable (0.15), topographic factors (elevation, slope, aspect) (0.03), and other site factors such as vegetation type and growth district (up to 0.03). Total site factors only explained two to six percent of the variation in basal area growth. The total model explained 20 to 63 percent of the variation in basal area growth for the nine species.

Another interesting study was completed for maritime pine (*Pinus pinaster* Ait.) in Northwestern Spain by Schroder et al. (2002). They indicated that basal area growth is a function of initial size, historical vigor, competition, and site productivity. Their results showed basal area increased with increasing diameter, crown spread, soil depth and decreasing competition. The model explained more than 78 percent of the total growth variation as indicated by an adjusted R^2 value.

The study that most closely resembles the present study is a thesis completed by Gibbs (1969). His study compared tree characteristics to basal area growth on five species [black cherry (*Prunus serotina* Ehrh.), red oak, sugar maple, and yellow-poplar]. Red oak was examined separately on two areas with site indicies of 60 and 80. All other species were examined on areas with a site index of 80. The variables computed for comparison are four-year basal area growth, mean DBH, mean crown diameter, mean crown length, mean total height, crown surface area, live crown ratio, number of trees in competition, number of quadrants occupied, sum of competing basal areas, and sum of competing basal areas divided by distances. The mean variables were the averages between the first measurement and the last measurement. The resulting R^2 values and levels of significance for yellow-poplar with linear regression equations are as follows:

Variable	**R^2 value**	**Level of Significance**
DBH	0.70	**
Crown diameter	0.62	**
Crown length	0.23	**
Crown surface area	0.58	**
Live crown ratio	negligible	NS
Total height	0.41	**
Number of competing trees	0.05	NS

Number of occupied quadrants	0.07	*
Sum of competing basal areas	0.12	**
Sum of competing basal areas / distances	0.27	**

** Highly significant (p <.01)

* Significant (p < .05)

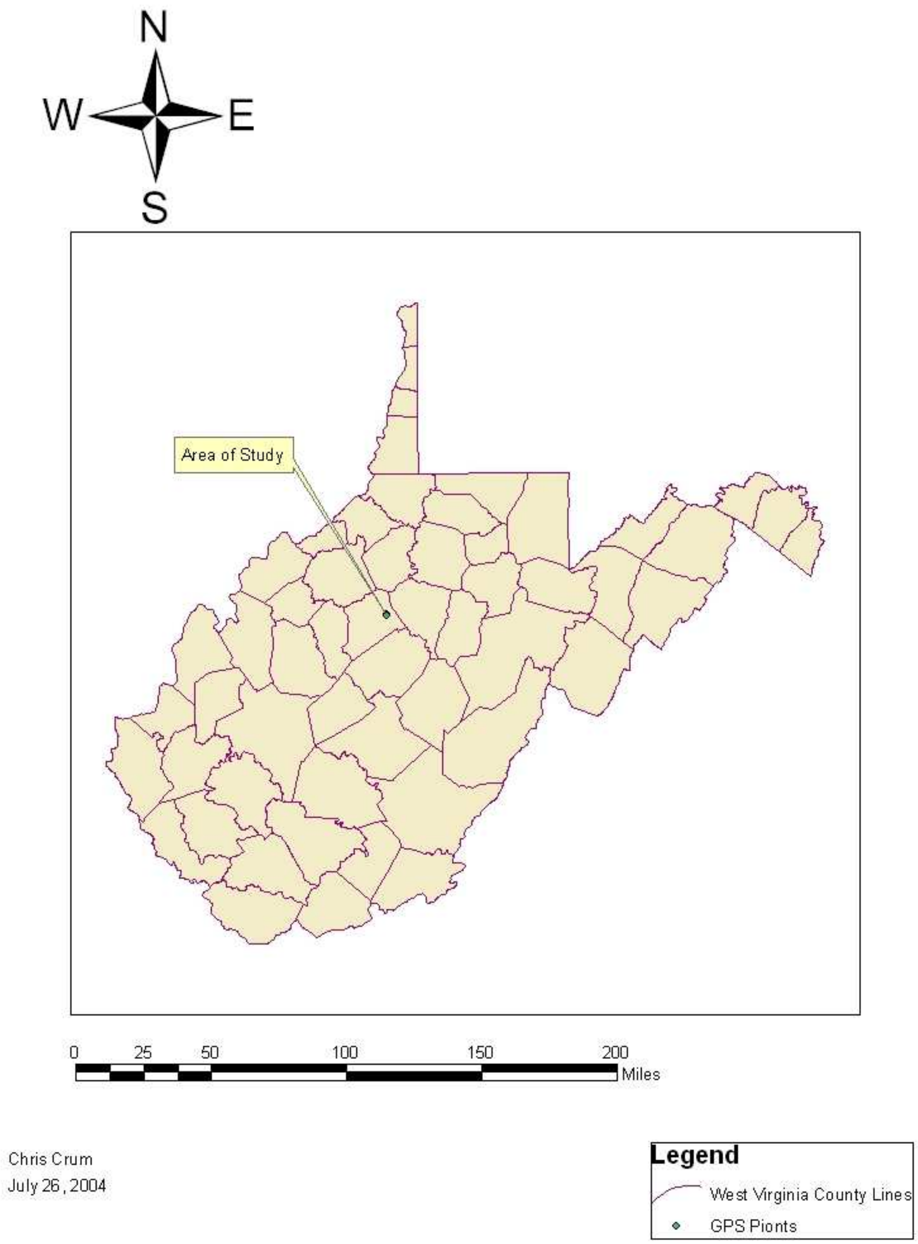
NS Not significant

CHAPTER 3: METHODS

Data

The data were collected from existing CFI plots located in Central West Virginia (fig. 3.1).

Figure 3.1: Location map for the area of study.



For this study, a 733-acre tract of second-growth forest was used. The tract was divided into compartments and subdivided into blocks. Within each block two to five CFI plots were established. The fixed-area CFI plots were one-tenth acre in size and were marked with an iron pipe in the center (fig. 3.2). The following data were recorded on most plots:

Tree number

Species

Diameter

Total height

Crown diameter

Age

Other data that was inconsistently measured included:

Height to a 4 inch top

Height to a 6 inch top

Height to an 8 inch top

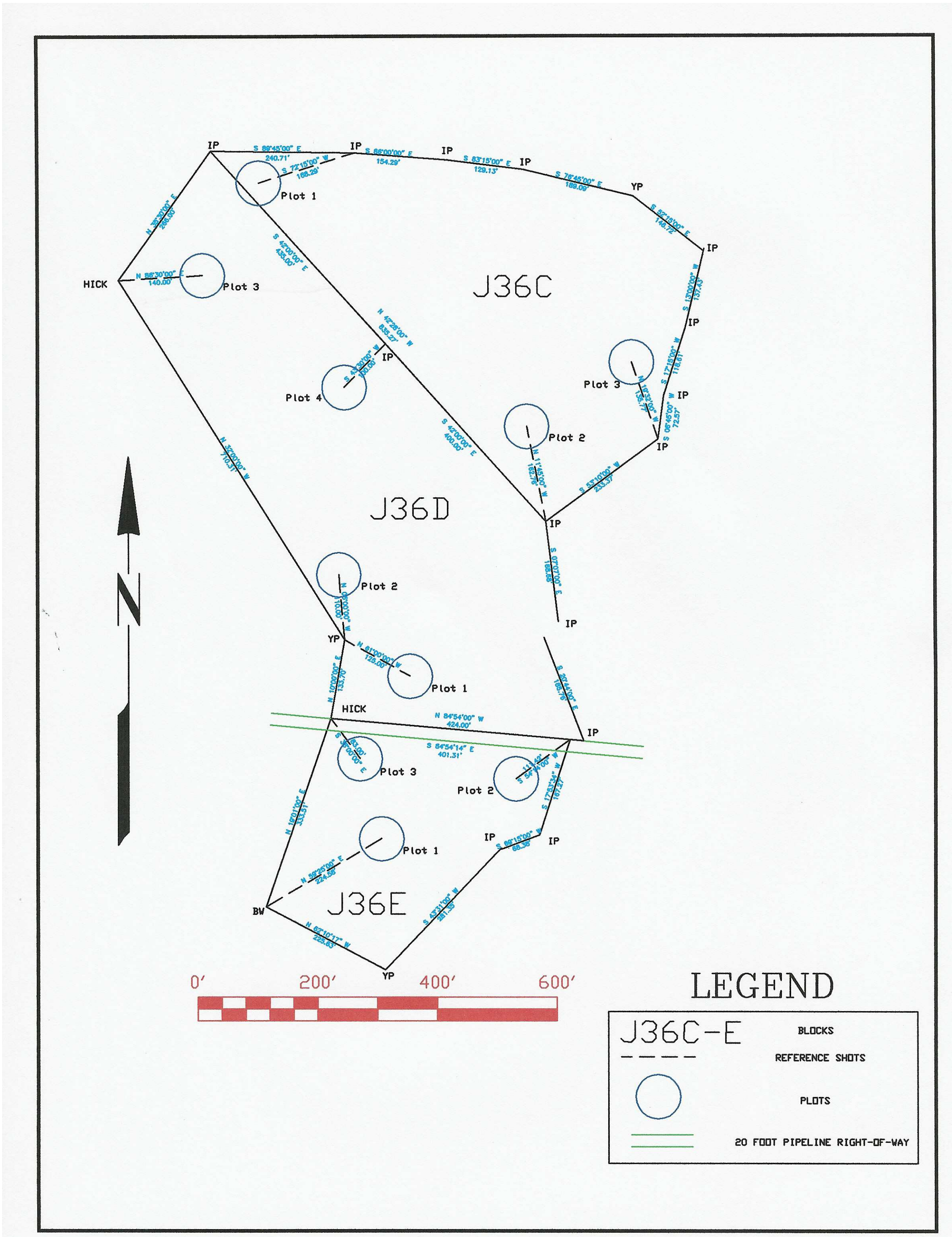
Height to a 12 inch top

Form class

Bark thickness

Only trees with a DBH of five inches or larger were measured if they were within a 37.2 foot radius from the plot center. Each tree was numbered with paint for later recognition. The initial CFI plot inventory for this tract began around 1979. No specific time was set for remeasurements, although most of the plots had been remeasured at least once. The location of the CFI plots with reference to the block boundary was also mapped (fig. 3.2).

Figure 3.2: Location of the CFI plots.



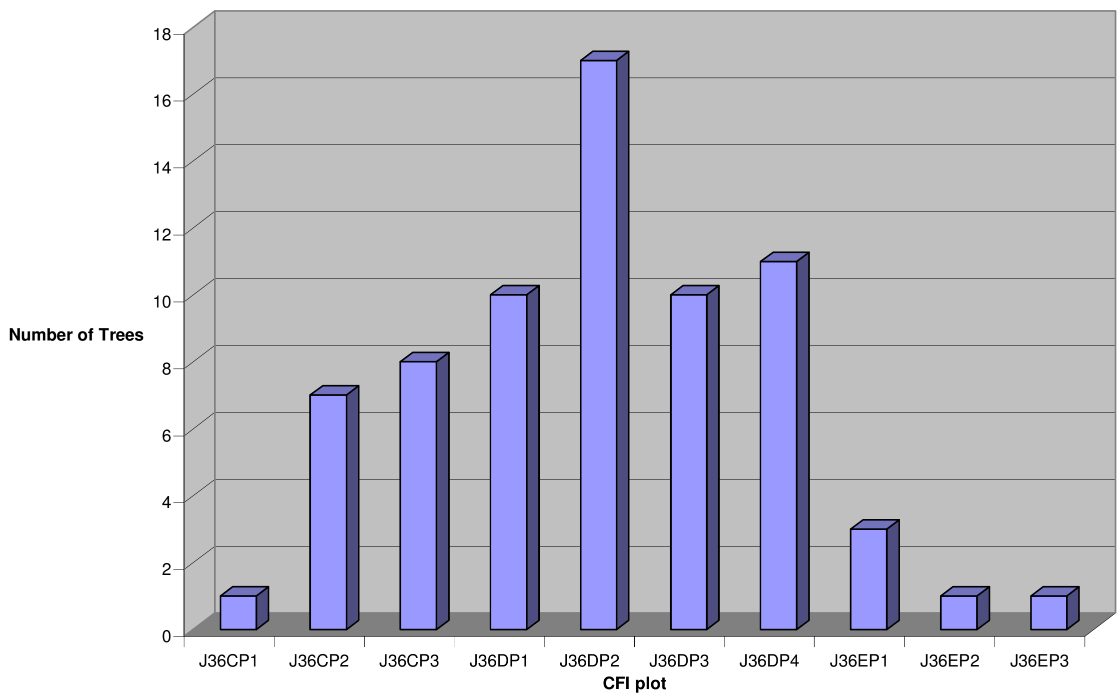
Some old aerial photographs were obtained from the years 1939, 1951, and 1958. In 1939 the area that was studied did not have any trees on it. In 1951 there were small trees all across the area and in 1958 there were medium sized trees. This information is in agreement with the data. When the first measurements were recorded around 1979, the approximate age of the stand was 31 years. There were several species associated with the yellow-poplar trees, however, the main species were Virginia pine (*Pinus virginiana* Mill.), hickory (*Carya spp*.), and sassafras (*Sassafras albidum* (Nutt.) Nees). As the years progressed, the Virginia pine and sassafras were out competed.

Field Observations

Diameter measurements of trees were taken with a diameter tape. The measurements were taken on the trunk at four and a half feet from the soil surface on the upslope side and were recorded to the nearest one-tenth inch (DBH). If the tree was less than five inches at this point it was not recorded. Total tree height measurements were recorded using a relascope. The crown diameters were obtained as an average of two measurements taken with a 100-foot tape. The first measurement was the largest diameter and the second was the smallest diameter of the crown. An increment borer was used to take a core sample at DBH. The core was placed in a straw for further analysis. The rings were counted on the core and the age was recorded. No additional years were added to account for the growth to breast height. All measurements were taken on standing trees. These measurements were taken at two different time periods on the CFI plots.

With emphasis on yellow-poplar, the CFI plots were first screened to find those plots containing the largest number of yellow-poplar trees. The next step was to examine the data and determine whether or not they were useable. Missing measurements or missing dates could render the data useless. CFI plots that showed the most potential were identified and reinventoried. Many tree numbers were not obtainable, which resulted in the elimination from further analysis. After a final examination of the data, reliable measurements taken from two time periods could be found for 69 yellow-poplar trees. These trees were distributed through ten CFI plots (fig. 3.3).

Figure 3.3: The number of yellow-poplar sample trees by plot number.



In the plot numbering system shown in Figure 3.3, the J represents Jakes Run which was the name for the tract. The 36 indicates compartments 3 and 6 combined. Next was the letter associated with the block and then the designated CFI plot number.

These ten plots were relocated on the ground and the coordinates were obtained using a hand held global positioning system (GPS).

Table 3.1: Coordinates for each CFI center point in decimal degrees.

NUMBER	NAME	LATITUDE	LONGITUDE
1	J36CP1	38.96799	-80.74576
2	J36CP2	38.96715	-80.74421
3	J36CP3	38.96749	-80.74352
4	J36DP1	38.96612	-80.74476
5	J36DP2	38.96655	-80.74506
6	J36DP3	38.9679	-80.74606
7	J36DP4	38.96716	-80.74477
8	J36EP1	38.96533	-80.74469
9	J36EP2	38.96568	-80.74398
10	J36EP3	38.96557	-80.7449

The information was put into a table (table 3.1) using Microsoft Excel and then added in ArcMap (ArcView 8 2002). ArcMap (ArcView 8 2002) was then used to obtain the aspect, slope position, and steepness associated with each of these CFI plots. This method was used because it produced more consistent results than field observations and was less time consuming. Slope position can be difficult to analyze without a relative knowledge of the distance from the bottom and top of the slope, which are not usually visible from the plot. Also the aspect is difficult to establish when plots are located on a spur or narrow draws. Thus, geographic information system (GIS) software was used to eliminate human error.

Data Analysis

The interval over which the two DBH measurements were collected did not occur over the same period for each tree. This time period varied between six and seven years. Because of this, basal area growth was expressed on a per year basis in order to facilitate comparisons to the other variables. The basal area growth per year (BAGY) was compared to the growth per year of total height, crown diameter, DBH, and the averages of total height, crown diameter, DBH, and age. The averages were calculated as the mean of the initial and final measurement.

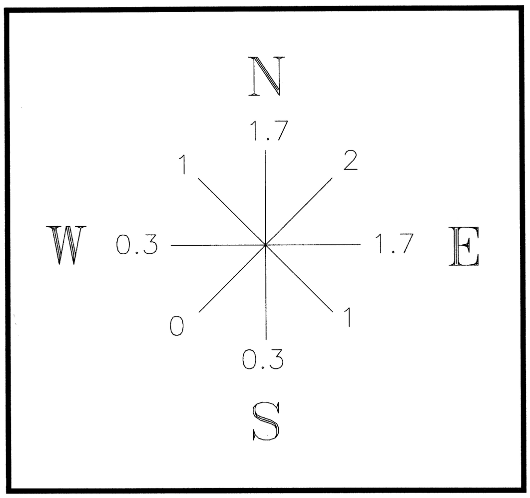
Basal area per acre was calculated for each plot by summing the basal areas of each tree within the plot and then expanded to a per acre basis. Although border trees do not directly affect each of the study trees in a particular plot, it was assumed that plot basal area was a reasonable representation of the stand density of the area.

The trees per acre were calculated based on the number of trees in each plot that were five inches DBH, or larger. BAGY was compared to the change in basal area per acre and trees per acre as well as the average basal area per acre and trees per acre. These averages were calculated as the mean of the beginning and ending measurement. The change was calculated as the difference between the final measurement and the beginning measurement. This was then placed on a per year basis by dividing that number by the years between these two measurements.

The topographic variables of aspect, steepness, and slope position were computed using ArcMap. All plot centers were established using a hand held GPS unit. A table of latitude and longitude values was imported into ArcMap (ArcView 8 2002) and placed over an elevation grid. Each cell of this grid represented about 9,688 square feet and contained a value associated with the elevation. The raster calculator was used to create aspect, steepness, and slope position grids. The grids were then reclassified to specification (Appendix B). The steepness and slope position were placed in three classes and the aspect was converted to a number based on the assumed site quality for that aspect with values ranging from zero to two. This number was calculated by using the cosine of the azimuth turned 45 degrees and then adding one:

$$\text{Aspect} = [\cos(Azimuth)] + 1$$

Figure 3.4: Values assigned to azimuths.



The turning of the azimuth assumes the best site to be at northeast and the poorest site to be at southwest. This formula resulted in values ranging from 0 to 2.

Steepness was divided into three classifications based on the range of percent slope in the area. The observed percent slope ranged from near zero to approximately 55 percent. This was split into three equal classes and given dummy values of 0, 1, and 2, with a higher value being associated with the less steep slopes which represent better sites (low=2, medium=1, high=0).

Slope position was also split into three categories based on the elevation of the surrounding area which included the top and bottom of the slope. The range in elevation was from 922 feet to 1,178 feet according to the elevation data obtained from the West Virginia State GIS Technical Center website (http://www.wvgis.wvu.edu). At the plot locations upper slopes were given a dummy value of 0, mid-slopes a value of 1 and lower slopes representing the best sites were assigned a value of 2.

A fourth topographic variable (landform) was based on the observed shape of the land where the CFI plot was located. These three shapes (spur/ridge, hillside, and draw/valley) were given dummy values according to their importance with yellow-poplar growth (spur/ridge = 0, hillside = 1, draw/valley = 2).

BAGY was compared to each of these and a combination of all four. The combination of these four variables, called total site (TS), could range from 0 (the worst site) to 8 (the best site). All of these comparisons were based on linear regressions and the R^2 value was examined to determine the best relationship of a characteristic to basal area growth.

BAGY was also compared to the individual data sets to look for inconsistencies. Once the best relationship was found, based on the R^2 value, the data were analyzed using SAS PROC REG (SAS v9.1 2004) to determine relationships and to test the significance of each relationship. All of the variables and the abbreviations associated with them can be found in Table 3.2.

Table 3.2: Variables and their abbreviations.

basal area growth per year	BAGY
landform	LF
aspect	ASP
steepness	STP
slope position	SP
total site	TS
diameter initial measurement	DBH1
crown diameter initial measurement	CD1
age initial measurement	A1
total height initial measurement	TH1
basal area per acre initial measurement	BAA1
trees per acre initial measurement	TPA1
diameter final measurement	DBH2
crown diameter final measurement	CD2
age final measurement	A2
total height final measurement	TH2
basal area per acre final measurement	BAA2
trees per acre final measurement	TPA2
change in basal area per acre per year	BAAGY
change in trees per acre per year	TPAGY
average basal area per acre	AVGBAA
average trees per acre	AVGTPA
diameter growth per year	DBHGY
crown diameter growth per year	CDGY
total height growth per year	THGY
average diameter	AVGDBH
average crown diameter	AVGCD
average total height	AVGTH
average age	AVGA

CHAPTER 4: RESULTS

Topographic Factors

All topographic factors were plotted against BAGY (Appendix C fig. A.1). Total site (TS) was also included which represents a combination of all four topographic factors. Next, the coefficient of determination (R^2) for each linear relationship was determined (table 4.1). Also, the significance of the relationship between BAGY and the variables was evaluated using the SAS PROC REG (SAS v9.1 2004) procedure (table 4.1).

Table 4.1: R^2 values of topographic factors and topographic variable results from SAS using simple linear regression.

Variable	R^2	Significance	MSE
Landform (LF)	0.0012	0.7732 (NS)	0.00029
Aspect (ASP)	0.0316	0.1439 (NS)	0.00028
Steepness (STP)	0.0001	0.9207 (NS)	0.00029
Slope position (SP)	0.0205	0.2411 (NS)	0.00028
Total site (TS)	0.00002	0.9681 (NS)	0.00029

(NS) Model was not significant with a 95 percent confidence interval

MSE is the mean squared error calculated using SAS. None of these variables proved to have a significant relationship with BAGY. Furthermore, combining them into the TS variable did not yield a significant relationship with BAGY.

Competition Variables

The relationship between basal area per acre and trees per acre was examined with respect to BAGY (Appendix C fig. A.2). Using a simple linear model, the basal area per acre for the first and second measurement periods (BAA1 and BAA2), trees per acre for the two periods (TPA1 and TPA2), average basal area per acre (AVGBAA), average trees per acre (AVGTPA), change in basal area per acre per year (BAAGY), and the change in trees per acre per year (TPAGY) were all examined with respect to BAGY (table 4.2).

Table 4.2: R^2 values of competition variables using simple linear regression.

Variables	R^2
Basal area per acre initial measurement (BAA1)	0.0067
Trees per acre initial measurement (TPA1)	0.0263
Basal area per acre final measurement (BAA2)	0.0018
Trees per acre final measurement (TPA2)	0.0328
Average basal area per acre (AVGBAA)	0.0037
Average trees per acre (AVGTPA)	0.0312
Change in basal area per acre per year (BAAGY)	0.0119
Change in trees per acre per year (TPAGY)	0.0155

The comparison made with regard to data from the two measurement periods was to look for obvious inconsistencies. The other variables were examined further to check the significance of their relationship with BAGY (table 4.3).

Table 4.3: Competition variable results from SAS.

Variables	Significance	MSE
Change in trees per acre per year (TPAGY)	0.3075 (NS)	0.00029
Change in basal area per acre per year (BAAGY)	0.3732 (NS)	0.00029
Average basal area per acre (AVGBAA)	0.6197 (NS)	0.00029
Average trees per acre (AVGTPA)	0.1466 (NS)	0.00028

(NS) Model was not significant in a 95 percent confidence interval

All of these variables showed negligible slope coefficients and were not significantly related to BAGY.

For further analysis, the relationship between the competition indices (y = BAAGY and x = TPAGY) was examined. The values were examined on a per plot basis (n = 10). The R^2 value was 0.5342 (Appendix C fig. A.3). The beta 0 and beta 1 values were 2.3575 and 0.1789. The MSE value was 0.2951 and the probability of a larger F was 0.0163. The relationship was significant at the ($p < .05$) level and both parameters were significant with a 95 percent confidence interval (Appendix D p. 73).

Tree Characteristics

Four tree characteristics (total height, age, crown diameter, and DBH) were compared to the BAGY. The average (AVG), change per year (GY), initial measurement (1), and final measurement (2) were all plotted against BAGY for comparison (Appendix C fig. A.4 – A.10). The resulting R^2 values were calculated from a linear relationship (table 4.4).

Table 4.4: R^2 values associated with the tree characteristics against basal area growth per year using simple linear regression.

Variables	R^2
Average age (AVGA)	0.3137
Average total height (AVGTH)	0.1761
Average crown diameter (AVGCD)	0.5537
Average diameter (AVGDBH)	0.7515
Total height growth per year (THGY)	0.0565
Crown diameter growth per year (CDGY)	0.034
Diameter growth per year (DBHGY)	0.8698
Age initial measurement (A1)	0.3098
Total height initial measurement (TH1)	0.0405
Crown diameter initial measurement (CD1)	0.4685
Diameter initial measurement (DBH1)	0.655
Age final measurement (A2)	0.3174
Total height final measurement (TH2)	0.3364
Crown diameter final measurement (CD2)	0.5123
Diameter final measurement (DBH2)	0.8213

The averages seemed to generally have higher R^2 values than the changes per year, with the exception of DBH. The averages of the characteristics should give a good estimation of the tree characteristics half way through the growth period from the first to the final measurement. The average variables were then examined to see if their linear coefficients were significant and the following results were calculated (table 4.5).

Table 4.5: Linear regression parameters for tree characteristics.

Variables	Estimated b0	Estimated b1	Significance	MSE
Average total height (AVGTH)	-0.0313	0.000806	0.0003**	0.00024
Average diameter (AVGDBH)	-0.0261	0.00569	<0.0001**	0.00007
Average crown diameter (AVGCD)	-0.0137	0.00212	<0.0001**	0.00013
Average age (AVGA)	-0.0298	0.00158	<0.0001**	0.00020

** Highly significant ($p < .01$)

All models were highly significant ($p < .01$) and all parameter estimates for each model were significant at the 95 percent confidence level.

CHAPTER 5: DISCUSSION

Topographic Factors

The topographic factors proved to have little or no correlation with basal area growth. This was also observed in other studies in the literature. Site class, slope, aspect, and elevation explained less than eight percent of the variation when compared to basal area growth in the study conducted by Poage and Tappeiner (2002). Total site factors only explained two to six percent of the variation when used to predict basal area growth according to Monserud and Sterba (1996).

McNab (1993) did find a correlation between landform index and terrain shape index when compared to the site index of yellow-poplar. However, site index as mentioned earlier is based on the dominant and codominant trees of the stand. This study looked at all the trees regardless of their crown class. Also this study showed a weaker relationship between total height and BAGY than the other three tree characteristics. This points to the fact that this study of all trees, regardless of crown class, may not be very comparable to studies dealing only with dominant or codominant trees.

The aspect variables appear to explain about three percent of the variation in BAGY and slope position appears to explain two percent of the variation. However, aspect shows a linear relationship of decreasing basal area growth with increasing aspect value. Slope position has the strongest positive relationship to BAGY of all the topographic features, even though it does not have a significant relationship ($p < .05$) with basal area growth. Although it was thought that the combination of these topographic factors may show a higher correlation with basal area growth than the individual variables, the opposite was true. The combination of these factors resulted in a weaker relationship with basal area growth than any of the variables had individually. Landform seemed to have a slight association with BAGY. There was no linear relationship of slope steepness and total site to BAGY.

Competition Variables

The variables BAAGY (change in basal area per acre per year) and TPAGY (change in trees per acre per year) were similar in their relationships to basal area growth per year. The R^2 values showed that about one percent of the variation in BAGY could be explained by each of these variables. Further analysis was completed on the comparison of these variables with each other. On a per plot basis the change in basal area per acre per year against the change in trees per acre per year resulted in an R^2 value of 0.5342. The p-value was 0.0163, which was significant ($p < .05$). Even though these two variables lack a significant correlation with basal area growth, they are significantly correlated with each other which stands to reason in unmanaged even-aged stands. Barnes et al. (1998) stated that diameter growth is strongly influenced by density, which is usually measured by the number of trees or basal area per unit area. Schroder et al. (2002) indicated that competition should be a factor when estimating basal area growth. Why was there such a lack of correlation between these variables? One reason could be the method of measurement. The variables were calculated by taking the sum of each tree that was five inches DBH or larger and contained within the one-tenth-acre plot. This should have given an overall basal area per acre and trees per acre, but did not give a good estimate for the competition that each individual yellow-poplar tree within the plot was experiencing. Thus, a lack of correlation may be due to every tree within a certain plot is assumed to be influenced the same amount by the competition variable of that plot.

Another reason might be that yellow-poplar trees typically grow faster in height than their competitors and the sample trees were probably mostly dominant or codominant. In this case, they are probably not competing as much for light as the other trees.

Gibbs (1969) measured competition differently. He used a prism to detect competing trees around a study tree. The larger the diameter of a tree the further it can be picked up and be counted as a competitor. This method proved to be more individualized toward the study tree than the plot method used in this study. The sum of competing basal areas and the sum of competing basal areas divided by their distances were both significant ($p < .01$) for yellow-poplar in Gibbs' study. However, the number of competing trees was not significant ($p < .05$) for yellow-poplar when compared to basal area growth.

Tree Characteristics

Of the tree characteristics, diameter had the best correlation, as expected. This is a result of DBH being used to compute basal area growth. The average DBH showed a linear relationship that explained 75 percent of the variation.

The next best linear relationship was with average crown diameter ($R^2 = 0.5537$). This relationship was explained in several different ways within the literature. One study explained that basal area growth increases with increasing crown size because of the mechanical stress on a tree's trunk (Dean, 2004). Barnes et al. (1998) stated that growth is related to the amount of hormones and photosynthate produced by the foliage. While these two factors make sense, the crown could also be a representation of the intensity of competition on a tree (after so many years). It could be assumed that more trees around a subject tree would hinder the expansion of its crown, which would in turn influence its physiological productivity and growth.

Average age versus basal area growth resulted in an R^2 value of 0.3137 and a significant correlation ($p < .01$). It should be noted that this study did not limit the trees to dominant and codominant crown classes. The best relationship with age should result from using only dominant and codominant crown classes.

The literature on age relationships is mixed. Gibbs (1963) found no relationship between diameter and age in uneven-aged stands. Loewenstein et al. (2000) found a good relationship between age and diameter in an uneven-aged oak forest by fitting a sigmoidal curve. Probably the greatest difference between these two studies is that Gibbs (1963) used two inch diameter classes and Loewenstein et al. (2000) measured diameter to the nearest 0.5 centimeters.

The reason uneven-aged stands are usually avoided when looking for a relationship among variables associated with tree size is because of the ability of some species to exist for years in the understory without much growth. Yellow-poplar is a very intolerant species and therefore will not exist in these conditions. This eliminates some of the variability. Buckner and McCraken (1978) explain that yellow-poplar can even exist in a climax forest. The reason they proposed for this was related to the species ability to outgrow its competitors when seeded into large openings, often created by a large mature tree falling.

Average total height versus BAGY resulted in an R^2 value of 0.1761. This was much smaller than the other tree characteristics. Total height for the initial measurement had an R^2 value of 0.0405 but the R^2 value was 0.3364 for the heights taken at the final measurement. It can only be assumed that error in tree height measurement for the initial period caused the difference. However, the average of these two measurements when compared to BAGY still resulted in a significant ($p < .01$) relationship.

O'Brien et al. (1995) developed a curvilinear relationship between DBH and total height for eight neotropical tree species and had resulting R^2 values range from 0.88 to 0.97. The average total height against basal area growth that Gibbs (1969) calculated had an R^2 value of 0.41. This further justifies the belief that some error occurred in the initial measuring of total height. Height can be a difficult measurement on large hardwood trees, as the forester is forced to sight through the crown to an assumed top of the tree. If the tree is leaning it further complicates the process.

Linear relationships might not be the best relationship between these variables and BAGY. Logrithmic, polynomial, power, and exponential regressions were all used on the relationship between BAGY and the following tree characteristics: AVGDBH, AVGTH, AVGCD, and AVGA. These provided only a slight increase in the R^2 value, if any at all, with the exception of AVGTH. AVGTH had an R^2 value of about .22 with both the power and exponential regressions. Since the power regression was a more simplistic equation of the two and the results were very similar, it was further evaluated using SAS PROC NLIN. SAS showed this new equation to have a p-value of <.0001, however, beta 0 was not significant (95% confidence interval). When beta 0 was dropped from the equation, the relationship still had a p-value of <.0001 (Appendix D p. 81).

AVGDBH, AVGCD, AVGA and AVGTH were also used in a multiple regression equation to predict BAGY. The resulting equation had an R^2 value of 0.81 with all beta values significant (95% confidence interval) (Appendix D p. 82). The p-value for this equation was <.0001.

BAGY = b0 + b1(AVGDBH) + b2(AVGCD) + b3(AVGA) + b4(AVGTH)

Where:

b0 = -0.0563

b1 = 0.00333

b2 = 0.000808

b3 = 0.000409

b4 = 0.000335

The residuals of this equation were plotted and showed that most of the estimates fell within plus or minus 0.01 square foot of basal area growth per year of the actual values (Appendix C fig. A.11 - A.15). The R^2 value did not increase by taking AVGTH out of the equation.

The R^2 for average DBH with BAGY in this study equals 0.75 as compared to Gibbs (1969) $R^2 = 0.70$; and average crown diameter R^2 value equals 0.55, as compared to Gibbs (1969) $R^2 = 0.62$. These values seem to be fairly consistent in comparison. It should be noted that, overall, data from the final measurement had slightly higher R^2 values with BAGY than data from the initial measurement period. It is logical to assume that individual tree measurements are better at predicting past basal area growth than future growth. It is also very obvious that individual tree measurements explain more about basal area growth than generalized site characteristics.

CHAPTER 6: CONCLUSION / COMMENTS

Topographic Factors

The site characteristics did not have a significant correlation ($p < .05$) with basal area growth per year. Several recommendations could be made to try to correct this problem.

1. Try to make the data as specific to the subject trees as possible. For example perhaps actual elevations would have yielded better results than the coded slope positions.
2. The data need to be more uniform. Four plots contained ten or more trees and three plots contained only one tree. This was a limitation of the overall data set, but it results in some plots having one topographic variable to account for ten different trees and other plots have one topographic variable to compare to one tree.
3. Try to obtain a more uniform distribution of trees over the different variables. This is frequently a problem with biological data sets. It is difficult to find as many yellow-poplar trees growing on southwest aspects as compared to northeast aspects in a given area. This can result in trying to eliminate some of the study trees on the northeast aspect. Most researchers are reluctant to remove plots from the data set, so it ends up being skewed, like the present study. Another option is to eliminate the classes of the variable where fewer study trees exist.

Competition Variables

The competition variables did not have a significant correlation ($p < .05$) with BAGY. They did, however, have a significant correlation ($p < .05$) with each other. The lack of relationship is most likely a function of the method used to account for competition than to the lack of a relationship. The recommendation is to make the measure of competition more individualized to the study tree. Gibbs (1969) provides an example of measuring competition variables on an individual tree basis. While two of his competition variables were significant ($p < .01$), a third (number of competing trees) was not significant ($p < .05$).

Tree Characteristics

All of the tree characteristics proved to have a significant relationship with BAGY. Average DBH, average age, and average crown diameter all had a p-value of <.0001 and average tree height had a p-value of 0.0003. It was proposed that average tree height could have a better correlation if the initial height measurements were more accurate. There was a better correlation among the tree characteristic variables with BAGY than the site characteristic variables because they are on an individual tree basis. Other studies predicting basal area growth have had similar results (Monserud and Sterba, 1996; Gibbs, 1969). Also, a higher correlation would probably exist if the study only used dominant and codominant trees.

The results did indicate that DBH had the highest R^2 value, which was expected since basal area is a function of DBH squared. Crown diameter also showed a high correlation. All the tree characteristics showed a positive relationship with BAGY. This proves that trees which have a history of good growth continue to grow fast and trees that have larger crowns will grow faster. It also has implications that management practices that increase crown growing space will increase basal area growth. Some of these management practices are thinnings, crop tree release, or any timber stand improvement that would open up the canopy. It is important that there is not too much light on the trunks, as this would result in epicormic branching which lowers the timber value. Another disadvantage in opening up the canopy would be more movement in the upper portion of the tree, which could result in broken tops. This can only be avoided by choosing the proper trees to be released. There is a fine line between maximizing DBH growth and maximizing quality. It is important to invest in the trees that have good form and are fast growers, so they will continue in this trend.

Other Objectives

CFI data, such as this, did not have enough individualized variables to produce a basal area growth prediction model. While the tree characteristics were accurate enough, the topographic factors and competition variables were too generalized.

In the past, topographic variables were acquired by using tapes, clinometers, Abney levels, and compasses (McNab, 1987; Munn and Vimmerstedt, 1980). The topographic variables used in this paper were calculated using GIS. This is not only easier but it eliminates human bias.

GIS is a powerful tool that can be used to compute many topographic variables from latitude and longitude coordinates. This data set was completed using a raster image made up of 30 meter by 30 meter grid squares. However, technology is increasing and with the increasing speed of computers and light detection and ranging (LiDAR) data it will be possible to compute these variables on one square meter of ground as long as the coordinates are as accurate. The world of forestry will have many uses for this new technology.

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APPENDIX A

DATA

Table A.1: Topographic Factors

CFI PLOT	TREE NUMBER	SPECIAL SITE	LANDFORM	AZIMUTH	ASPECT DIRECTION	ASPECT	%SLOPE	STEEPNESS CLASS	STEEPNESS	SLOPE POSITION CLASS	SLOPE POSITION	TOTAL SITE
J36CP1	12	top of spur	0	146	southeast	0.8092	28	medium	1	middle	1	2.8092
J36CP2	1	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	2	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	3	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	4	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	6	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	10	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP2	14	close to draw	2	126	southeast	1.1564	15	low	2	low	2	7.1564
J36CP3	2	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	4	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	6	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	8	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	10	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	11	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	12	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36CP3	13	in a draw	2	204	southwest	0.0664	25	medium	1	low	2	5.0664
J36DP1	1	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	2	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	3	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	5	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	8	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	12	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572

J36DP1	16	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	19	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	20	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP1	21	hillside	1	76	east	1.8572	29	medium	1	high	0	3.8572
J36DP2	2	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	3	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	4	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	5	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	6	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	7	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	11	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	12	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	13	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	14	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	15	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	16	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	18	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	19	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	22	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	23	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP2	24	hillside	1	52	northeast	1.9925	36	high	0	high	0	2.9925
J36DP3	3	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	6	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	7	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	9	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	11	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	12	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	13	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	14	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	15	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP3	16	hillside	1	120	southeast	1.2588	28	medium	1	middle	1	4.2588
J36DP4	1	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925

J36DP4	2	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	3	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	4	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	5	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	6	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	8	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	13	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	17	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	18	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36DP4	19	hillside	1	52	northeast	1.9925	21	medium	1	middle	1	4.9925
J36EP1	4	hillside	1	114	southeast	1.3584	37	high	0	middle	1	3.3584
J36EP1	10	hillside	1	114	southeast	1.3584	37	high	0	middle	1	3.3584
J36EP1	11	hillside	1	114	southeast	1.3584	37	high	0	middle	1	3.3584
J36EP2	4	hillside	1	111	east	0.4067	32	medium	1	low	2	4.4067
J36EP3	9	hillside	1	120	southeast	1.2588	38	high	0	middle	1	3.2588

Table A.2: Initial Tree Measurements

CFI PLOT	TREE NUMBER	DBH1	BA1	BAA1	TPA1	A1	TH1	CD1
J36CP1	12	9.9	0.534547	62.371	230	44	64	22
J36CP2	1	13.1	0.935961	69.844	170	25	73	29
J36CP2	2	5.2	0.147476	69.844	170	23	52	16
J36CP2	3	10.5	0.601304	69.844	170	30	63	25
J36CP2	4	6.9	0.259665	69.844	170	27	56	24
J36CP2	6	8.8	0.422358	69.844	170	30	59	24
J36CP2	10	7.9	0.340384	69.844	170	37	52	22
J36CP2	14	7.8	0.331821	69.844	170	20	49	21
J36CP3	2	10.4	0.589905	71.063	160	32	57	24
J36CP3	4	9	0.441774	71.063	160	36	47	20
J36CP3	6	9.4	0.481915	71.063	160	31	35	19

J36CP3	8	9.4	0.481915	71.063	160	34	47	22
J36CP3	10	10.2	0.567434	71.063	160	37	48	10
J36CP3	11	13.9	1.053767	71.063	160	39	72	30
J36CP3	12	7.9	0.340384	71.063	160	25	28	27
J36CP3	13	5.8	0.183473	71.063	160	30	37	23
J36DP1	1	9.1	0.451646	77.213	220	35	67	15
J36DP1	2	7.5	0.306788	77.213	220	28	79	13
J36DP1	3	11	0.659934	77.213	220	31	83	19
J36DP1	5	8.5	0.394052	77.213	220	34	70	15
J36DP1	8	10	0.5454	77.213	220	31	70	18
J36DP1	12	7	0.267246	77.213	220	38	75	19
J36DP1	16	8.7	0.412813	77.213	220	37	80	11
J36DP1	19	6.7	0.24483	77.213	220	22	67	14
J36DP1	20	5.8	0.183473	77.213	220	32	49	13
J36DP1	21	6.7	0.24483	77.213	220	33	69	10
J36DP2	2	7.7	0.323368	80.947	240	28	67	14
J36DP2	3	6	0.196344	80.947	240	25	66	10
J36DP2	4	5.9	0.189854	80.947	240	26	55	13
J36DP2	5	7.8	0.331821	80.947	240	26	77	15
J36DP2	6	8.2	0.366727	80.947	240	28	78	16
J36DP2	7	7.3	0.290644	80.947	240	31	72	15
J36DP2	11	6.6	0.237576	80.947	240	28	70	12
J36DP2	12	10.6	0.612811	80.947	240	32	80	24
J36DP2	13	5.5	0.164984	80.947	240	25	63	9
J36DP2	14	9	0.441774	80.947	240	25	75	12
J36DP2	15	5.7	0.1772	80.947	240	31	62	14
J36DP2	16	12.2	0.811773	80.947	240	31	86	25
J36DP2	18	14.4	1.130941	80.947	240	32	85	20
J36DP2	19	5.4	0.159039	80.947	240	29	69	11
J36DP2	22	5.4	0.159039	80.947	240	24	55	11
J36DP2	23	5.9	0.189854	80.947	240	26	62	13
J36DP2	24	6.8	0.252193	80.947	240	21	70	13

J36DP3	3	6.6	0.237576	54.999	180	28	69	11
J36DP3	6	6.6	0.237576	54.999	180	30	71	15
J36DP3	7	5.9	0.189854	54.999	180	29	54	16
J36DP3	9	9.7	0.513167	54.999	180	31	70	20
J36DP3	11	6.7	0.24483	54.999	180	21	62	12
J36DP3	12	8.6	0.403378	54.999	180	37	70	20
J36DP3	13	5.7	0.1772	54.999	180	23	66	11
J36DP3	14	6	0.196344	54.999	180	30	66	12
J36DP3	15	6.1	0.202943	54.999	180	34	64	9
J36DP3	16	6.2	0.209652	54.999	180	36	72	13
J36DP4	1	5.2	0.147476	59.838	190	30	61	14
J36DP4	2	5.8	0.183473	59.838	190	25	71	14
J36DP4	3	5.9	0.189854	59.838	190	29	67	10
J36DP4	4	6	0.196344	59.838	190	27	75	13
J36DP4	5	5.9	0.189854	59.838	190	33	64	11
J36DP4	6	6	0.196344	59.838	190	29	71	11
J36DP4	8	8	0.349056	59.838	190	29	79	16
J36DP4	13	7.5	0.306788	59.838	190	35	60	15
J36DP4	17	7.1	0.274936	59.838	190	24	65	15
J36DP4	18	5.5	0.164984	59.838	190	35	65	15
J36DP4	19	7.3	0.290644	59.838	190	33	70	17
J36EP1	4	11.9	0.772341	75.426	180	43	61	30
J36EP1	10	11	0.659934	75.426	180	52	53	29
J36EP1	11	11.2	0.68415	75.426	180	39	56	32
J36EP2	4	13.7	1.023661	64.491	170	44	66	23
J36EP3	9	10.5	0.601304	70.402	180	29	51	20

Table A.3: Final Tree Measurements

CFI PLOT	TREE NUMBER	DBH2	BA2	BAA2	TPA2	A2	TH2	CD2
J36CP1	12	12.1	0.79852	75.968	240	50	83	39
J36CP2	1	14.6	1.162575	86.285	180	31	79	42
J36CP2	2	6.6	0.237576	86.285	180	29	55	24
J36CP2	3	12.2	0.811773	86.285	180	36	63	32
J36CP2	4	7.4	0.298661	86.285	180	33	63	19
J36CP2	6	10.2	0.567434	86.285	180	36	64	32
J36CP2	10	9.3	0.471716	86.285	180	43	59	17
J36CP2	14	10	0.5454	86.285	180	26	62	24
J36CP3	2	12.2	0.811773	77.081	130	38	85	23
J36CP3	4	10.1	0.556363	77.081	130	42	70	15
J36CP3	6	10.7	0.624428	77.081	130	37	69	15
J36CP3	8	10.8	0.636155	77.081	130	40	69	16
J36CP3	10	11.2	0.68415	77.081	130	43	83	12
J36CP3	11	16.7	1.521066	77.081	130	45	90	30
J36CP3	12	8	0.349056	77.081	130	31	46	15
J36CP3	13	6.7	0.24483	77.081	130	36	55	20
J36DP1	1	10.8	0.636155	90.085	200	41	80	17
J36DP1	2	8.1	0.357837	90.085	200	34	72	11.5
J36DP1	3	12.4	0.838607	90.085	200	37	75	19
J36DP1	5	10.6	0.612811	90.085	200	40	68	16.5
J36DP1	8	12.6	0.865877	90.085	200	37	77	18
J36DP1	12	8.7	0.412813	90.085	200	44	69	15.5
J36DP1	16	10.9	0.64799	90.085	200	43	81	19
J36DP1	19	7.8	0.331821	90.085	200	28	62	14.5
J36DP1	20	6.8	0.252193	90.085	200	38	54	16
J36DP1	21	7.5	0.306788	90.085	200	39	69	12
J36DP2	2	8.3	0.375726	102.653	250	34	68	13.5
J36DP2	3	6.4	0.223396	102.653	250	31	63	10.5
J36DP2	4	6.1	0.202943	102.653	250	32	70	14

J36DP2	5	8.9	0.432011	102.653	250	32	68	15.5
J36DP2	6	9.6	0.502641	102.653	250	34	82	17
J36DP2	7	8.1	0.357837	102.653	250	37	78	12
J36DP2	11	7.4	0.298661	102.653	250	34	68	14.5
J36DP2	12	12.7	0.879676	102.653	250	38	74	24
J36DP2	13	5.8	0.183473	102.653	250	31	66	10.5
J36DP2	14	10.5	0.601304	102.653	250	31	74	16.5
J36DP2	15	5.9	0.189854	102.653	250	37	55	12.5
J36DP2	16	14.4	1.130941	102.653	250	37	82	26.5
J36DP2	18	16	1.396224	102.653	250	38	81	21
J36DP2	19	6.3	0.216469	102.653	250	35	70	14
J36DP2	22	6	0.196344	102.653	250	30	61	12.5
J36DP2	23	6.9	0.259665	102.653	250	32	64	12.5
J36DP2	24	8	0.349056	102.653	250	27	77	16.5
J36DP3	3	7.5	0.306788	70.897	190	34	74	13.5
J36DP3	6	7.6	0.315023	70.897	190	36	78	14
J36DP3	7	6.6	0.237576	70.897	190	35	75	16
J36DP3	9	11.7	0.746598	70.897	190	37	83	25
J36DP3	11	7.5	0.306788	70.897	190	27	66	15.5
J36DP3	12	10.5	0.601304	70.897	190	43	83	22
J36DP3	13	6.1	0.202943	70.897	190	29	72	10.5
J36DP3	14	7.2	0.282735	70.897	190	36	73	14
J36DP3	15	7	0.267246	70.897	190	40	74	19
J36DP3	16	7.7	0.323368	70.897	190	42	74	18
J36DP4	1	6.6	0.237576	69.947	180	36	60	12
J36DP4	2	6.8	0.252193	69.947	180	31	75	11
J36DP4	3	6.8	0.252193	69.947	180	35	68	12
J36DP4	4	6.7	0.24483	69.947	180	33	75	11
J36DP4	5	6.5	0.230432	69.947	180	39	63	12
J36DP4	6	6.9	0.259665	69.947	180	35	78	13
J36DP4	8	9.9	0.534547	69.947	180	35	79	18
J36DP4	13	9.4	0.481915	69.947	180	41	82	15

J36DP4	17	9.3	0.471716	69.947	180	30	74	15
J36DP4	18	7.2	0.282735	69.947	180	41	72	15
J36DP4	19	10.1	0.556363	69.947	180	39	70	19.5
J36EP1	4	14.9	1.210843	96.337	180	50	77	29
J36EP1	10	14.2	1.099745	96.337	180	59	79	29
J36EP1	11	13.8	1.03866	96.337	180	46	84	28
J36EP2	4	15.1	1.243567	84.312	210	51	77	21
J36EP3	9	12.9	0.9076	83.139	170	36	75	22.5

Table A.4: Tree Characteristics

CFI PLOT	TREE NUMBER	BAGY	A2-A1	THGY	CDGY	DBHGY	AVGA	AVGTH	AVGCD	AVGDBH
J36CP1	12	0.043996	6	3.166667	2.833333	0.366667	47	73.5	30.5	11
J36CP2	1	0.037769	6	1	2.166667	0.25	28	76	35.5	13.85
J36CP2	2	0.015017	6	0.5	1.333333	0.233333	26	53.5	20	5.9
J36CP2	3	0.035078	6	0	1.166667	0.283333	33	63	28.5	11.35
J36CP2	4	0.006499	6	1.166667	-0.83333	0.083333	30	59.5	21.5	7.15
J36CP2	6	0.024179	6	0.833333	1.333333	0.233333	33	61.5	28	9.5
J36CP2	10	0.021889	6	1.166667	-0.83333	0.233333	40	55.5	19.5	8.6
J36CP2	14	0.035596	6	2.166667	0.5	0.366667	23	55.5	22.5	8.9
J36CP3	2	0.036978	6	4.666667	-0.16667	0.3	35	71	23.5	11.3
J36CP3	4	0.019098	6	3.833333	-0.83333	0.183333	39	58.5	17.5	9.55
J36CP3	6	0.023752	6	5.666667	-0.66667	0.216667	34	52	17	10.05
J36CP3	8	0.025707	6	3.666667	-1	0.233333	37	58	19	10.1
J36CP3	10	0.019453	6	5.833333	0.333333	0.166667	40	65.5	11	10.7
J36CP3	11	0.077883	6	3	0	0.466667	42	81	30	15.3
J36CP3	12	0.001445	6	3	-2	0.016667	28	37	21	7.95
J36CP3	13	0.010226	6	3	-0.5	0.15	33	46	21.5	6.25
J36DP1	1	0.030751	6	2.166667	0.333333	0.283333	38	73.5	16	9.95
J36DP1	2	0.008508	6	-1.16667	-0.25	0.1	31	75.5	12.25	7.8

J36DP1	3	0.029779	6	-1.33333	0	0.233333	34	79	19	11.7
J36DP1	5	0.03646	6	-0.33333	0.25	0.35	37	69	15.75	9.55
J36DP1	8	0.053413	6	1.166667	0	0.433333	34	73.5	18	11.3
J36DP1	12	0.024261	6	-1	-0.58333	0.283333	41	72	17.25	7.85
J36DP1	16	0.039196	6	0.166667	1.333333	0.366667	40	80.5	15	9.8
J36DP1	19	0.014499	6	-0.83333	0.083333	0.183333	25	64.5	14.25	7.25
J36DP1	20	0.011453	6	0.833333	0.5	0.166667	35	51.5	14.5	6.3
J36DP1	21	0.010326	6	0	0.333333	0.133333	36	69	11	7.1
J36DP2	2	0.008726	6	0.166667	-0.08333	0.1	31	67.5	13.75	8
J36DP2	3	0.004509	6	-0.5	0.083333	0.066667	28	64.5	10.25	6.2
J36DP2	4	0.002182	6	2.5	0.166667	0.033333	29	62.5	13.5	6
J36DP2	5	0.016698	6	-1.5	0.083333	0.183333	29	72.5	15.25	8.35
J36DP2	6	0.022652	6	0.666667	0.166667	0.233333	31	80	16.5	8.9
J36DP2	7	0.011199	6	1	-0.5	0.133333	34	75	13.5	7.7
J36DP2	11	0.010181	6	-0.33333	0.416667	0.133333	31	69	13.25	7
J36DP2	12	0.044477	6	-1	0	0.35	35	77	24	11.65
J36DP2	13	0.003082	6	0.5	0.25	0.05	28	64.5	9.75	5.65
J36DP2	14	0.026588	6	-0.16667	0.75	0.25	28	74.5	14.25	9.75
J36DP2	15	0.002109	6	-1.16667	-0.25	0.033333	34	58.5	13.25	5.8
J36DP2	16	0.053195	6	-0.66667	0.25	0.366667	34	84	25.75	13.3
J36DP2	18	0.044214	6	-0.66667	0.166667	0.266667	35	83	20.5	15.2
J36DP2	19	0.009572	6	0.166667	0.5	0.15	32	69.5	12.5	5.85
J36DP2	22	0.006218	6	1	0.25	0.1	27	58	11.75	5.7
J36DP2	23	0.011635	6	0.333333	-0.08333	0.166667	29	63	12.75	6.4
J36DP2	24	0.016144	6	1.166667	0.583333	0.2	24	73.5	14.75	7.4
J36DP3	3	0.011535	6	0.833333	0.416667	0.15	31	71.5	12.25	7.05
J36DP3	6	0.012908	6	1.166667	-0.16667	0.166667	33	74.5	14.5	7.1
J36DP3	7	0.007954	6	3.5	0	0.116667	32	64.5	16	6.25
J36DP3	9	0.038905	6	2.166667	0.833333	0.333333	34	76.5	22.5	10.7
J36DP3	11	0.010326	6	0.666667	0.583333	0.133333	24	64	13.75	7.1
J36DP3	12	0.032988	6	2.166667	0.333333	0.316667	40	76.5	21	9.55
J36DP3	13	0.00429	6	1	-0.08333	0.066667	26	69	10.75	5.9

J36DP3	14	0.014399	6	1.166667	0.333333	0.2	33	69.5	13	6.6
J36DP3	15	0.010717	6	1.666667	1.666667	0.15	37	69	14	6.55
J36DP3	16	0.018953	6	0.333333	0.833333	0.25	39	73	15.5	6.95
J36DP4	1	0.015017	6	-0.16667	-0.33333	0.233333	33	60.5	13	5.9
J36DP4	2	0.011453	6	0.666667	-0.5	0.166667	28	73	12.5	6.3
J36DP4	3	0.01039	6	0.166667	0.333333	0.15	32	67.5	11	6.35
J36DP4	4	0.008081	6	0	-0.33333	0.116667	30	75	12	6.35
J36DP4	5	0.006763	6	-0.16667	0.166667	0.1	36	63.5	11.5	6.2
J36DP4	6	0.010553	6	1.166667	0.333333	0.15	32	74.5	12	6.45
J36DP4	8	0.030915	6	0	0.333333	0.316667	32	79	17	8.95
J36DP4	13	0.029188	6	3.666667	0	0.316667	38	71	15	8.45
J36DP4	17	0.032797	6	1.5	0	0.366667	27	69.5	15	8.2
J36DP4	18	0.019625	6	1.166667	0	0.283333	38	68.5	15	6.35
J36DP4	19	0.044286	6	0	0.416667	0.466667	36	70	18.25	8.7
J36EP1	4	0.062643	7	2.285714	-0.14286	0.428571	46.5	69	29.5	13.4
J36EP1	10	0.06283	7	3.714286	0	0.457143	55.5	66	29	12.6
J36EP1	11	0.050644	7	4	-0.57143	0.371429	42.5	70	30	12.5
J36EP2	4	0.031415	7	1.571429	-0.28571	0.2	47.5	71.5	22	14.4
J36EP3	9	0.043757	7	3.428571	0.357143	0.342857	32.5	63	21.25	11.7

Table A.5: Competition Variables

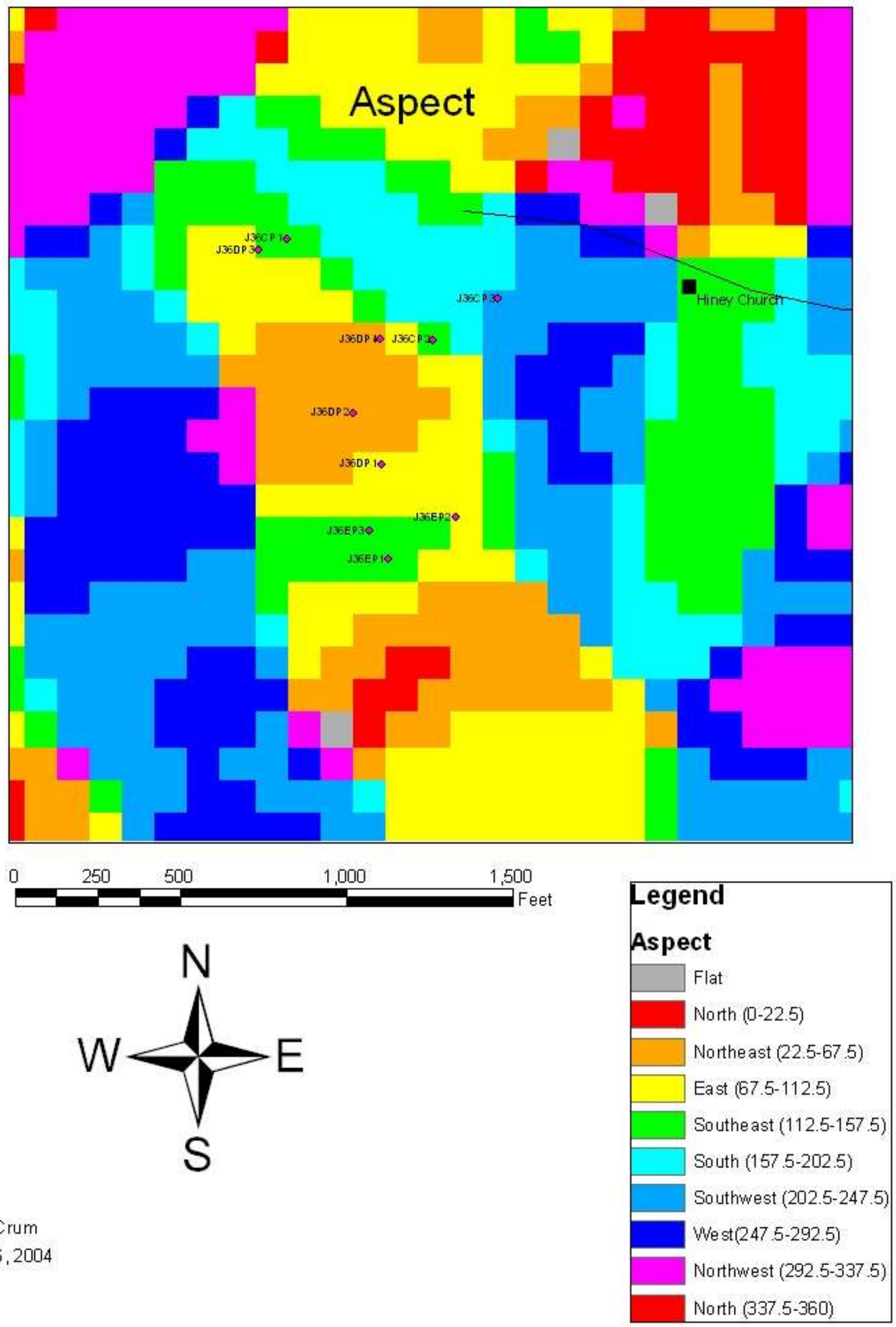
CFI PLOT	TREE NUMBER	BAAGY	TPAGY	AVGBAA	AVGTPA
J36CP1	12	2.266167	1.666667	69.1695	235
J36CP2	1	2.740167	1.666667	78.0645	175
J36CP2	2	2.740167	1.666667	78.0645	175
J36CP2	3	2.740167	1.666667	78.0645	175
J36CP2	4	2.740167	1.666667	78.0645	175
J36CP2	6	2.740167	1.666667	78.0645	175
J36CP2	10	2.740167	1.666667	78.0645	175

J36CP2	14	2.740167	1.666667	78.0645	175
J36CP3	2	1.003	-5	74.072	145
J36CP3	4	1.003	-5	74.072	145
J36CP3	6	1.003	-5	74.072	145
J36CP3	8	1.003	-5	74.072	145
J36CP3	10	1.003	-5	74.072	145
J36CP3	11	1.003	-5	74.072	145
J36CP3	12	1.003	-5	74.072	145
J36CP3	13	1.003	-5	74.072	145
J36DP1	1	2.145333	-3.33333	83.649	210
J36DP1	2	2.145333	-3.33333	83.649	210
J36DP1	3	2.145333	-3.33333	83.649	210
J36DP1	5	2.145333	-3.33333	83.649	210
J36DP1	8	2.145333	-3.33333	83.649	210
J36DP1	12	2.145333	-3.33333	83.649	210
J36DP1	16	2.145333	-3.33333	83.649	210
J36DP1	19	2.145333	-3.33333	83.649	210
J36DP1	20	2.145333	-3.33333	83.649	210
J36DP1	21	2.145333	-3.33333	83.649	210
J36DP2	2	3.617667	1.666667	91.8	245
J36DP2	3	3.617667	1.666667	91.8	245
J36DP2	4	3.617667	1.666667	91.8	245
J36DP2	5	3.617667	1.666667	91.8	245
J36DP2	6	3.617667	1.666667	91.8	245
J36DP2	7	3.617667	1.666667	91.8	245
J36DP2	11	3.617667	1.666667	91.8	245
J36DP2	12	3.617667	1.666667	91.8	245
J36DP2	13	3.617667	1.666667	91.8	245
J36DP2	14	3.617667	1.666667	91.8	245
J36DP2	15	3.617667	1.666667	91.8	245
J36DP2	16	3.617667	1.666667	91.8	245
J36DP2	18	3.617667	1.666667	91.8	245

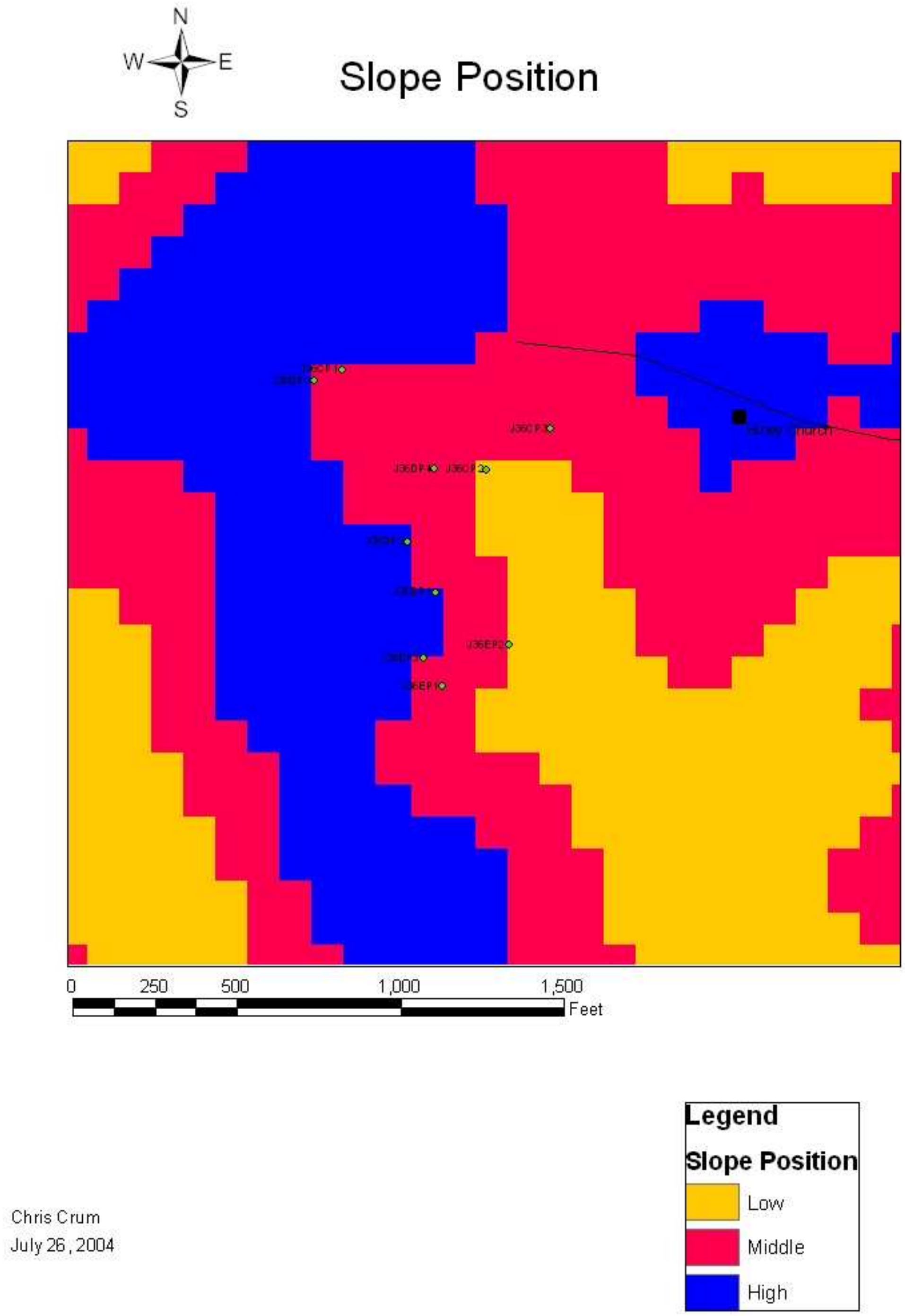
J36DP2	19	3.617667	1.666667	91.8	245
J36DP2	22	3.617667	1.666667	91.8	245
J36DP2	23	3.617667	1.666667	91.8	245
J36DP2	24	3.617667	1.666667	91.8	245
J36DP3	3	2.649667	1.666667	62.948	185
J36DP3	6	2.649667	1.666667	62.948	185
J36DP3	7	2.649667	1.666667	62.948	185
J36DP3	9	2.649667	1.666667	62.948	185
J36DP3	11	2.649667	1.666667	62.948	185
J36DP3	12	2.649667	1.666667	62.948	185
J36DP3	13	2.649667	1.666667	62.948	185
J36DP3	14	2.649667	1.666667	62.948	185
J36DP3	15	2.649667	1.666667	62.948	185
J36DP3	16	2.649667	1.666667	62.948	185
J36DP4	1	1.684833	-1.66667	64.8925	185
J36DP4	2	1.684833	-1.66667	64.8925	185
J36DP4	3	1.684833	-1.66667	64.8925	185
J36DP4	4	1.684833	-1.66667	64.8925	185
J36DP4	5	1.684833	-1.66667	64.8925	185
J36DP4	6	1.684833	-1.66667	64.8925	185
J36DP4	8	1.684833	-1.66667	64.8925	185
J36DP4	13	1.684833	-1.66667	64.8925	185
J36DP4	17	1.684833	-1.66667	64.8925	185
J36DP4	18	1.684833	-1.66667	64.8925	185
J36DP4	19	1.684833	-1.66667	64.8925	185
J36EP1	4	2.987286	0	85.8815	180
J36EP1	10	2.987286	0	85.8815	180
J36EP1	11	2.987286	0	85.8815	180
J36EP2	4	2.831571	5.714286	74.4015	190
J36EP3	9	1.819571	-1.42857	76.7705	175

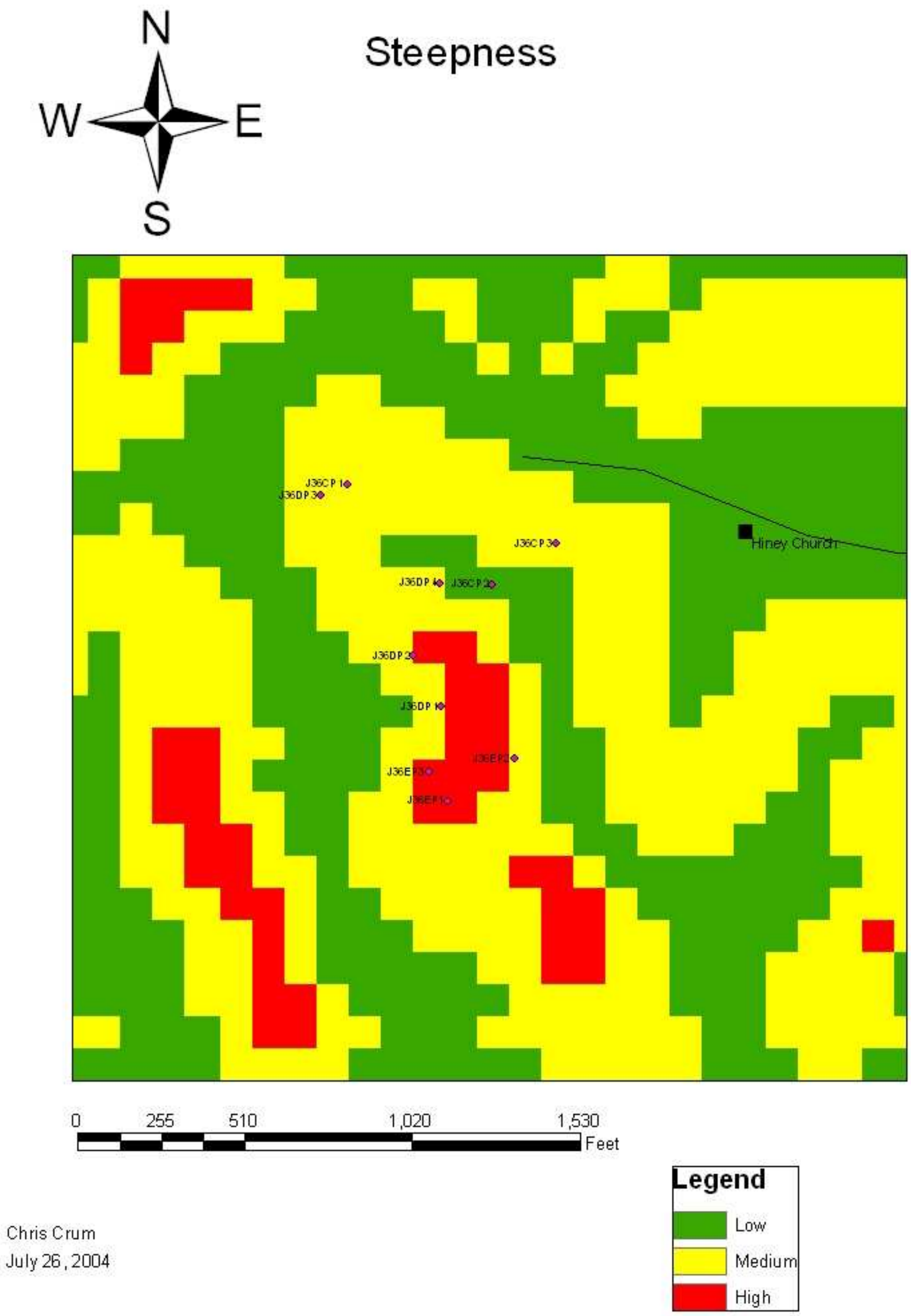
APPENDIX B

GIS MAPS



Chris Crum
July 26, 2004


N
W
E
S
Slope Position
0
250
500
1,000
1,500
Feet
Legend
Slope Position
Low
Middle
High
Chris Crum
July 26, 2004



Steepness
N
W
E
S
J36CP1
J36DP3
J36CP3
J36DP4
J36CP2
J36DP2
J36DP1
J36EP3
Hiney Church
0
255
510
1,020
1,530
Feet
Legend
Low
Medium
High
Chris Crum
July 26, 2004

APPENDIX C

GRAPHS

Figure A.1: Basal Area Growth per Year Plotted Against Topographic Factors

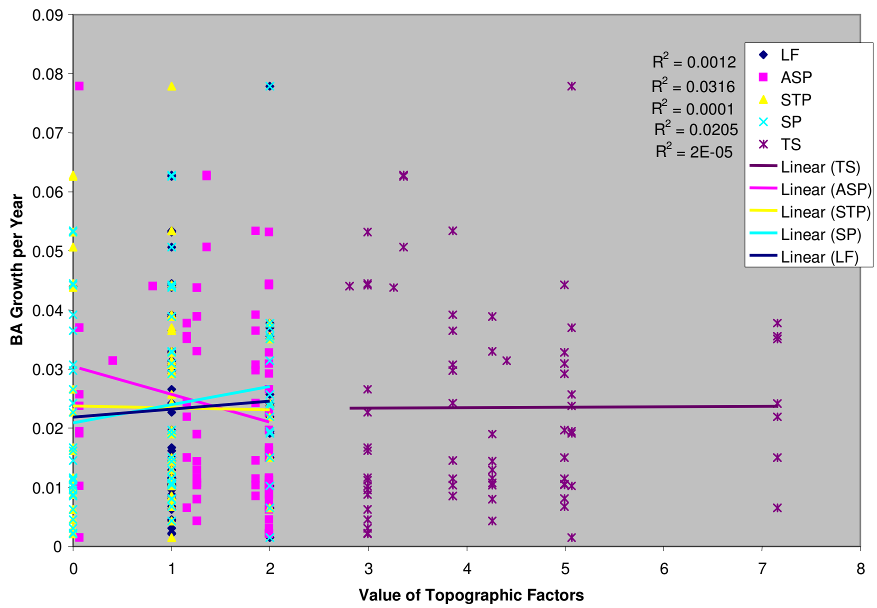


Figure A.2: Basal Area Growth per Year Plotted Against Basal Area per Acre and Trees per Acre

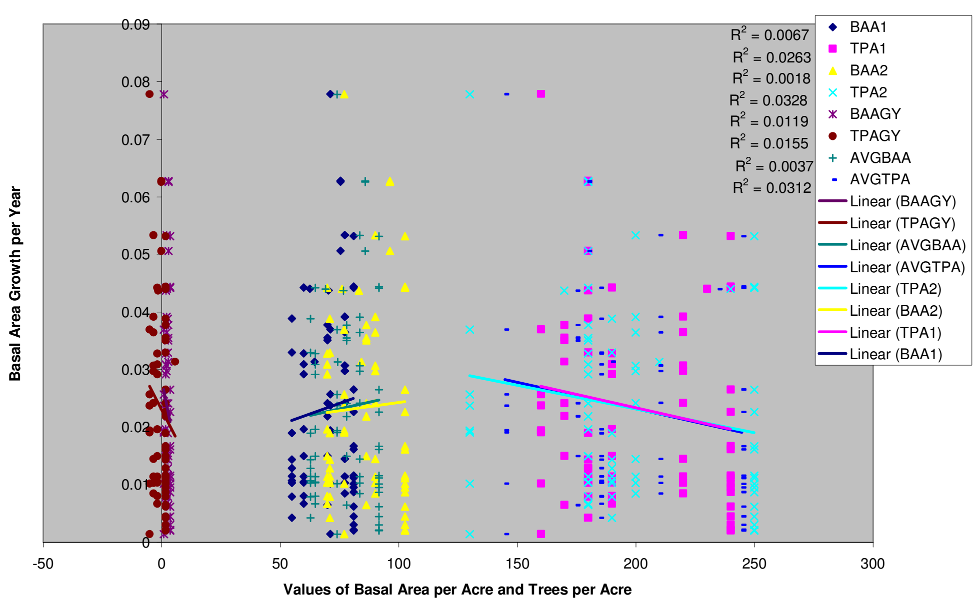


Figure A.3: Change in Basal Area per Acre per Year Versus Change in Trees per Acre per Year

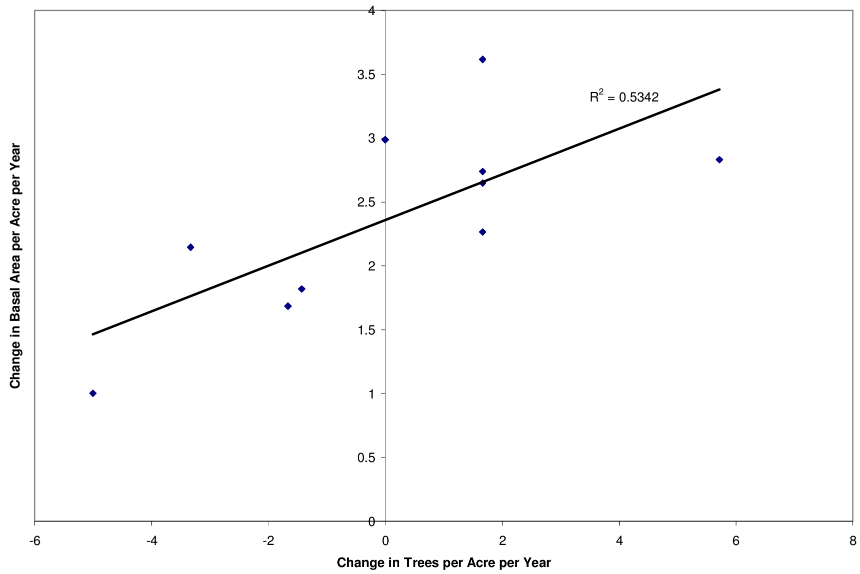


Figure A.4: Basal Area Growth per Year Plotted Against Average Age

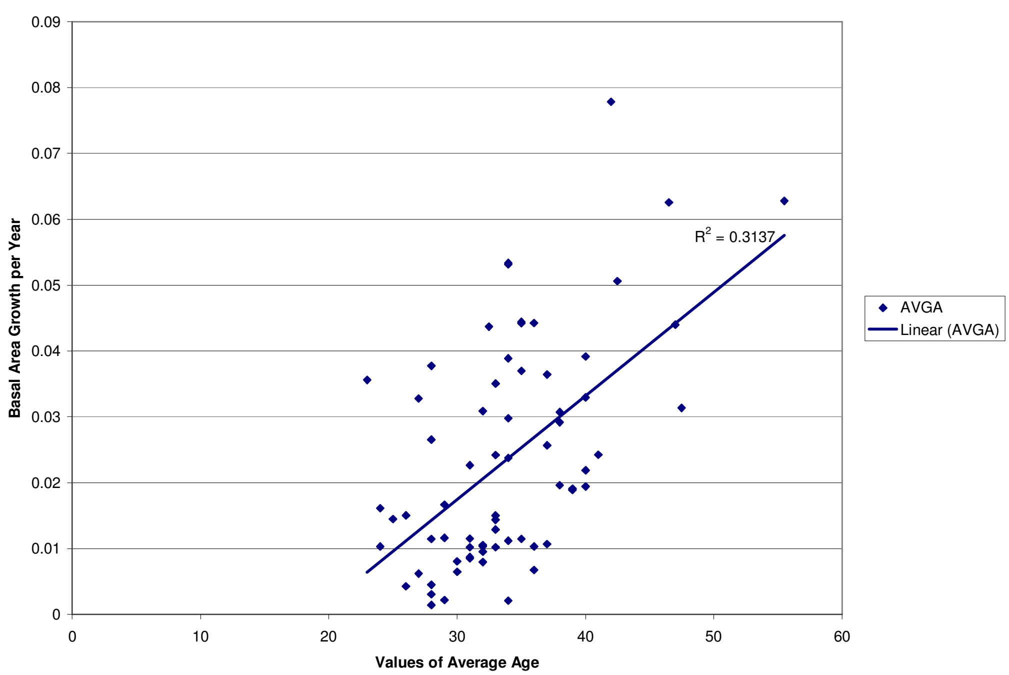


Figure A.5: Basal Area Growth per Year Plotted Against Average Total Height

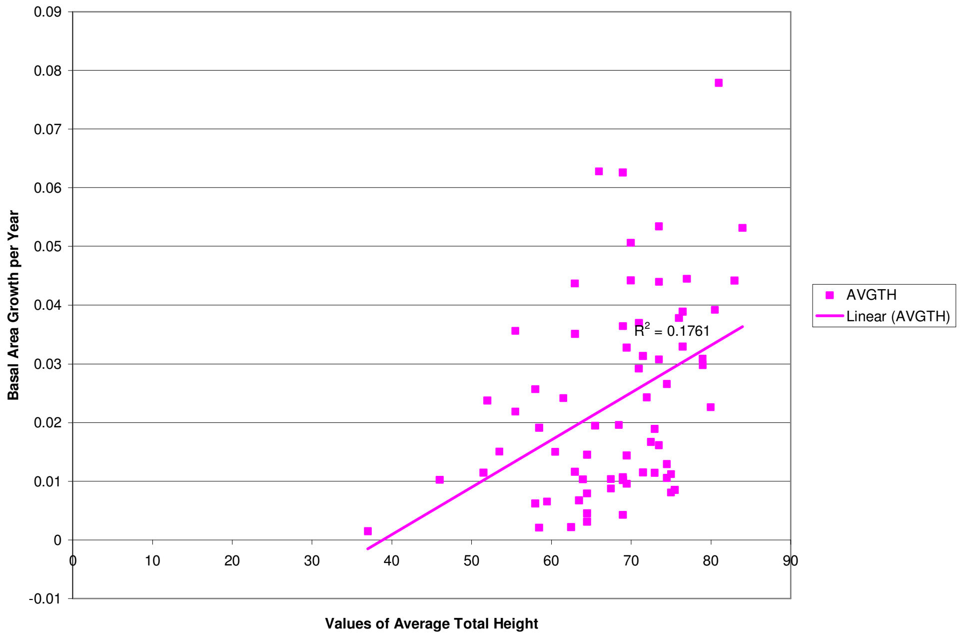


Figure A.6: Basal Area Growth per Year Plotted Against Average DBH

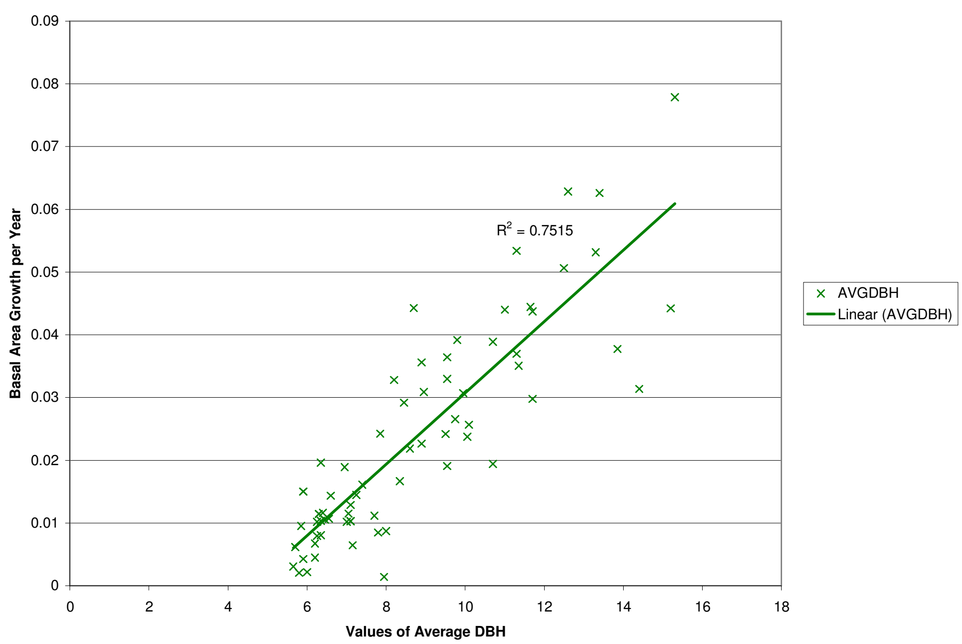


Figure A.7: Basal Area Growth per Year Plotted Against Average Crown Diameter

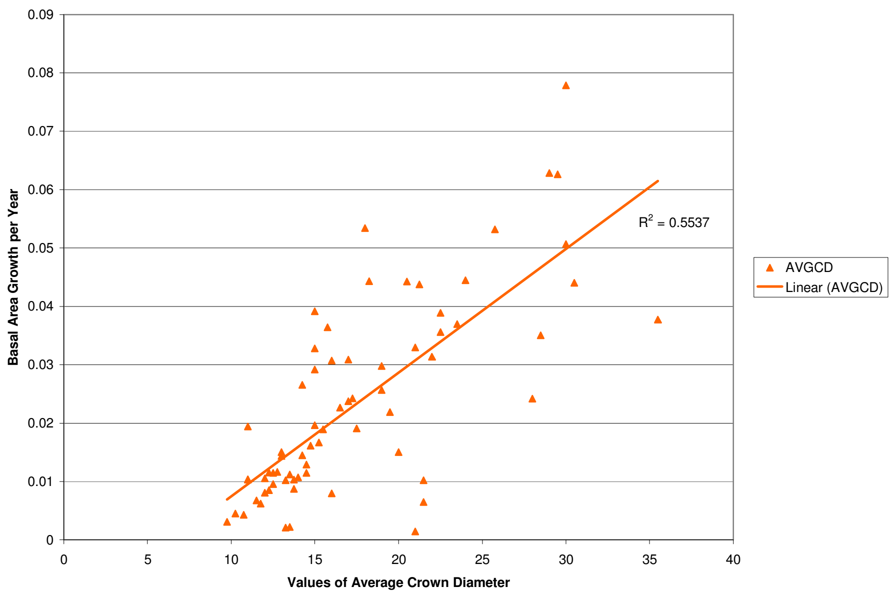


Figure A.8: Basal Area Growth per Year Plotted Against Change in Tree Characteristics per Year

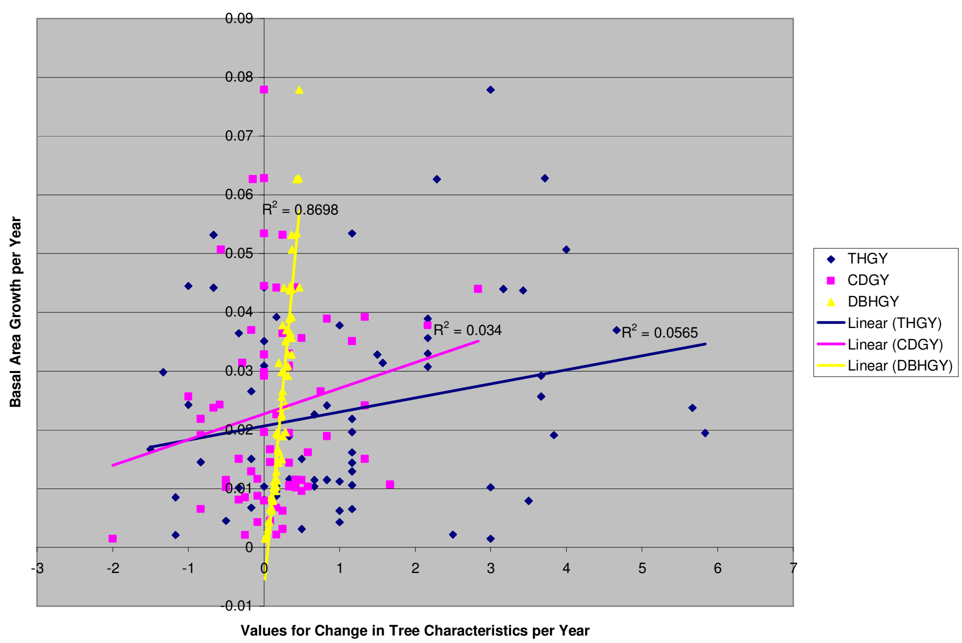


Figure A.9: Basal Area Growth per Year Plotted Against Initial Tree Characteristic Measurements

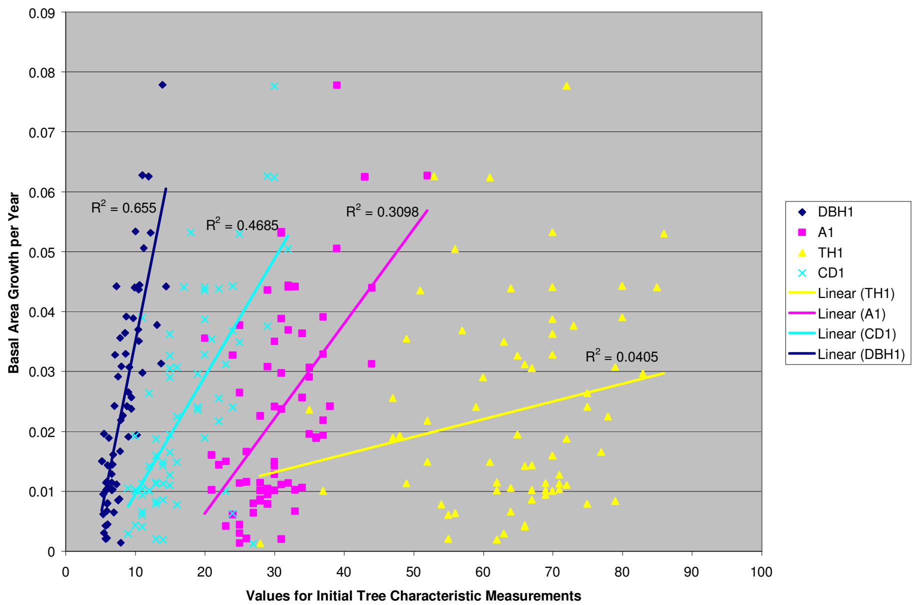


Figure A.10: Basal Area Growth per Year Plotted Against Final Tree Characteristic Measurements

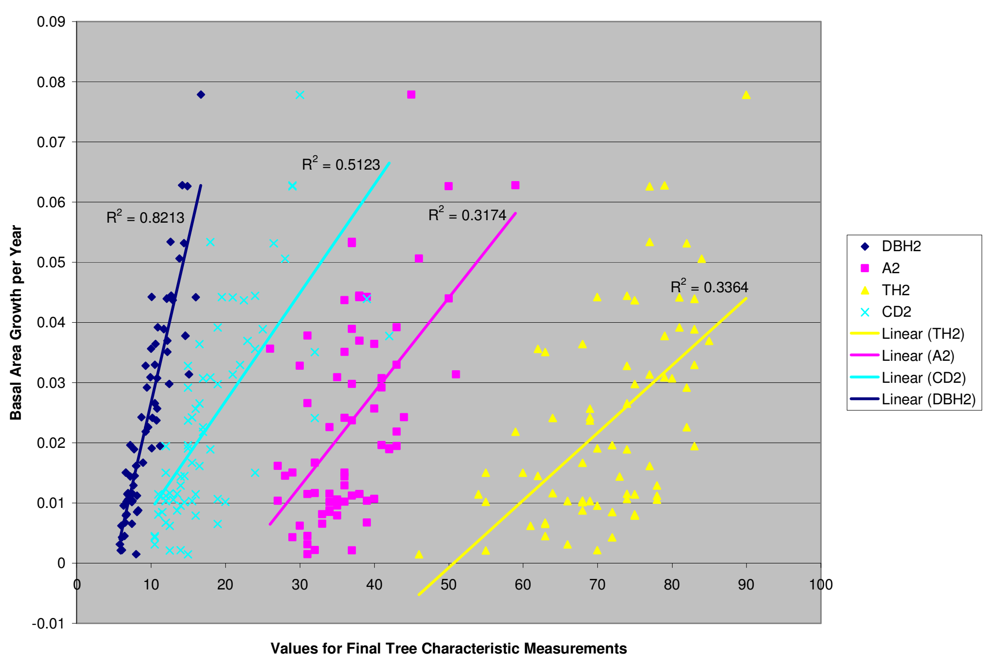


Figure A.11: Basal Area Growth per Year Plotted Against Residuals for Multiple Linear Regression Using the Averages of the Tree Characteristics

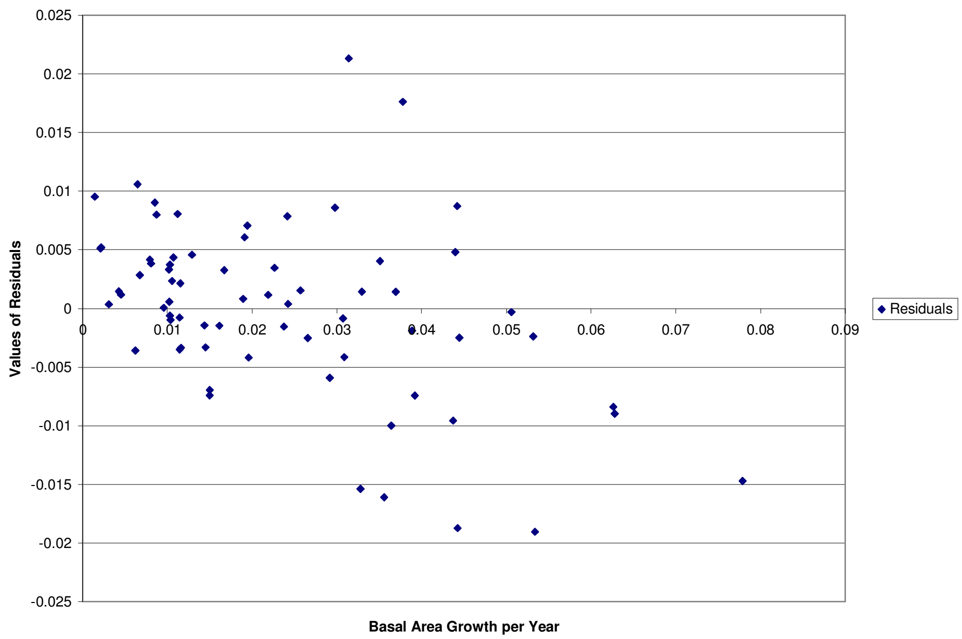


Figure A.12: Average DBH Plotted Against Residuals for Multiple Linear Regression Using the Averages of the Tree Characteristics

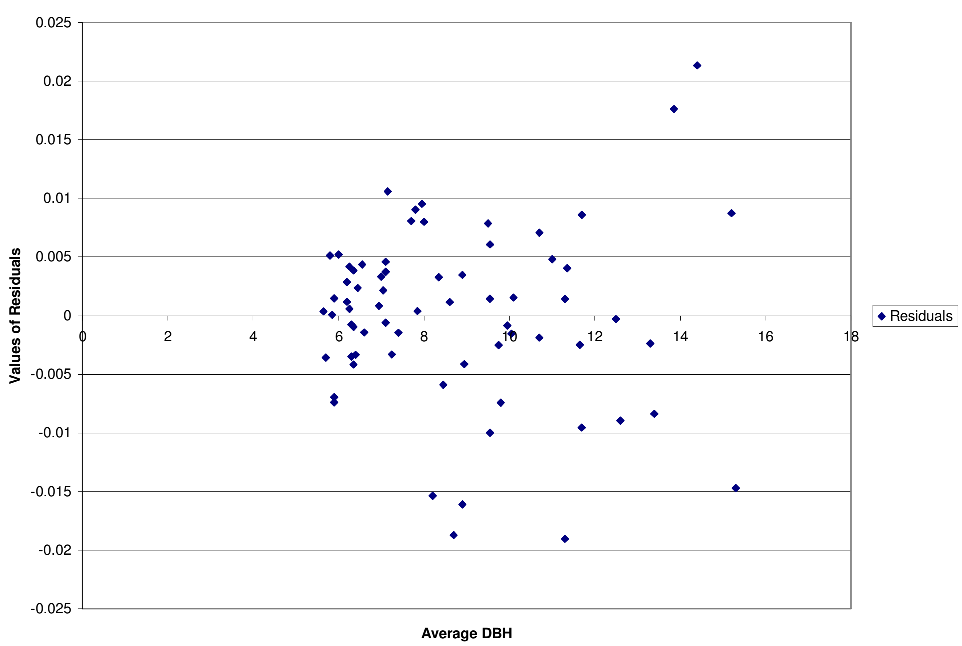


Figure A.13: Average Crown Diameter Plotted Against Residuals for Multiple Linear Regression Using the Averages of the Tree Characteristics

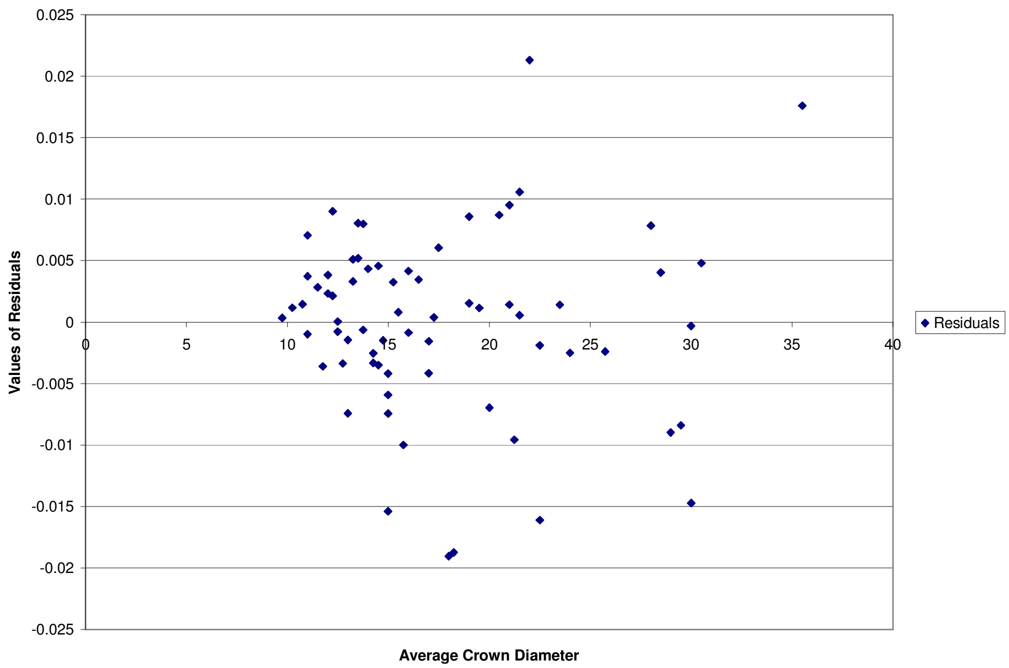


Figure A.14: Average Age Plotted Against Residuals for Multiple Linear Regression Using the Averages of the Tree Characteristics

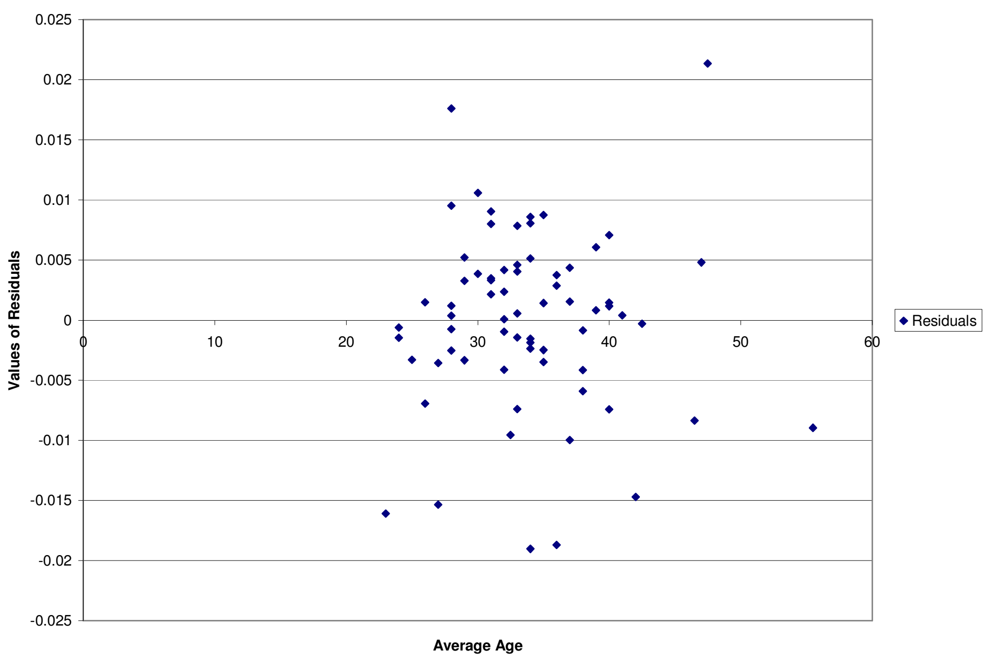
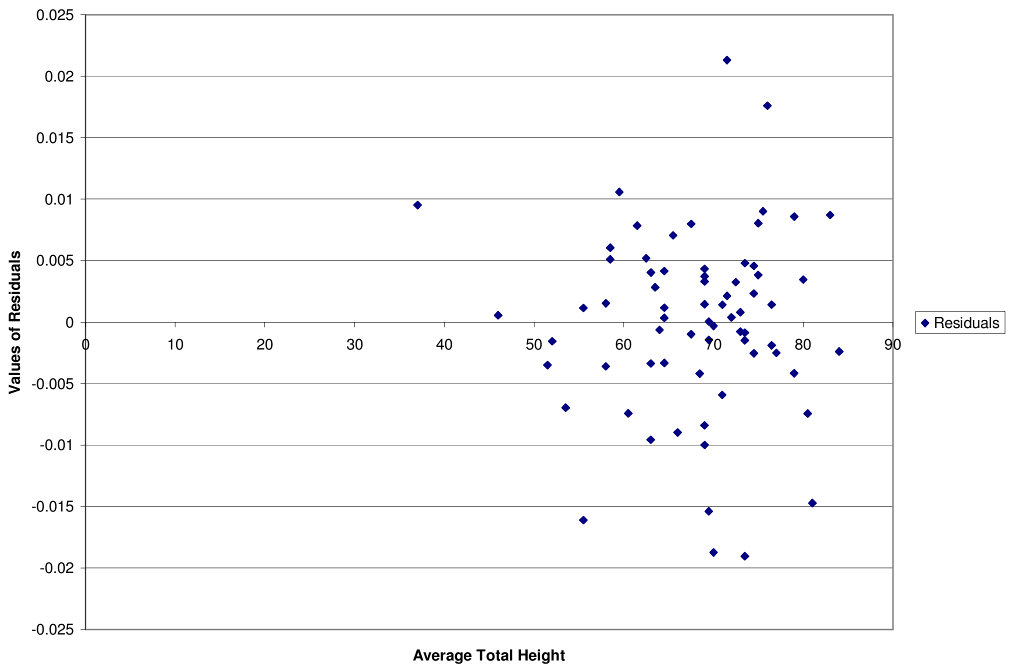


Figure A.15: Average Total Height Plotted Against Residuals for Multiple Linear Regression Using the Averages of the Tree Characteristics



APPENDIX D

SAS OUTPUT

Aspect
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00061581	0.00061581	2.19	0.1439
Error	67	0.01887	0.00028165		
Corrected Total	68	0.01949			

Root MSE	0.01678	R-Square	0.0316
Dependent Mean	0.02348	Adj R-Sq	0.0171
Coeff Var	71.48381		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.03046	0.00514	5.93	<.0001
ASP	ASP	1	-0.00472	0.00319	-1.48	0.1439

Slope Position
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00039851	0.00039851	1.40	0.2411
Error	67	0.01909	0.00028489		
Corrected Total	68	0.01949			

Root MSE	0.01688	R-Square	0.0205
Dependent Mean	0.02348	Adj R-Sq	0.0058
Coeff Var	71.89422		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02086	0.00300	6.95	<.0001
SLP	SLP	1	0.00311	0.00263	1.18	0.2411

Steepness
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00000290	0.00000290	0.01	0.9207
Error	67	0.01948	0.00029080		
Corrected Total	68	0.01949			

Root MSE	0.01705	R-Square	0.0001
Dependent Mean	0.02348	Adj R-Sq	-0.0148
Coeff Var	72.63543		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02375	0.00340	6.99	<.0001
STP	STP	1	-0.00033966	0.00340	-0.10	0.9207

Landform
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00002433	0.00002433	0.08	0.7732
Error	67	0.01946	0.00029048		
Corrected Total	68	0.01949			

Root MSE	0.01704	R-Square	0.0012
Dependent Mean	0.02348	Adj R-Sq	-0.0137
Coeff Var	72.59547		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02184	0.00601	3.63	0.0005
LF	LF	1	0.00136	0.00470	0.29	0.7732

Total Site
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	4.700804E-7	4.700804E-7	0.00	0.9681
Error	67	0.01949	0.00029083		
Corrected Total	68	0.01949			

Root MSE	0.01705	R-Square	0.0000
Dependent Mean	0.02348	Adj R-Sq	-0.0149
Coeff Var	72.63996		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02319	0.00751	3.09	0.0029
TS	TS	1	0.00006721	0.00167	0.04	0.9681

Change in Basal Area per Acre per Year
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00023100	0.00023100	0.80	0.3732
Error	67	0.01926	0.00028739		
Corrected Total	68	0.01949			

Root MSE	0.01695	R-Square	0.0119
Dependent Mean	0.02348	Adj R-Sq	-0.0029
Coeff Var	72.20900		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02882	0.00630	4.57	<.0001
BAAGY	BAAGY	1	-0.00216	0.00241	-0.90	0.3732

Change in Trees per Acre per Year
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00030274	0.00030274	1.06	0.3075
Error	67	0.01918	0.00028632		
Corrected Total	68	0.01949			

Root MSE	0.01692	R-Square	0.0155
Dependent Mean	0.02348	Adj R-Sq	0.0008
Coeff Var	72.07435		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.02314	0.00206	11.21	<.0001
TPAGY	TPAGY	1	-0.00081006	0.00078779	-1.03	0.3075

Change in Basal Area per Acre per Year versus Change in Trees per Acre per Year
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAAGY

Number of Observations Read	10
Number of Observations Used	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	2.70751	2.70751	9.18	0.0163
Error	8	2.36066	0.29508		
Corrected Total	9	5.06816			

Root MSE	0.54321	R-Square	0.5342
Dependent Mean	2.37453	Adj R-Sq	0.4760
Coeff Var	22.87677		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	2.35749	0.17187	13.72	<.0001
TPAGY	TPAGY	1	0.17889	0.05906	3.03	0.0163

Average Basal Area per Acre
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00007202	0.00007202	0.25	0.6197
Error	67	0.01941	0.00028976		
Corrected Total	68	0.01949			

Root MSE	0.01702	R-Square	0.0037
Dependent Mean	0.02348	Adj R-Sq	-0.0112
Coeff Var	72.50647		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.01616	0.01482	1.09	0.2796
AVGBAA	AVGBAA	1	0.00009426	0.00018907	0.50	0.6197

Average Trees per Acre
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00060770	0.00060770	2.16	0.1466
Error	67	0.01888	0.00028177		
Corrected Total	68	0.01949			

Root MSE	0.01679	R-Square	0.0312
Dependent Mean	0.02348	Adj R-Sq	0.0167
Coeff Var	71.49918		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.04173	0.01259	3.31	0.0015
AVGTPA	AVGTPA	1	-0.00009210	0.00006271	-1.47	0.1466

Average Age
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00611	0.00611	30.63	<.0001
Error	67	0.01337	0.00019959		
Corrected Total	68	0.01949			

Root MSE	0.01413	R-Square	0.3137
Dependent Mean	0.02348	Adj R-Sq	0.3035
Coeff Var	60.17617		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.02982	0.00978	-3.05	0.0033
AVGA	AVGA	1	0.00158	0.00028473	5.53	<.0001

Average Total Height
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00343	0.00343	14.32	0.0003
Error	67	0.01605	0.00023962		
Corrected Total	68	0.01949			

Root MSE	0.01548	R-Square	0.1761
Dependent Mean	0.02348	Adj R-Sq	0.1638
Coeff Var	65.93478		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.03132	0.01460	-2.15	0.0355
AVGTH	AVGTH	1	0.00080605	0.00021299	3.78	0.0003

Average Crown Diameter
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01079	0.01079	83.12	<.0001
Error	67	0.00870	0.00012980		
Corrected Total	68	0.01949			

Root MSE	0.01139	R-Square	0.5537
Dependent Mean	0.02348	Adj R-Sq	0.5470
Coeff Var	48.52808		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.01372	0.00430	-3.19	0.0022
AVGCD	AVGCD	1	0.00212	0.00023230	9.12	<.0001

Average DBH
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read	69
Number of Observations Used	69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01464	0.01464	202.58	<.0001
Error	67	0.00484	0.00007228		
Corrected Total	68	0.01949			

Root MSE	0.00850	R-Square	0.7515
Dependent Mean	0.02348	Adj R-Sq	0.7478
Coeff Var	36.21407		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.02608	0.00363	-7.19	<.0001
AVGDBH	AVGDBH	1	0.00569	0.00039944	14.23	<.0001

Average Total Height Power Regression BAGY = b0*AVGTH^b1
The SAS System

The NLIN Procedure
Dependent Variable BAGY
Method: Gauss-Newton

Iterative Phase

Iter	b0	b1	Sum of Squares
0	9E-8	2.8797	0.0181
1	4.683E-8	3.0657	0.0163
2	5.538E-8	3.0559	0.0156
3	5.586E-8	3.0553	0.0156
4	5.589E-8	3.0551	0.0156

NOTE: Convergence criterion met.

Estimation Summary

Method	Gauss-Newton
Iterations	4
R	3.491E-6
PPC(b1)	7.514E-6
RPC(b1)	0.000039
Object	1.481E-9
Objective	0.015624
Observations Read	69
Observations Used	69
Observations Missing	0

NOTE: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	2	0.0419	0.0209	89.82	<.0001
Error	67	0.0156	0.000233		
Uncorrected Total	69	0.0575			

Approximate Correlation Matrix

	b0	b1
b0	1.0000000	-0.9997666
b1	-0.9997666	1.0000000

Average Total Height Without beta 0 BAGY = AVGTH^b1
The SAS System

The NLIN Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	1	0.0345	0.0345	101.67	<.0001
Error	68	0.0231	0.000339		
Uncorrected Total	69	0.0575			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
b1	-0.9032	0.0234	-0.9499	-0.8565

Approximate Correlation Matrix

	b1
b1	1.0000000

Tree Characteristics Multiple Linear Regression
The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: BAGY

Number of Observations Read 69
Number of Observations Used 69

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.01569	0.00392	66.18	<.0001
Error	64	0.00379	0.00005928		
Corrected Total	68	0.01949			

Root MSE	0.00770	R-Square	0.8053
Dependent Mean	0.02348	Adj R-Sq	0.7931
Coeff Var	32.79536		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	-0.05627	0.00902	-6.24	<.0001
AVGDBH	AVGDBH	1	0.00333	0.00068595	4.85	<.0001
AVGCD	AVGCD	1	0.00080777	0.00026379	3.06	0.0032
AVGA	AVGA	1	0.00040865	0.00018142	2.25	0.0277
AVGTH	AVGTH	1	0.00033452	0.00012498	2.68	0.0094