AN ASSESSMENT OF THE WHOLE TREE WEIGHT, WOOD DENSITY, AND SPECIFIC GRAVITY OF FOUR SPECIES GROUPS IN WASHINGTON COUNTY, MISSOURI

A Thesis

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In Partial Fulfillment

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Master of Science

By

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The undersigned, appointed by the dean of the Graduate School,

have examined the Thesis entitled:

AN ASSESSMENT OF THE WHOLE TREE WEIGHT, WOOD DENSITY, AND SPECIFIC GRAVITY OF FOUR SPECIES GROUPS IN WASHINGTON COUNTY, MISSOURI

Presented by Charles Daniel Keating

A candidate for the degree of

Master of Science

And hereby certify that, in their opinion, it is worthy of acceptance.

David R. Larsen, PhD

John P. Dwyer, PhD

Randall J. Miles, PhD

Dedication

To my wonderful and amazing wife, Ashley, this would not have been possible without your love and support. Thank you for always being there for me, for believing in me when I doubt my abilities, and for keeping me motivated throughout all of this. I love you very much and I look forward to the journey which life has in store for us.

To my son, Matthew Garrett, you are my greatest creation and I love you very much. Your birth has impacted my way of thinking more than you will ever know and, while I owe my success to many, you were my true motivation for finishing this project. I look forward to raising you with your mother and, while it makes me sad to think of you growing up and leaving us one day, I also look forward to watching you become a man.

To Dale and Becky Carlson, for without their love, support, and belief in my abilities I would never have attempted furthering my education after high school, let alone making an attempt at earning my Master's degree. I love you both very much.

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Abstract

New methods of scaling logs by weight are becoming more prevalent in the Ozark forests of Missouri. In 2009, a major weather event known as a derecho downed millions of board feet of timber in Missouri and the ensuing salvage harvest following the event necessitated the need for a faster method of scaling logs at area sawmills. It is now common in Missouri for sawmills to assume that a green board foot (bf) of oak (*Quercus spp.*) will weigh approximately 12 pounds (lbs.). This study focuses on a review of the 12 lb./bf. rule to see if the method is accurately estimating board foot volumes in logs and if not, to see whether it is over or underestimating the volumes. Four species groups were selected for harvest; white oak (*Quercus alba*), black oak (*Quercus velutina*), post oak (*Quercus stellata*), and hickories (*Carya spp.*) which were not separated into specific species. Of these species groups, 220 trees were selected for harvest and felled following the collection of the diameter (in.), total height (ft.), and crown height (ft.). Upon felling, the weights of each individual specimen were collected through the use of a load cell equipped front end loader. The total weight of the trees were collected prior to bucking and followed with the collection of the weight of the merchantable portion of the stem alone, without the tree top, and the weights of any sawlogs bucked from the merchantable stem. The data collected were used to produce averages of weight per board foot that are species specific to some of Missouri's oaks species and hickories and that will allow for better estimation of board feet volume at the sawmill.

CHAPTER 1: INTRODUCTION

Background

Weight and Volume Estimation

Gaining an accurate estimate of the potential yield from a stand of timber is exceedingly important to landowners, forest managers and researchers, and to the forest products industry. Many methods currently exist that aid in the estimation of volume for the whole tree and for the merchantable stems and sawlogs contained within the whole tree. Over the years the most common forest measurements, and thereby the most common measurements of forest productivity, have been the board foot (bf), the cubic foot (ft^3), and the cord (1 cord = 4'x4'x8' =128 ft^3) (Blackmon and Ralston, 1968). Being able to estimate the volume of wood, whether in board feet, cubic feet, or cords, can provide another valuable measurement; the weight of the log or logs in question. This is an extremely important factor to those involved in the transport of harvested sawlogs.

For example, log truck drivers need to know an estimate of log weights to ensure they are not overtaxing their equipment or hauling more weight that allowable by law on public highways (Patterson and Wiant, 1993). Loggers in the Pacific Northwest need to be able to estimate the weight of logs quickly so that they can cut felled trees into lengths that will not surpass the load limits of the aerial cable systems or the yarder (Mann and Lysons, 1972). Helicopter logging operations cannot haul more weight than the capabilities of the aircraft but, due to the high cost of such type of logging operation, they also cannot afford to carry less weight than that required to be cost effective (Patterson and Wiant, 1993). In all of these examples, an estimate of the board-feet contained within the log would not yield an estimate of the log's weight. An incorrect estimation of weight in these instances could lead to something as small as an overweight citation from a Department of Transportation official, or to a disaster such as the loss of an aircraft.

Improved Utilization of Timber Resources

The timber and forest products industries are becoming increasingly attentive to ensuring efficient resource utilization. Increased importance has been placed on sawmills to efficiently produce lumber from sawlogs (Wade *et al.*, 1992). In 1979, Craft and Baumgras advocated for the utilization of residues and whole trees for forest products (fuelwood, mine timbers, pulp, *etc.*) as a way to entice private landowners into removing smaller, undesirable stock in competition with the quality timber on their land. Research by Craft (1976) in West Virginia showed that leaving behind the tops and limbs from merchantable sawtimber on just one acre of timber left 33.3 tons of forest residues behind that went unused.

The idea of whole tree harvest – using all portions of the tree (tops, limbs, the merchantable stem, bark, *etc.*) instead of simply sawing the sawlogs produced by the tree into lumber – is gaining more attention as saw and paper mills attempt to reduce overhead in order to cope with increased operating costs (fuel, electricity, *etc.*). Utilization practices have evolved and trees are now a multi-product commodity with veneers, chips, sawdust, and lumber all being marketed from the same tree (Hanks, 1977). Advances in saw and paper mill efficiency and improved usage of residues reduce the amount of raw materials initially required for product manufacturing (Youngquist and Hamilton, 2000). These increases in harvesting and processing efficiency have led to a change in the way forest residues (residues created at the harvest site such as tree tops and limbs) and forest product residues (residues created at the mill such as sawdust, log slabs, and bark) are viewed.

Residues from the production of lumber, paper and other forest products that were once considered waste are now seen as an energy source with the potential to offset or reduce operating costs. For example, in the present day's lumber and paper mills sawdust, bark and wood defects that cannot be used to produce lumber or pulped for paper are now burned to produce energy to offset the cost of electricity. Slabs from the sides of logs and bark removed prior to sawing and pulping are now also burned as fuel for energy or sold to be used in another forest product such as the production of charcoal. In some instances, the residues produced by sawmills may be utilized in the production of manufactured forest products such as plywood, medium-density fiberboards (MDF), and oriented strand board (OSB) (Bowyer *et al.,* 2007).

Technology is also playing a major role in increased sawmill efficiency. Modern sawmills are vastly more technical than those of the past and benefit from automation and computer controls and scanners that increase production rates (Bowyer *et al.,* 2007). Many sawmills now utilize band-style saw blades that are thinner and produce a smaller "kerf", or width of the cut made by the saw blade, and less sawdust leaving more useable wood for lumber production. Nevertheless, many hardwood sawmills still rely on circular saws, or headrigs, due to the reduced cost associated with circular saw maintenance compared to that of band-style saws (Steele *et al.,* 1991).

Log Scaling and Volume Estimation

Log scales are a common method of estimating the amount of board feet contained within a sawlog and are based upon the diameter inside the bark of the small end of the log and the overall length of the log. However, log scales merely estimate the lumber yield of a log and not the log's actual wood content (Mann and Lysons, 1972). Another method of quantifying harvest yields is to estimate the cubic foot (ft^3) volume of the wood contained within the tree stem. According to Hanks (1977), after much time, the cubic foot is beginning to be acknowledged favorably in the forest products industry. Estimations of cubic volume are usually made using formulae by Smalian, Huber, or Newton but each formula has caveats that can lead to erroneous estimates (Husch *et al.*, 2003).

When estimating board feet the most commonly encountered log scales in the United States are Doyle, Scribner, and International one-quarter inch (¼") (Husch *et al.*, 2003). International ¼" provides the most accurate estimate of board feet of the three logs scales utilized and is the only scale that accounts for taper of the merchantable stem and for saw kerf (Bond, 1999). While these three are the most common, a multitude of different log scaling methods exist in North America. Hundreds of log scales have been developed since the 1800s (Jones and Daniels, 2012), many of which are the same scale but are referred to by regional or local vernaculars making them appear to be entirely different scales. In fact, so many different scales exist that one researcher was able to compile approximately 95 different log scales in the United States and Canada (Freese, 1973). Many of these scaling methods are highly regionalized and will not work well in areas outside that which they were designed for (Spelter, 2003). Using these log scales may also be expensive in terms of labor and time requirements to scale the actual logs.

Some of these scaling methods are recent and were developed by forestry researchers and forest product companies. Most, however, are aged and were designed during a time when the timber harvested and the technologies in use were very different from modern forests and harvesting technologies. Today's timber harvests are yielding lumber from second growth forests where smaller timber diameters are the new normal while volumes and board feet are lessened (Spelter, 2004). Average log diameters have decreased since the early 1900s, and it has become more expensive for sawmills to scale the increased number of smaller-diameter logs compared to the times when log diameters were greater in size (Daniels, 2005). Nonetheless, these smaller diameter trees are being processed using technology that is more advanced and can remove the merchantable product from the log in a more efficient manner with less forest product residues (Spelter, 2003).

Weight Scaling

Weight scaling is another method of buying sawlogs that has gained more attention in recent decades. Researchers first began investigating the purchase of sawlogs via weight in the southeastern United States during the 1950s and 1960s for Southern pine species found within the region (Daniels, 2005). Then, in the late 2000's and following pressures within the forest products industry, a nationwide push for marketing wood on a weight basis began (Goerndt *et al.*, 2014). While weight scaling is usually reserved for purchasing softwoods, many sawmills and forestry researchers are studying the purchase of hardwoods by weight and some sawmills are already buying hardwood logs based on weight (Adams, 1971). Weight scaling is attractive to sawmills because it encourages timber harvesters and landowners to expedite the delivery of harvested sawlogs to the mill. Sawmills favor fresh cut sawlogs over air-dried (AD) logs that may have increased stain, decay, and insect damage (Bond, 1999).

While this is not a new method of timber purchasing, it has become increasingly popular since it allows for a much faster determination of estimated board foot or cubic foot volumes. In most instances, trucks loaded with sawlogs are weighed upon reaching the mill to obtain a total weight. The trucks are subsequently off loaded and the truck that delivered the load is then weighed again empty as it exits the mill (Mercker and Taylor, 2012). The difference in weight is the total weight of the logs the truck delivered to the mill and is usually recorded in tons (1 ton = 2,000 lbs. or 907.18 kilograms (kg.)).

The total weight of the sawlogs is then divided by a predetermined factor of weight per board foot (usually lbs. per board foot in the United States) or tons per one-thousand board feet (tons/MBF). This can be a species specific value or an overall average of all species found within delivery range of the mill in instances where mixed hardwoods or softwoods loads are being delivered to the sawmill (Myers *et al.* 1976). This factor is usually based upon the weight of the logs in green condition and, because weights vary greatly from region to region, on the averaged weights of the regional timber species available. Dividing the total weight by the factor the mill decides yields an estimate of the board or cubic feet contained in that particular load of sawlogs. This information is used to estimate expected outputs from the mill and as a method for determining the amount of money to pay the logging company that harvested and delivered the logs.

Weight scaling is more commonly used in paper mills and other industries (charcoal, pelletized fuel wood, *etc*.) where all logs will be chipped and either pulped or used to make other products following purchase. Sawlog quality is less important to these industries. The hardwood timber industry has been reluctant to adopt weight scaling, as weight scaling cannot account for the quality (clearness of wood, straightness of grain, *etc*.) of sawlogs (Daniels, 2005). In most cases, weight scaling would not be advantageous to a hardwood lumber mill as of yet. No current method of weight scaling exists that can account for wood and log quality in order to aid in the purchase of the high quality sawlogs necessary for the production of quality-dependent forest products such as lumber or staves to be used in cooperage. Nonetheless, it is still utilized in some hardwood mills.

Weight Scaling in Missouri Sawmills

Recently some Missouri sawmills have begun to forgo the traditional method of purchasing logs based upon the log scale and grade (or quality of the wood within the log) (Goerndt *et al.*, 2014). This trend was exacerbated when, on May 8th of 2009, an unprecedented weather event known as a derecho occurred and left Missouri landowners, loggers, and sawmills faced with a major challenge; either leave millions of board feet in downed timber to decay in the forest, or figure out a method to collect and process the downed trees that was rapid enough to salvage the timber before it was too far gone to utilize.

Derechos are not necessarily an uncommon event. Almost 21 derechos occurred annually in the United States between 1986 and 2003 (Vaughn, 2013). However, the intensity of this particular weather system was greater than that of typically recorded derechos and led to it eventually being classified as a “Super Derecho” (Corfidi *et al*., 2010). The derecho, or “inland hurricane” as it became known by some, produced enormously strong winds of 80 to 100 miles per hour (Coniglio *et al.,* 2011) that severely damaged an estimated 113,000 acres (Stelzer, 2009) of timber on public and private lands and left an estimated 204 million board feet (Stelzer, 2009) to be salvaged before it decomposed beyond the point of being useable. The severe weather system was also accompanied by sporadic tornado activity that only aided in the destruction of the timber resources in the affected area. The sheer volume of the timber requiring salvage quickly overwhelmed area logging companies and sawmills. To expedite the purchasing and the processing of the salvage timber local landowners and area sawmills began buying and selling salvaged timber by the truckload using the weight of the logs to estimate the number of board feet contained in that particular load of logs.

In the case of Missouri’s oaks, it is often assumed that a board foot of oak (12”x12”x1”) weighs approximately 12 lbs. (5.44 kg.). This assumption is ambiguous and doesn’t differentiate amongst different oak species. This is advantageous to the sawmill because the cost of logs can be determined much faster through the use of an equipment scale and leaves the mill’s log buyer to focus on the purchase of higher quality sawlogs. Dividing the standalone weight of the logs by a factor of 12 is presumed to provide the number of board feet delivered and the customer can be paid accordingly. For example, a load of logs weighing 144,000 lbs. would be assumed to contain 12,000 board feet of lumber.

Specific Gravity

It is said that specific gravity was first discovered by Archimedes, in the year 250 B.C., at the request of King Heiro II of Syracuse (Iowa State University, 2014). Legend tells that the King believed he had been deceived by a local goldsmith whom he had hired to fashion a new crown for the throne. The goldsmith had been given an amount of gold from the treasury for which to make the crown from and the King believed the goldsmith had used other metals in the crowns making and had kept some of the gold for himself. Archimedes, in looking for a solution, discovered that an object held submerged in water has buoyancy equal to the weight of the water displaced by said object (Smith, 1961).

Specific gravity is often mistakenly assumed to be synonymous with an object's density. In fact, specific gravity is the ratio – which is why it is unitless – of an object's density and the amount of fresh water (H_2O) that object would displace if immersed. The U.S. Forest Service (USFS) Forest Products Laboratory (1987) describes specific gravity from a forestry and forest products specific standpoint as the ratio of wood density to the density of water at a given temperature. The exact density of water fluctuates slightly with increases and decreases in temperature (U.S. Geological Survey, 2015) therefore, specific gravity measurements made by immersion should be conducted using water at 4.0° Celsius (°C) where the density of water is at its greatest point; 1.00 grams per cubic centimeter (1.00 g/cm^3). However, maintaining a perfectly stable water temperature of 4.0° C (39.2° Fahrenheit (°F)), is difficult so the density of water is often assumed to be 1.00 g/cm^3 regardless of temperature, provided the temperature is not extremely hot. Extreme cold is not an issue as the water would obviously be frozen and immersion of an object impossible.

Bowyer *et al.* (2007) states that specific gravity is the most important physical property of wood, and that most physical and mechanical characteristics of wood are directly correlated to the wood sample's specific gravity. The specific gravity values determined from a sample of wood can be directly correlated with the wood's density, weight, strength, and even the rate at which heat moves through the sample.

Research Objectives

The overall goal of this research is to collect data from at least 200 sample trees from 4 species groups that are common to southeastern Missouri's forests. With the data collected from the sample trees the validity of the 12 lbs./bf rule, that sawmills in Missouri are currently using to purchase logs with, can be tested for accuracy. The data collected also provides the opportunity for other research as well. Ancillary objectives of this study include the production of average green, air-dried, and oven dried densities and specific gravities for each species that are Missouri specific.

CHAPTER 2: METHODOLOGY

Research Site Description

Geographic Location

The field work and data collection for this study commenced in June of 2011 approximately 12.4 miles (19.96 kilometers) northwest of the city of Potosi, Missouri which is located in Washington County, Missouri (Figure 1). The specific geographical location of this research site is within the western ½ of Section 34, Township 39 North, and Range 1 East, or at the intersection of latitude 38.0682° and longitude -90.91265°, on land currently owned by The Doe Run mining company.

The research area encompasses 36.52 acres (14.79 hectares) as seen in Figure 2 and follows a curved section of unimproved logging trail for 0.68 miles (1.09 km) or 1199.32 yards (1096.66 meters). The selection of sample trees was restricted to within 200 feet (60.96m) of the trail to minimize skidding operations thus increasing data collection efficiency. Accessing the research area is accomplished via the same route of unimproved logging trail that the site boundaries follow and can also be seen in Figure 2.

The study site experiences elevation changes of approximately 110 feet (33.53m) above sea level (ASL) over the length of the study tract (Figure 3). The elevation at the site entrance is approximately 900 feet (274.32m) ASL and ascends rapidly to approximately 980 feet (294.7m) ASL following the crossing of an ephemeral stream. Elevation changes are more gradual after the initial climb to 980 feet (294.7m) ASL and the site's apex is reached at 1015 feet ASL.

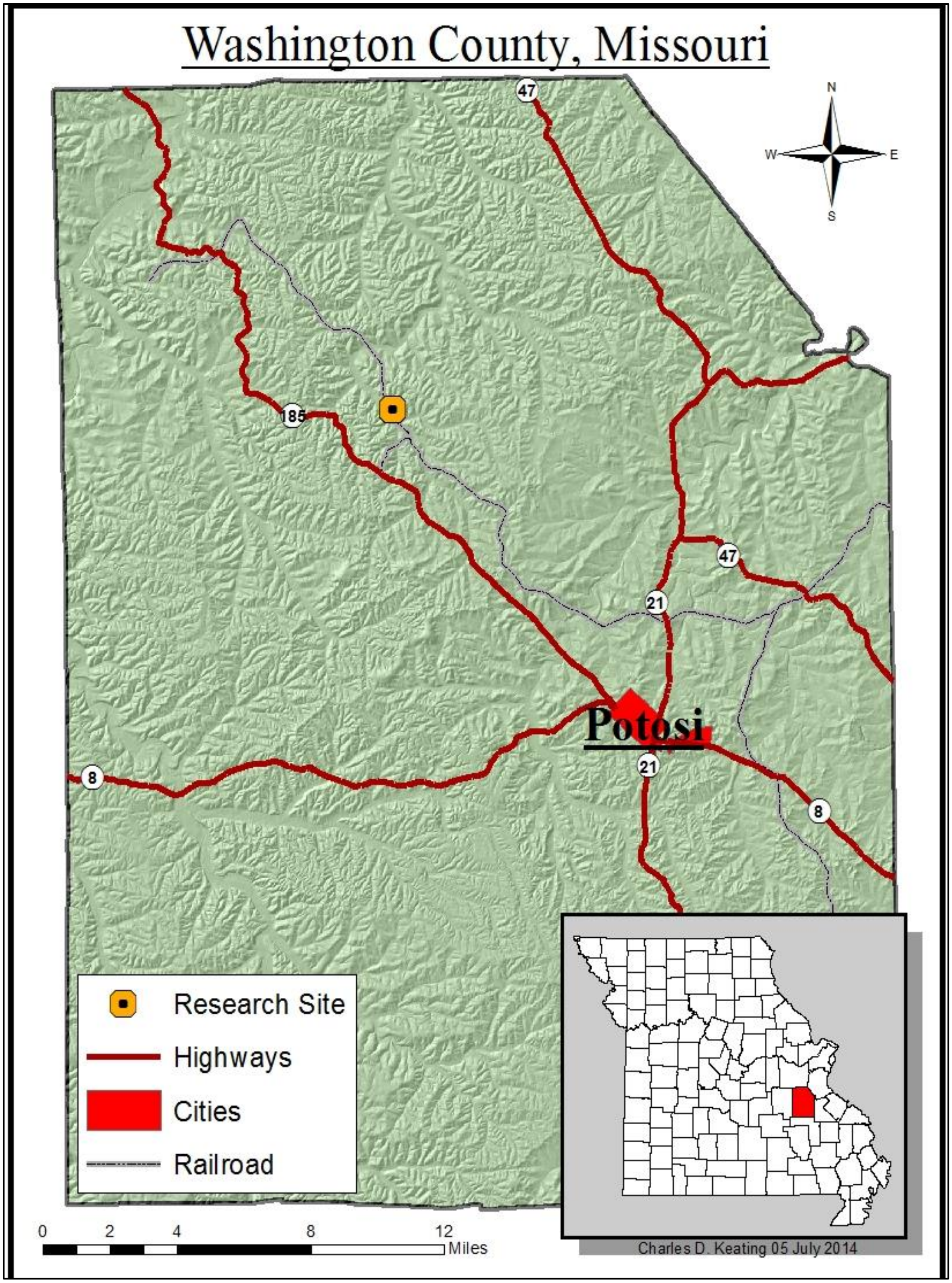

Figure 1. Washington County, Missouri with research site location and Missouri inset map. Transverse Mercator projection with data from the University of Missouri Center for Applied Research and Environmental Systems (CARES: http://cares.missouri.edu/default.aspx).

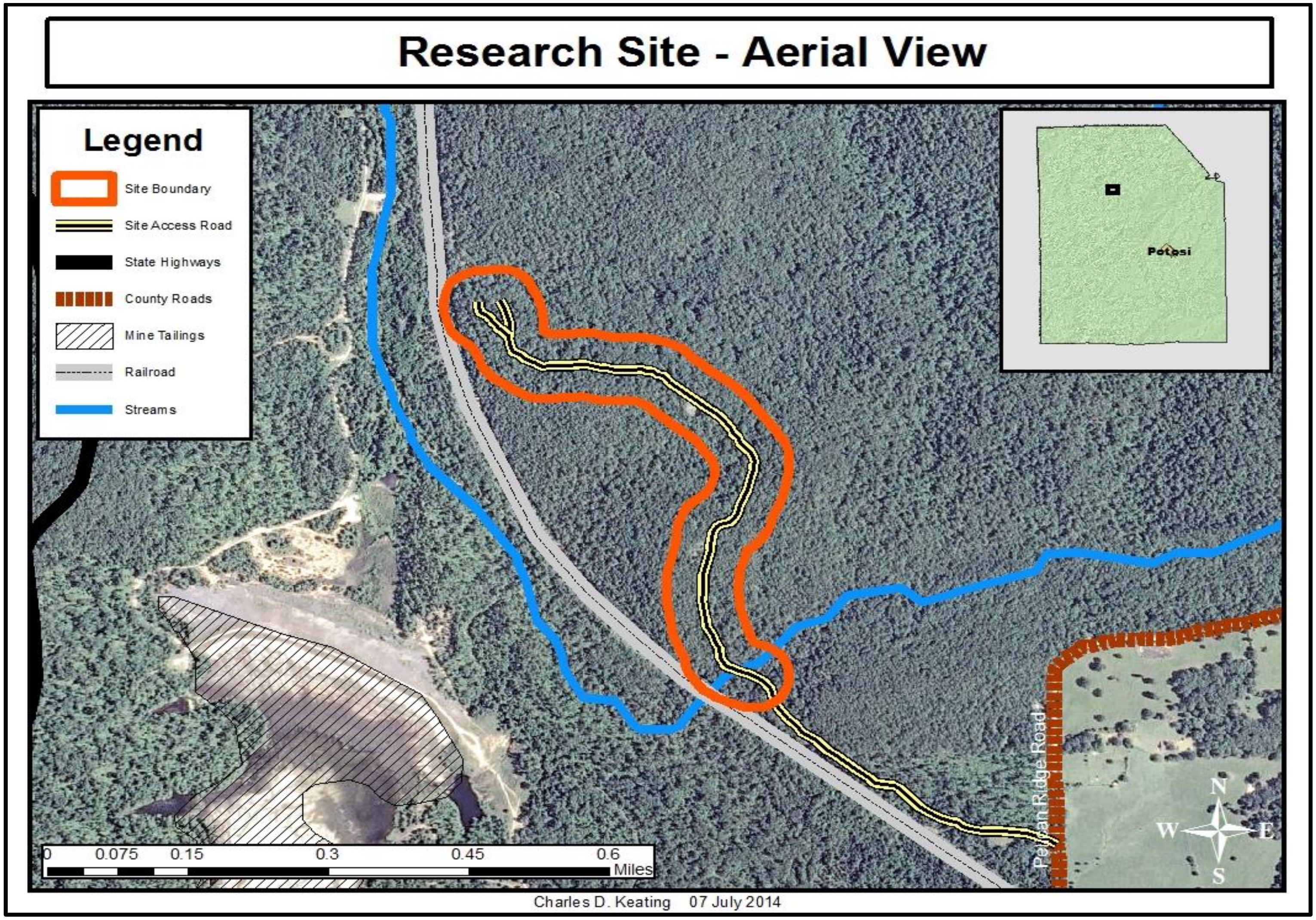

Figure 2. An aerial view of the research area in 2010. Transverse Mercator projection with data from the University of Missouri Center for Applied Research and Environmental Systems (CARES: http://cares.missouri.edu/default.aspx).

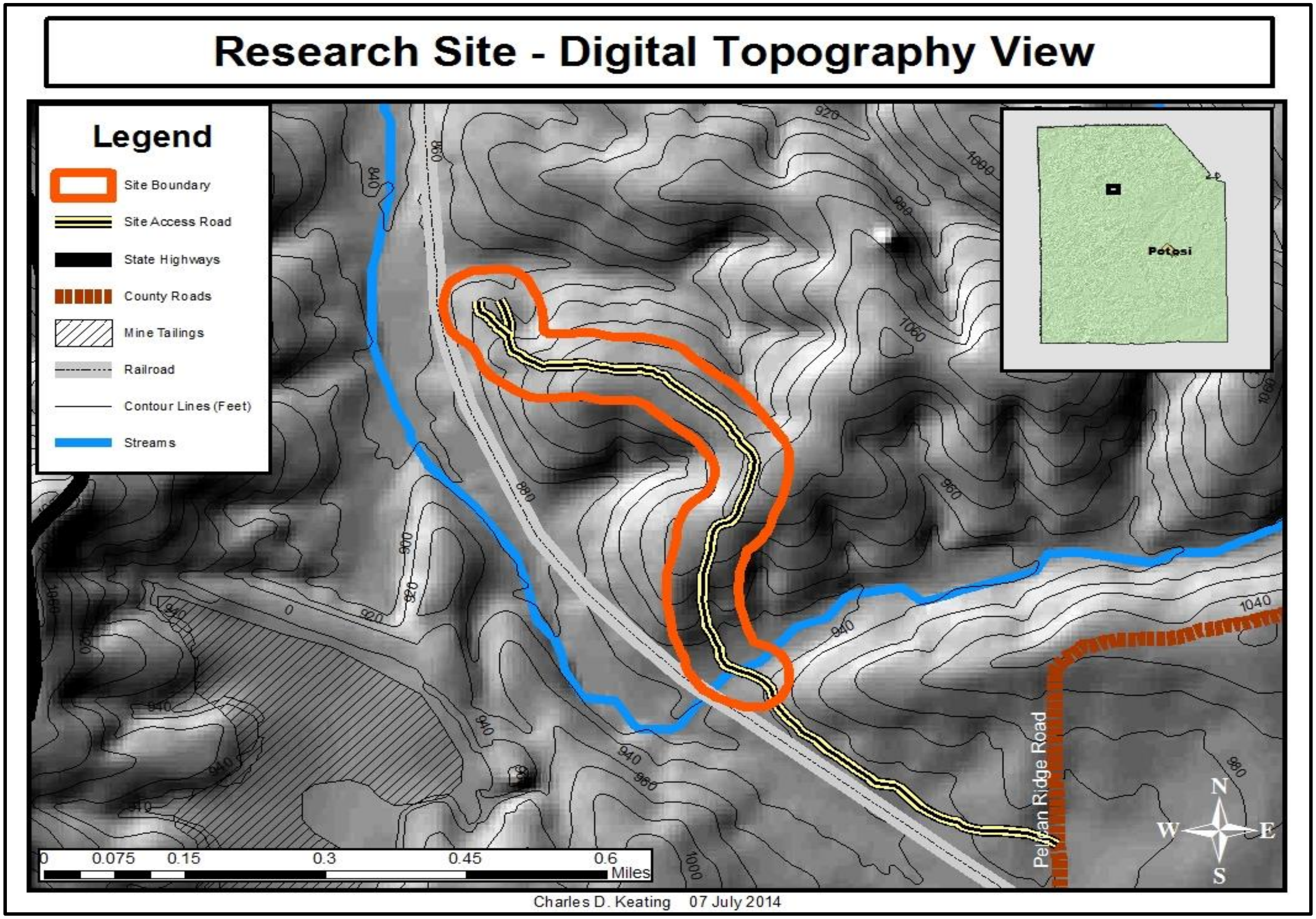

Figure 3. A view of the research area's topography with a Digital Elevation Model. Transverse Mercator projection with data from the University of Missouri Center for Applied Research and Environmental Systems (CARES: http://cares.missouri.edu/default.aspx).

Vegetation

The research site is forested with a mixture of black oak (*Quercus velutina*), white oak (*Q. alba*), post oak (*Q. stellata*), and hickories (*Carya spp.*) with the occasional scarlet oak (*Q. coccinea*) and shortleaf pine (*Pinus echinata*). Understory species consist mostly of sassafras (*Sassafras albidum*), dogwoods (*Cornus spp.*), hawthorns (*Crataegus spp*.), winged elm (*Ulmus alata*) and redbud (*Cercis canadensis*). Species of *Vaccinium* and *Desmodium*, along with aromatic sumac (*Rhus aromatica*) periodically dot the forest floor. Poison ivy (*Toxicodendron radicans*) is a frequent occurrence on the forest floor, growing freely to a height of 3-4 feet tall (0.91-1.21m) or as a vine on the trunks of many of the area's trees. A general inventory of the site's vegetation was not relevant to this research and was not performed. Thus, species composition, site index, basal area, and stocking percentages are not currently available for the research site.

Soils

Four soil mapping units are located within the research area confines. A map of the research area's soils can be viewed in Figure 4. Table 1 provides a listing of the soils that can found within the site boundaries as well as the corresponding map unit identification number.

Table 1: Listing of categories and coverage areas of soils found within the research confines.

Research Site Soil Categories					
Map Unit	Soil	Slope (%)	Acres	Hectares	Area (%)
73089	Rueter very gravelly silt loam	15 -35 %	3.26	1.32	8.93%
73277	Goss gravelly silt loam	3-15 %	15.86	6.42	43.43%
73282	Alred-Sonsac complex	15-35 %	14.62	5.92	40.03%
75376	Cedargap gravelly silt loam	1-3 %	2.78	1.13	7.61%
		Total	36.52	14.79	100.00%

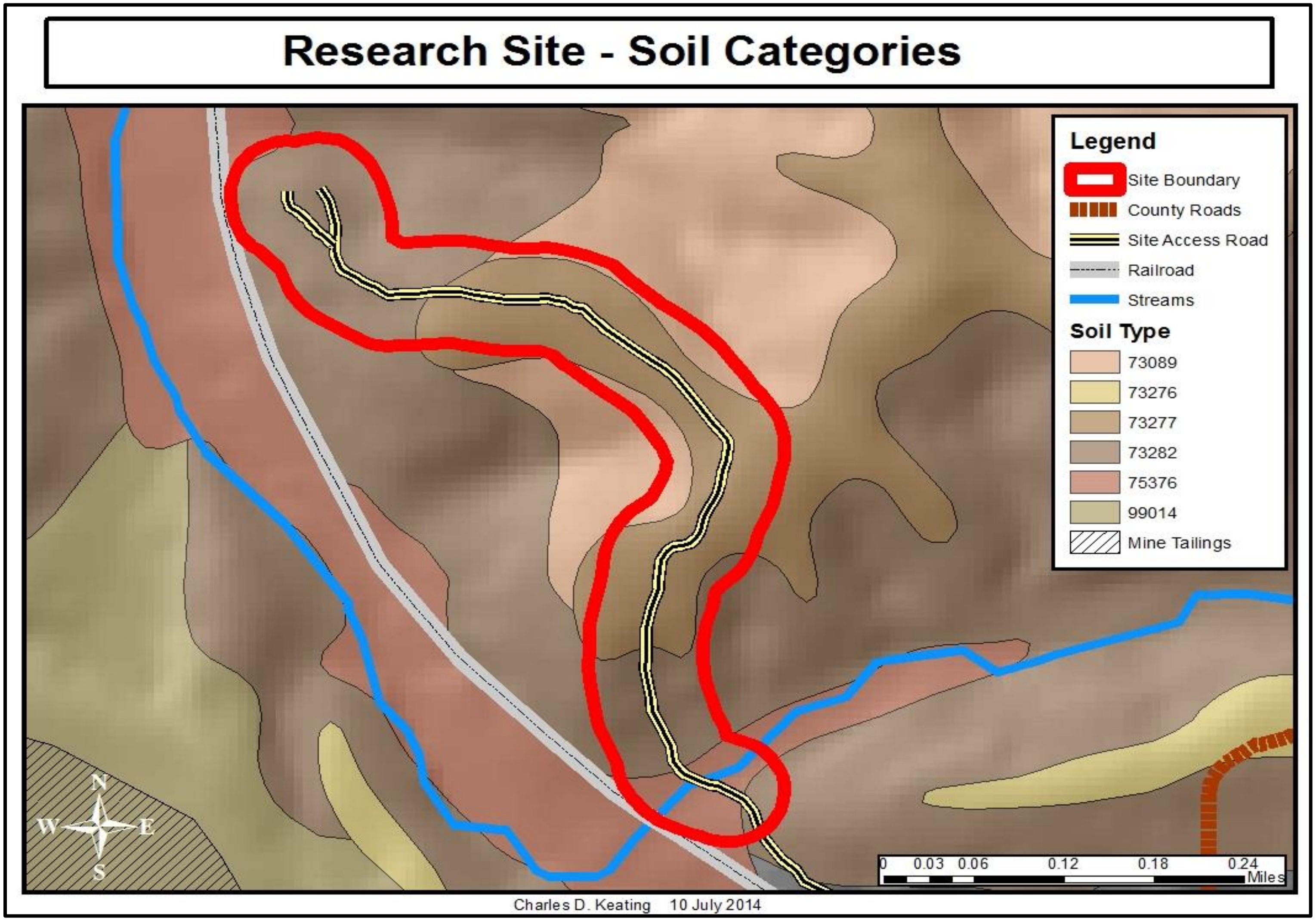

Figure 4: A map of the soil categories found within the research site boundaries. Transverse Mercator projection with data from the University of Missouri Center for Applied Research and Environmental Systems (CARES: http://cares.missouri.edu/default.aspx).

Figure four provides a location of the soil mapping units encountered at the research site and the surrounding area. The extent of the map encompasses six soil categories whereas the research area only encompasses four soil categories (Table 1). Brief descriptions of the soils encountered in this area are as follows and are as described in the Washington County, Missouri soil survey (NRCS, 2005).

73089 - Rueter very gravelly silt loam: A somewhat excessively drained, very stony silt loam formed on 15 – 35 percent slopes from colluvium over weathered residuum of dolomite. Soil pH increases with depth from extremely acidic, to very strongly acidic, to strongly acidic. Taxonomic classifications for the Reuter series are loamy-skeletal, siliceous, active, mesic Typic Paleudalfs.

73276 - Rueter-Hildebrecht complex: This soil mapping unit exhibits properties found in both Rueter (see above description) and Hildebrecht soil series. Hildebrecht soils are classified as fine-silty loess over weathered residuum of dolomite forming on convex slopes with 3- 15 percent grades. Hildebrecht soils are moderately well drained and possess fragipans. Soil pH is listed as very strongly acid throughout the soil profile. Taxonomic classifications for the Hildebrecht series are fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs.

73277 - Goss gravelly silt loam: A well-drained, extremely stony soil series formed on 3 – 15 percent slopes from colluvium over residuum of cherty dolomite. Goss soils are very cobbly silt loams and are very strongly acidic throughout the soil profile. Taxonomic classifications for the Goss series are clayey-skeletal, mixed, active, mesic Typic Paleudalfs.

73282 - Alred-Sonsac complex: This soil mapping unit exhibits properties found in both the Alred and Sonsac soil series. Alred soils are well drained, very stony and/or rocky soils formed on 15 – 35 percent slopes from gravelly colluvium over residuum weathered from dolomite. Alred soils are very gravelly silt loams and are strongly acidic in the upper A, E, and EB horizons. Soil pH decreases in the Bt, 2Bt2, and 2Bt3 horizons to very strongly acidic before increasing to moderately acidic in the 2Bt4 horizon and then to neutral pH in the 2Bt5 horizon. Taxonomic classifications for the Alred series are loamy-skeletal over clayey, siliceous, semi-active, mesic Typic Paleudalfs.

Sonsac soils are well drained, very stony and/or/ rocky soils formed on 15 – 35 percent slopes from colluvium over residuum weathered from cherty dolomite. Sonsac soils are extremely gravelly silt loams and are moderately acidic in the A and E horizons but become neutral in pH in the Bt1 horizon and remain at that pH through the rest of the profile. Taxonomic classifications for the Sonsac series are clayey-skeletal, mixed, active, mesic Typic Hapludalfs.

75376 - Cedargap gravelly silt loam: A well-drained, gravelly, frequently flooded soil formed on 1 – 3 percent slopes from gravelly alluvium parent materials. Soil pH is neutral throughout the profile. Taxonomic classifications for the Cedargap Series are loamy-skeletal, mixed, super-active, mesic Cumulic Hapludolls.

99014 - Mine tailings: Listed in the soil survey as sandy and gravelly mine spoils or earthy fills. This type of material has been displaced through mining operations.

Precipitation

Precipitation data for the exact location of the research area is not available as there are no meteorological instruments located within the site boundaries. Data from nearby Potosi, Missouri are available and are used in this study. The state of Missouri averaged 40.86 inches (103.78 centimeters) of precipitation per annum for the years 1895 – 2013 (Missouri Climate Center, 2014). Potosi, Missouri received 49.1 inches of precipitation in 2011 and the average precipitation per annum for Potosi, Missouri for the years 1971 – 2001 and 1981 – 2010 was 40.17 inches (102.03cm) and 43.94 inches (111.61cm), respectively (NCDC, 2014). Figure 5 displays the average monthly rainfall for the years, 1971 – 2001 and 1981 – 2010, compared with the total monthly precipitation reported for the year 2011.

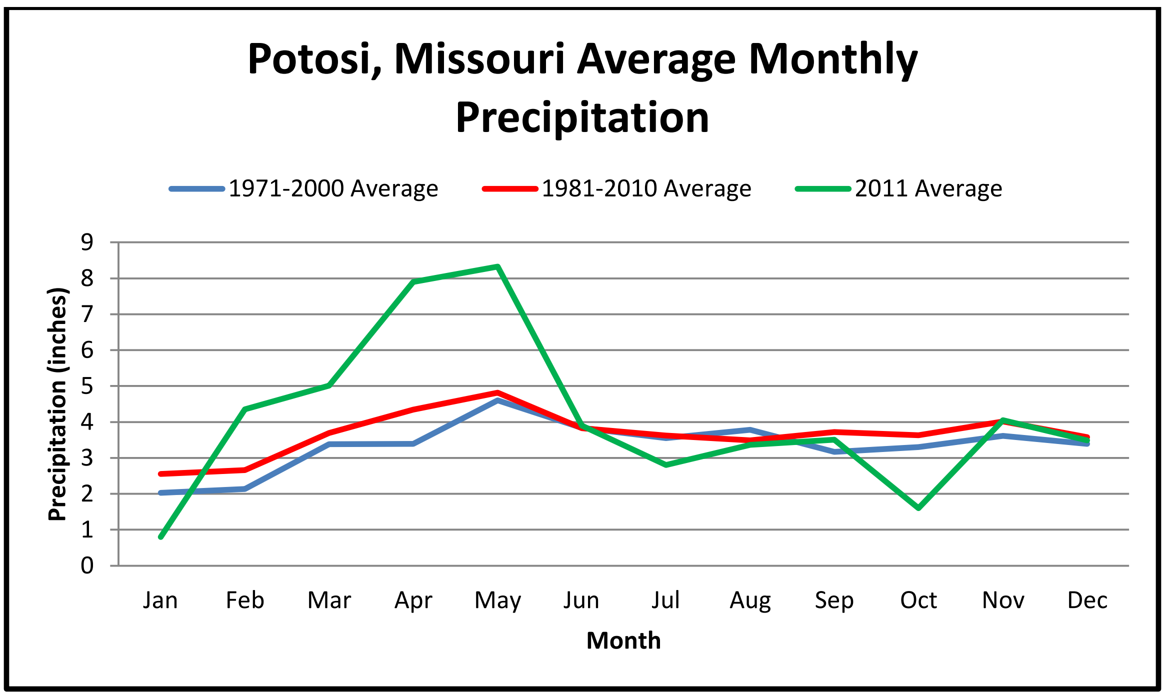

Figure 5. Average monthly precipitation received in Potosi, Missouri. The graph displays two 30 year averages (1971-2001 & 1981-2010) compared to the monthly totals for the year 2011. Data from the Missouri Climate Center (www.climate.missouri.edu) and the National Climatic Data Center (NCDC) (www.ncdc.noaa.gov).

Precipitation totals for the months of February 2011 to May 2011 were much greater than both 30 year averages. The month of April saw the largest increases in precipitation with 4.51 more inches (11.46 cm) falling than expected compared to the 1971- 2001 average and 3.51 more inches (8.92 cm) of precipitation than expected when compared to the 1981- 2010 average. Overall the year 2011 saw increases in precipitation by 8.93 inches (22.68 cm) and 5.16 inches (13.12 cm) compared to the averages from 1971 – 2001 and 1981 – 2010, respectively (Table 2).

Table 2. Average monthly precipitation received in Potosi, Missouri. 1971-2001 and 1981-2010 precipitation amounts are averages for those combined years whereas amounts for 2011 are for that year only. Rows labeled as "Δ Precipitation" show the change in precipitation received for the year 2011 as compared to the 30 year average. Data from the National Climatic Data Center (NCDC) (www.ncdc.noaa.gov).

Potosi, Missouri Average Monthly Precipitation (inches)													
Year(s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2011	0.8	4.35	5.01	7.9	8.33	3.9	2.8	3.36	3.51	1.6	4.05	3.49	49.1
1971-2001 (AVG)	2.03	2.13	3.38	3.39	4.6	3.84	3.55	3.78	3.17	3.3	3.61	3.39	40.2
Δ Precipitation	-1.23	2.22	1.63	4.51	3.73	0.06	-0.75	-0.42	0.34	-1.7	0.44	0.1	8.93
1981-2010 (AVG)	2.55	2.66	3.69	4.34	4.82	3.83	3.62	3.49	3.72	3.63	4.01	3.58	43.9
Δ Precipitation	-1.75	1.69	1.32	3.56	3.51	0.07	-0.82	-0.13	-0.21	-2.03	0.04	-0.09	5.16

Temperature

Temperature data for the exact research location is also not available so data from Potosi, Missouri were used much like the precipitation data were. The average annual temperature for the state of Missouri is 54.6° Fahrenheit (12.6°Celcius) and is also calculated from data recorded for the years 1895 – 2013 (Missouri Climate Center, 2014). The average annual temperature in Potosi, Missouri from 1971 – 2001 was 55.0°F (12.8°C) (NCDC, 2014). That number decreased slightly from 1981 – 2010 to an average temperature of 54.6°F (12.6°C) (NCDC, 2014).

Figure 6 displays the average monthly temperature for the years 1971 – 2001 and 1981 – 2010 compared to the average monthly temperatures for the year 2011.

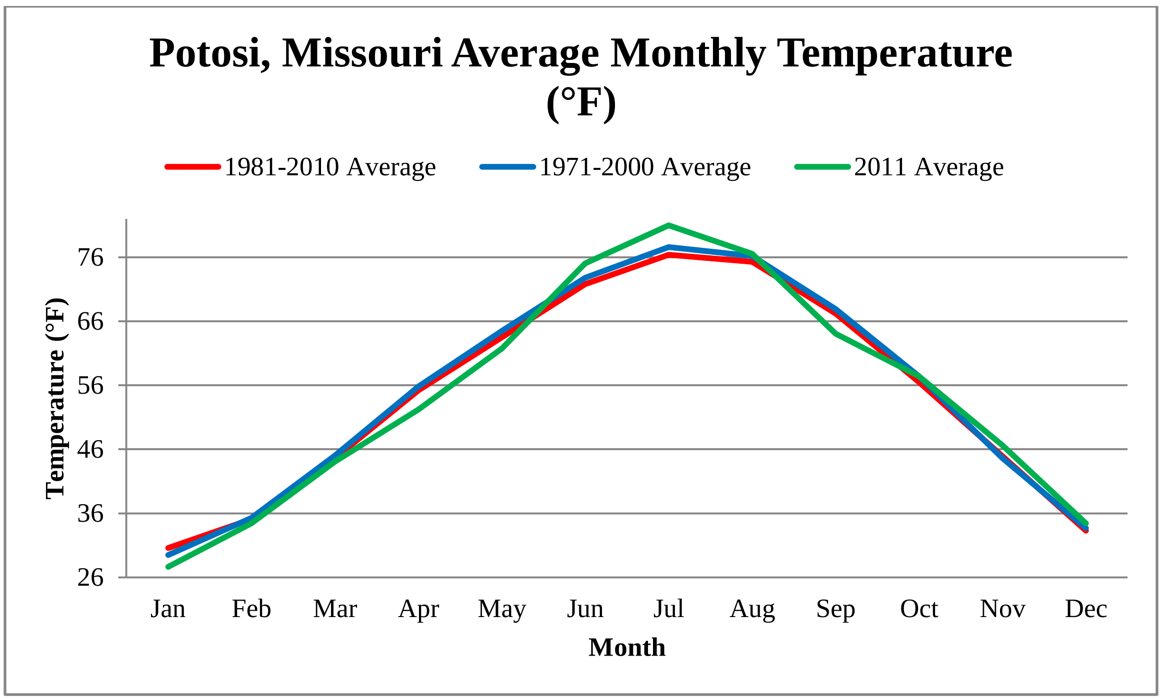

Figure 6. Average monthly temperatures for Potosi, Missouri. Thirty year climatic averages for the years 1971 - 2001 and 1981- 2010 are plotted along with the averages for the year 2011 for comparison. Data from the Missouri Climate Center (www.climate.missouri.edu) and from the National Climatic Data Center (NCDC) (www.ncdc.noaa.gov).

Average temperatures for the Potosi area are fairly consistent for both of the 30 year averages (1971 – 2001, 1981 -2010) and the data for the year 2011 only differs slightly. The months of January, April, May and September 2011 were slightly cooler than the 30 year averages while June and July were warm compared to what is typically experienced during the those months. A list of temperatures for comparison is provided in Table 3.

Table 3. Average monthly temperatures for Potosi, Missouri. Thirty year averages are provided for the years 1971 - 2001 and 1981 – 2010 as well as the year 2011. Rows labeled as "Δ Temperature" list the change in temperature for the year 2011 as compared to both 30 year averages. Data from the National Climatic Data Center (NCDC) (http://www.ncdc.noaa.gov).

Potosi, Missouri Average Monthly Temperatures (°F)													
Year(s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
2011	27.7	34.5	44.1	52.2	61.8	75.1	81.0	76.6	64.1	57.4	46.6	34.5	54.6
1971-2001 (AVG)	29.5	35.3	45.0	55.8	64.5	72.8	77.6	76.2	67.9	57.4	44.6	33.7	55.0
Δ Temperature	-1.9	-0.8	-1.0	-3.6	-2.8	2.3	3.4	0.3	-3.9	0.0	2.0	0.8	-0.4
1981-2010 (AVG)	30.6	35.1	44.6	55.2	63.5	71.8	76.4	75.3	67.2	56.5	44.9	33.3	54.6
Δ Temperature	-3.0	-0.6	-0.6	-3.0	-1.8	3.3	4.6	1.3	-3.2	0.9	1.7	1.2	0.0

Research Equipment

Forestry Equipment

The equipment used to collect and record the data for this research are fairly typical of what one would encounter in any forestry related study. To avoid erroneous data recordings, one should familiarize themselves thoroughly with the equipment to be used prior to heading to their study site.

Hypsometers

Tree heights were a very important aspect of the data collection for this research and were determined through the use of a hypsometer. Instead of using the traditional method which requires a clinometer and a logger's tape, this device allows the user to determine tree heights using lasers to measure the distance from the sample tree being measured, as well as the tree's highest point in the crown and its lowest point at the soil level.

Figure 7. An image showing the hypsometer used in this study.

In this study the hypsometer used for data collection was a LaserAce® Model 3D made by Measurement Devices US, LLC of Houston, Texas (Figure 7). Operators' using a hypsometer look through the device's viewing optic much as they would a monocular (Figure 8). The siting optic has a crosshatched reticle like a hunting optic for aiming the apparatus. This aiming point is focused on the tree's bole or stem for distance measurement and on the highest and lowest visible points on the tree. The hypsometer then uses the distance (measured via laser) from the tree and the angles (measured by an inclinometer) required to view the tree's top and base to compute the total height of the sample tree. Hypsometers such as this one are also capable of calculating stem diameters at various heights and log volumes in sample trees. They can also be used as a rangefinder to measure distances and in measuring angles to determine slope grades.

Figure 8. The author viewing a sample tree through the LaserAce® 3D hypsometer in preparation for determining the tree's height.

Logger’s Tapes & Diameter Tapes

Diameter is another measurement with critical importance to this thesis. One of the most common tools used in determining diameter, and in forestry related field work, is the logger’s tape. This measurement tool operates much like a carpenter’s tape measure but offers other features that aid the user in collecting diameter as well as lengths and distances. Logger’s tapes come in several lengths to accommodate different needs and are available in both English and Metric measurements. The model used in this study is a 100 foot (30.48m) Spencer® Loggers Tape Model 900DC (Figure 9).

Figure 9. An image showing the logging tape measure used in this study.

For this model, the steel tape is marked on both sides with different English measurement systems. One side is marked in feet with tenths (1/10th) and hundredths (1/100th) of an inch for measuring distances or log lengths (see Figure 10). The other side is marked for determining tree diameters to the nearest tenth (1/10th) of an inch, such as the diameter at breast height (4.5ft/1.37m) and the diameters of individual logs up to 120 inches (304.8cm).

Figure 10. The author employing a logger's tape to measure the length of a hickory (*Carya spp.*) log.

It is not absolutely necessary to use a logger's tape to replicate the measurements collected in this research. If no loggers tape is available a standard measuring tape in whichever system of measurement (English or Metric) the user desires will suffice. However, it is often difficult to find a standard measuring tape in the lengths required that retracts automatically as the loggers tape does and the manual retraction will increase the time required for data collection. Measuring tapes designed to obtain diameters alone are also available and will aid the user to quickly determine log and tree diameters as needed or required. Diameters can also be obtained by using diameter calipers or Biltmore sticks but these tools may sacrifice some accuracy if the tree or log is oblong or elliptical in shape. The logger's tape simply combines these two tools and keeps them readily available to the user all the while accounting for out-of-round trees and logs.

Data Collection Materials

Data were recorded on printed spreadsheets designed specifically for this study prior to field operations. Recordings were made in pencil instead of ink since pencil markings can be erased and changed should an error be found and because pencil markings will not bleed into the paper if the document gets wet as ink tends to do. Black ink markers were used to mark the stumps and cross-sections of harvest trees for later identification. The constant change in location required a clipboard to facilitate the recording of data. The use of two-way radios enhanced communication between personnel in the field due to distances encountered and the noise levels inherent to the heavy machinery used in this study. Fluorescent paints were used in the initial stages to mark the sample trees destined for harvest. Bright colors are essential in forested environments as visibility is often obstructed by the understory vegetation. Fluorescent orange and pink were used for this reason but paint color is a user preference. It is also a good idea to keep black paint on hand as cover paint in the event that marking errors are encountered effectively allowing the user to "erase" erroneous markings.

Photography Equipment

It is a good idea to employ a camera throughout the data collection process (both in the field and the laboratory setting). Photographs ease the explanation of difficult data collection techniques in presentations and texts regarding the study and aid the user in later remembering the steps taken during the data collection when documenting the events become necessary.

Tree Felling Equipment

All trees designated for use in this research were felled by an experienced, professional logger using a STIHL® MS 660 MAGNUM® chainsaw (Figure 11), plastic felling wedges, and a single bit hand axe (Figure 12). A feller-buncher was available for use but was not a viable option for this study as it would have felled the trees too quickly.

Figure 11. An image of the STIHL® MS 660 MAGNUM® chainsaw used to fell the sample trees in this study.

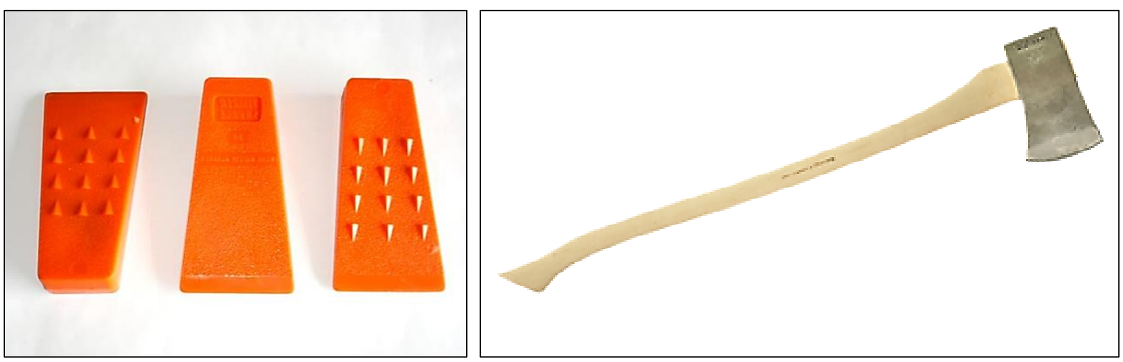

Figure 12. Images showing examples of felling wedges and a single bit felling axe.

Personal Protective Equipment (PPE)

Field work can be a hazardous task and equipment necessary for protecting one's self is always important to remember prior to heading to the field. During harvest operations the field crew donned a variety of Personal Protective Equipment (PPE) to help protect themselves from accidents on the research site. Hard hats were employed to protect from falling and/or swinging hazards (Figure 13). Brightly colored reflective vests increased the visibility of crew members on the ground to those operating heavy equipment and to the logger felling the sample trees (Figure 13). Crew members not involved in felling operations were kept at a safe distance from any falling trees. The logger employed a specialized forestry hardhat equipped with a face shield and hearing protection and wore protective chaps while performing felling tasks. Eye protection and sturdy leather boots were also a necessity to protect from injuries related to this type of work. Leather gloves were used whenever possible to protect the hands from injury.

Figure 13. Field crew members displaying some of the Personal Protective Equipment (PPE) utilized (hardhats and reflective vests) during harvest operations.

Heavy Equipment

To effectively meet the parameters of this study the use of heavy equipment would be necessary to move freshly felled, whole trees to open areas and to lift the entire tree off of the ground to obtain the trees green weight. The equipment used would need to be capable of lifting and moving a great amount of weight to accomplish the goals of this study.

Wheel Loader

The ability to weigh an entire tree post-harvest was one of the main goals and requirements of this research. Thus, a method of getting the tree completely off of the ground was essential. A Volvo® L110F Wheel loader was provided by Rudd Equipment Company of Saint Louis, Missouri for this study to lift and to weigh the trees at the same time (Figure 14). The wheel loader was equipped with a “combi-fork” style fork lift attachment with a grapple clamp for securing loads on the forks (Figure 14). This application would prove ideal when lifting whole trees, merchantable stems or individual logs. The clamp added an increased level of safety to lifting the trees and logs by ensuring the load could not shift or roll off of the forks.

Load Cell

While lifting the tree was the main task of the wheel loader it also served a dual purpose by providing the weight of the load it was lifting. Prior to its arrival at the study site, the loader was equipped with a Rice Lake Weighing Systems Model WLS-1C load cell. A load cell is a device that is spliced into the hydraulic system of the wheel loader and is designed to convert the hydraulic pressure it detects into an accurate weight.

These devices are typically used in quarry operations and tally the weights of the loads that a loader handles for efficiency analysis and for tracking and billing purposes. According to Rice Lake Weighing Systems, this model of load cell is accurate to +/- 1 percent of the load weight.

Figure 14. Image of the Volvo® L110F Wheel Loader used in this study. The lift attachment is known as a "Combi-Fork" and has a grapple style clamp for securing loads. This loader was supplied by Rudd Equipment Company of Saint Louis, Missouri (www.ruddequipment.com).

Calibration of the load cell required a counterweight of 5,000 lbs (2267.96 kg.) or more. Figure 15 shows the wheel loader lifting a bundle of green railroad ties from a nearby sawmill as part of the calibration process. The tie bundle weighed 5420 lbs. (2458.47 kg) at the sawmill and that exact weigh was later recorded with the load cell following calibration.

Figure 15. Image showing the Volvo® L110F Wheel Loader lifting a bundle of green railroad ties in order to calibrate the load cell. The weight of the tie bundle was 5420 lbs. (2458.47 kg).

Skidder

Following felling of the sample tree it would have to be moved to an open location, such as a landing, where lifting it with the wheel loader would not be impeded by other trees or vegetation. Allowing it to be in contact with the ground or with other vegetation at any point would have resulted in an inaccurate weight reading from the load cell. A rubber tired skidder (Figure 16) was used to drag felled trees short distances to open landings along the access road for weighing. This type of skidder uses cables and chokers to drag the trees whereas other types of skidders employ a grapple mechanism instead of cables and chokers.

Figure 16. The rubber tire skidder used for relocating logs to the landing so they could be weighed for this study. This skidder was provided by the Jarvis Timber Company of Potosi, Missouri (www.jarvistimber.com).

Laboratory Equipment

Cross-sections were removed from each sample tree at stump height and at the small end of any log bucked from the merchantable portion of the stem. After main harvest operations and field data collection were concluded the study focus shifted from the field to the lab where much more work remained in processing the cross-sections removed from the sample trees. The processing of the cross-sections and the data collected from those cross-sections will be covered in greater detail in the data collection section of this thesis. Explanations of how scales and woodworking tools were used as research equipment to obtain the data from those cross-sections are provided on the following pages in the “Weight Scales” and “Woodworking Equipment” sub-sections.

Weight Scales

Prior to leaving the field site the green weights of all cross-sections removed from each tree were weighed using a Pesola® PHS100 digital suspension scale. This scale offers a 220 pound (99.79 kg) capacity and boasts a tare function to zero out any weight the user does not want to record (Figure 17).

Figure 17. The author using the Pesola® PHS100 suspension scale to gather the green weight of a cross-section from a sample tree. The cross-section is suspended from the scale using a plastic trash bag.

Cuboids, or somewhat cubic sections of wood, were removed from the cross-sections taken from the sample trees in the processing phase of this study. An Ohaus Scout™ *Pro* Model SP401 table scale (Figure 18) was used to obtain the air and oven dried weights of each cuboid in grams (g). This scale has a maximum capacity of 400 grams (14.12 ounces) and is, according to Ohaus, accurate to +/- 0.1 gram. It also offers a tare function to zero out any weigh the user does not want recorded. The same table scale was also used to obtain the air and oven dried volume of each cuboid in cubic centimeters (cm^3) using a method that will be described later in this thesis.

Figure 18. An image of the Ohaus Scout ™ *Pro* table scale (Model SP401) used in this study to weigh the cuboids produced from the sample tree cross-sections. The scale is being calibrated in this photo using the supplied 200 gram (7.06 ounce) counter weight.

Woodworking Equipment

The cuboids mentioned in the previous section were cut from the cross-sections using a bandsaw and a wood chisel. Lines were drawn with construction pencils on the cross-section to indicate where the saw cuts were to be made (Figure 19). On a few occasions, prior to sawing, some of the cross-sections had to be planed with a hand planer and then sanded with a palm sander in order for the growth rings to be counted later in the data collection process. Each cuboid was marked with its location within the cross-section and the corresponding tree number and cross-section number for identification purposes with a very fine point waterproof marker. The cuboids were then placed in paper bags to keep them organized with each bag containing all the cuboids from one cross-section. Paper bags were chosen over plastic because paper could withstand the heat required (221°F/105°C) to oven-dry the cuboids without being damaged.

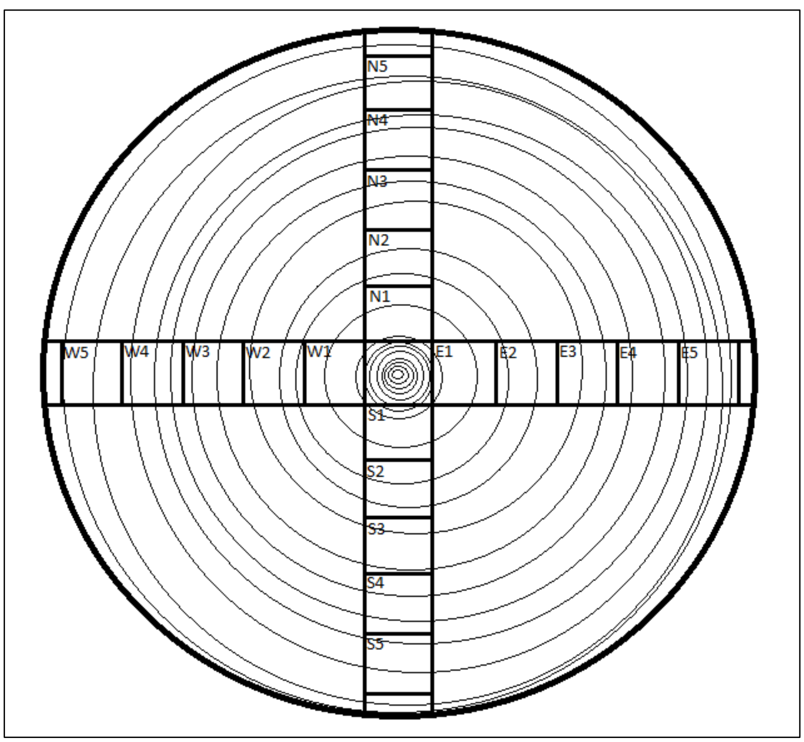

Figure 19. Computerized sketch depicting a sample cross-section and the layout of the cuboids contained in the cross-section prior to removal.

Data Collection

Sample Specifications

Sample Quantity (n) and Species

This research called for a sample size of 200 trees (n=200) from four species groups. To ensure that the target sample size was met it was decided that data would be collected on 220 trees in case data were lost or some of the trees were later deemed incompatible with study requirements. The initial goal was 55 specimens per species group but attaining that goal proved to be extremely difficult. Eventually the decision was made to collect more trees in certain species groups to offset those missing in others (Table 4).

The species chosen for the focus of this study were black oak *(Quercus velutina)*, white oak *(Quercus alba)*, post oak *(Quercus stellata)* and hickories *(Carya spp.*) which are all species common in the state Missouri and the research area (Massengale, 2008). It was determined prior to the commencement of field operations that identifying separate species of hickories would not be necessary due to the fact that they are not likely to be separated into separate species by sawmills.

Diameter Classes

Selected sample trees were separated into two inch (5.08cm) diameter classes from 8-20 inches (20.32-50.8cm) with the exception that any trees encountered that were greater than the twenty inch size class they would also be included in the sample. Each diameter class actually encompasses a range of diameters measuring one inch (2.54cm) greater than and 9/10th of an inch (2.29cm) less than the designated size class. For instance, the 10 inch (25.40cm) diameter class included trees with diameters ranging from 9.10 inches (23.11cm) to 11.00 inches (27.94cm).

Preliminary planning of this study called for seven trees for every two inch (5.08cm) diameter class within each species category. However, during the initial phase of data collection it was noted that meeting this requirement would be difficult and would greatly increase the size of the research area and the time required to transport felled trees to landing sites for weight determination. The decision was made to increase the number of trees to at least eight samples in the 8-10 inch (20.32-25.40cm) diameter classes and to at least nine samples in the 12-18 inch (30.48-45.72cm) diameter classes so the target sample size could be met. Sample trees of greater diameters were infrequent and were collected as they were encountered. No trees were encountered at the research site with a diameter greater than that required for the 26 inch (66.04cm) diameter class. Table 4 lists the number of samples trees harvested for each species and each diameter class.

Table 4. A listing of the total number of sample trees in each diameter class and for each species.

Species	Diameter Class (inches)										Total
	8	10	12	14	16	18	20	22	24	26	
Quercus velutina	9	8	12	10	11	6	5	2	2	0	65
Quercus alba	9	8	10	10	10	7	4	1	0	1	60
Quercus stellata	9	9	10	12	11	5	1	0	1	1	59
Carya spp.	9	9	9	7	0	2	0	0	0	0	36
Total	36	34	41	39	32	20	10	3	3	2	220

Field Operations

Sample Selection

Trees that fit the criteria for selection as study samples were chosen as they were encountered at the research site. White oak (*Q. alba*) and black oak (*Q. velutina*) are plentiful at the research site and the sample needed for those species was fulfilled in a relatively short period of time. It was more difficult to locate qualifying post oak (*Q. stellata*) specimens but an appropriate sample size was eventually located. Hickories (*Carya spp.*) are by far the most difficult species to locate on the research site and this explains the low number of samples taken during the harvest (Table 4).

Sample Markings

Marking qualifying specimens would be necessary in order to harvest those same trees at a later date. Selected sample trees were numbered in fluorescent orange paint from sample 001 to sample 220 (Figure 20). At first, the samples were numbered on two sides for increased visibility but this practice was later deemed excessive and subsequently discontinued. The sample tree was then marked with the same fluorescent paint around the stem horizontally at 4.5 feet (1.37m) to indicate the location of the diameter-at-breast-height (DBH) measurement and to add visibility to the sample. A measurement of the diameter-at-breast-height (DBH) was taken prior to its marking in order to prevent paint from obscuring the increments on the logger's tape.

A compass was used to determine the location of magnetic north on the bole, or stem, of the tree. A line was painted in fluorescent orange paint vertically to the highest point the field crew could reach at that position. This line would later be extended across the entire merchantable length of the tree once the tree was felled so that the north side could be determined on all cross-sections that were removed from that specimen.

Figure 20. A photograph of sample tree 001 showing the location of the identification markings used in this research. The horizontal line indicates the location of the diameter-at-breast-height (DBH) while the vertical line indicates the position of magnetic north.

Data Recorded

Diameter-at-breast-height (DBH) measurements were recorded on each specimen at 4.5 feet (1.37m) directly above the highest point of the soil level around the sample tree's base using a taught and level logger's tape. The diameter for each sample was recorded to the nearest 1/10th of an inch (0.25cm). Height determinations were made in feet using the hypsometer previously mentioned in the Forestry Equipment subsection of this thesis. The total height of each sample tree was collected along with the estimated merchantable height in the early stages of data collection. However, estimating the merchantable height was later deemed excessive as the actual merchantable height would be determined later during harvest operations. The idea of this study is to collect data on trees that a logging operation would harvest and that were cut by a professional logging expert. It was decided that the best method of collecting merchantable height data was to allow the logger to cut the log where they normally would and then take the measurement of merchantable height.

Sample Locations

An attempt was made to annotate the location of each sample tree with a Global Positioning System (GPS) unit but a portion of the data points were lost. The loss was not discovered until long after harvest operations had ceased making a return to the site to retrieve the missing data points impossible. Figure 21 displays the data points that were retained and location of the sample trees corresponding to those points. Bear in mind that data points should exist along the entire length of the site access road that falls within the research site boundary. It is also important to remember that GPS accuracy is dependent on factors such as canopy cover and atmospheric conditions and decreases greatly under forest canopies and during cloudy conditions.

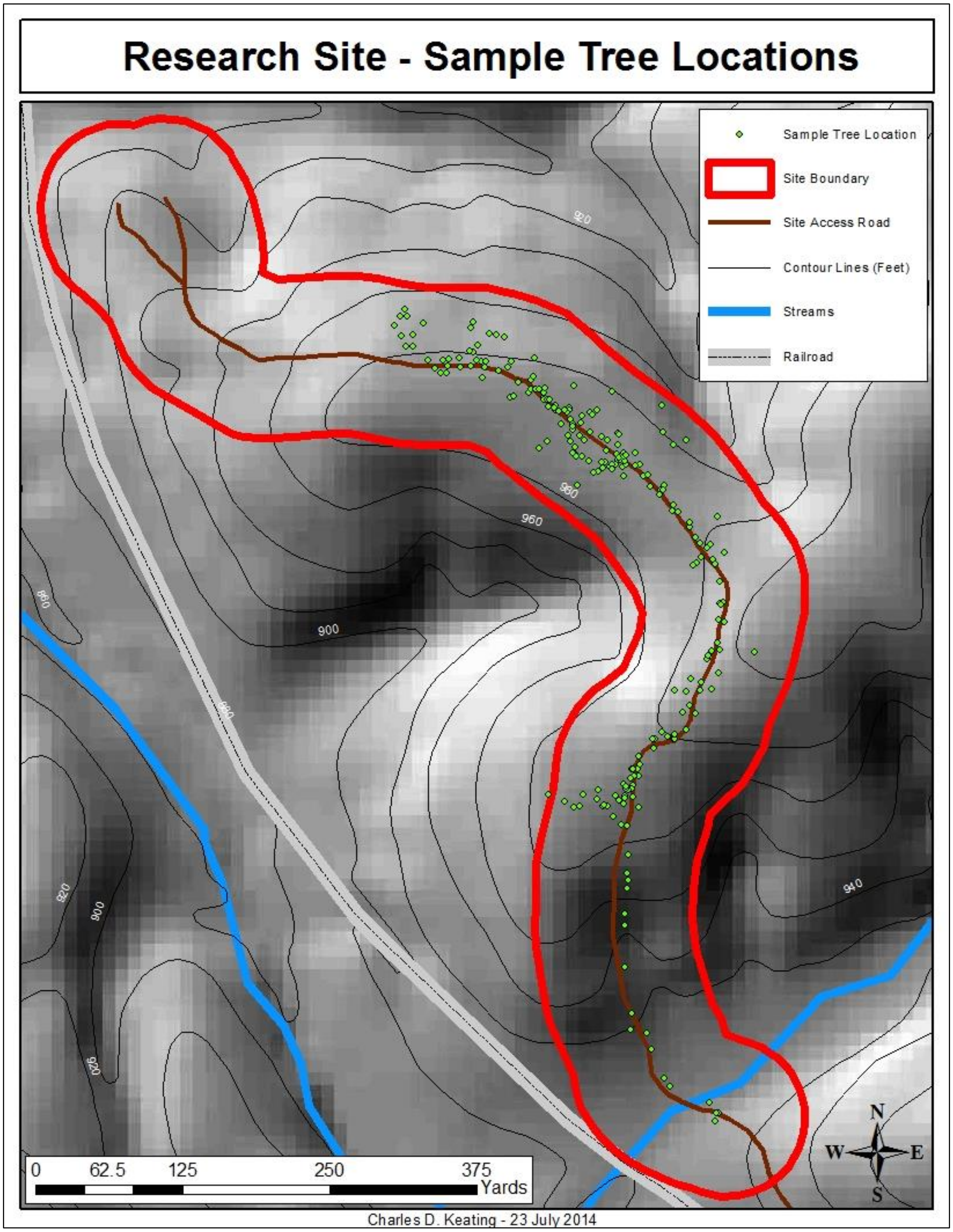

Figure 21. A map detailing the location of sample trees harvested from the research site. A portion of the data points collected were lost and could not be recovered which explains the lack of points in the northernmost portion of the site. Sample trees were selected along the entire length of the site access road within the research boundary. Transverse Mercator projection with data from the University of Missouri Center for Applied Research and Environmental Systems (CARES: http://cares.missouri.edu/default.aspx).

Sample Harvest Procedures

Once all 220 samples were located, marked, and all pre-harvest data had been collected, harvesting operations began on the study site. Ensuring that each tree was weighed as soon as possible following felling was paramount. All trees that were cut were weighed on the same day prior to concluding harvest operations. This was a necessity in order to reduce error in the recorded weights due to the loss of moisture through evaporation that occurs in trees post-harvest. This requirement made hand felling the only option as a means of harvesting. The use of a feller-buncher would have felled trees more quickly than the field crew could possibly weigh in one day. All felling operations were handled by a highly experienced Master Logger to minimize the risk of injury to personnel on the ground during the harvesting operations.

In some instances the trees could be weighed where they fell without any interference from other vegetation. In most cases it was necessary to drag felled trees to a landing site which was open and cleared of over and understory vegetation. Figure 22 shows the skidder described in the Heavy Equipment section moving some recently felled sample trees to the landing to obtain their weights.

One would be right to assume that the impact of the felled tree on the ground and the dragging action of the skidder would lead to losses in overall tree weight from detached branches and/or foliage. However since the first weight measured for each tree would come post felling and skidding, any branches and/or foliage that were going to detach from the tree would have already detached and would not be included in the overall weight negating the need for any weight loss corrections or assumptions.

Figure 22. Image of the skidder used in this study dragging recently felled trees to the landing to be weighed. Skidder provided by Jarvis Timber of Potosi, Missouri (www.jarvistimber.com).

Data Recorded

Data recordings at this juncture were limited to simple weights and lengths. Weights were obtained by lifting the tree off the ground with the wheel loader and recording the weight displayed by the load cell. Weights were collected for the entire tree (before any portion was removed), for the merchantable portion of the stem (with the top and branches removed), and for each individual sawlog removed from the merchantable portion of the stem. The points at which the trees were cut was left solely to the Master Logger to maintain the similarity of this harvest to that of a standard timber harvest. The length of the merchantable stem portion and that of any logs bucked from the merchantable stem portion were recorded as part of the data collection. The small end diameters of logs bucked from the merchantable stem portion were also collected.

To obtain precise weight recordings of the trees and logs careful operation of the wheel loader was essential. Sample trees were lifted as near as possible to the balance point in between the stem and the tree's top to avoid any excess loading on either side of the wheel loader forks (Figure 23 and Figure 24). Having the tree too far to one side or the other of the combi-fork attachment may have yielded an incorrect weight reading at the load cell. Raising the tree off of the ground was performed at a slow rate to prevent the tree and the wheel loader from rocking front to back after the tree was lifted. This too may have caused an incorrect weight to be displayed by the load cell.

Once the tree or sawlog being weighed was completely off the ground and stable the load cell display was read by the loader operator and the weight was relayed to the data recorder via two-way radio. Clear and concise communication is essential between crew members using radios to avoid errors in data recording. It was decided that the data recorder would repeat the weight back to the loader operator to ensure that the correct weight was received.

The process of lifting and weighing each tree or sawlog was repeated at least twice to ensure that the weight recorded was accurate. In instances where the merchantable potion of the stem was further cut, or bucked, into shorter sawlogs the weights of each log would be determined individually and then all the logs were picked up together and weighed again so that weight could be compared the that of the merchantable stem (Figure 25). A difference in those weights would indicate that an error had been made. The calibration process for the load cell mentioned in the Heavy Equipment section was performed twice during harvest operations to ensure precise weights were being reported.

Figure 23. An image showing the wheel loader lifting an entire tree to obtain the tree's overall weight via the load cell. The tree being lifted is sample number 100, a 22.0 inch (55.88cm) diameter (DBH) black oak that weighed 7,848 lbs. (3,559.79 kg.).

Figure 24. An image of the wheel loader lifting the merchantable portion of sample tree 100's stem. The merchantable portion of the stem weighed 4,012 lbs. (1819.81 kg.) which means the tree's top weighed 3836 lbs. (1739.98 kg.). This also means that the merchantable portion and the tree's top weighed 51.12% and 48.87% of tree 100's total weight, respectively.

Figure 25. An image of the wheel loader lifting three logs to obtain the weight of the combined three. This was performed as an error checking method to see if the combined weight matched that of the merchantable portion of the tree's stem which is what these logs were cut from. An error was indicated if the weights did not match.

Sample Cross-sections

Another aspect of the field data collection process for this study was the removal and collection of cross-sections from predetermined points on the sample trees. This is a relatively common method of data collection in forestry research and methods that are similar to those used in this work can be reviewed in studies made by Myer et al. (1976), Blackmon and Ralston (1968), Manwiller (1976), Oderwald and Yaussy (1980), and Williamson and Wiemann (2009). A cross-section is a disc of wood sawn from the stem or branches of a tree so that all the growth rings at that point and the pith are visible (Figure 19). Cross-sections can provide much data and are often used in tree stem analysis to determine growth rates and the age of the tree when it reached a certain height. It also provides researchers with a portable sample of the tree's wood which can be transported to the lab for further studying which was the case in this study.

The study required at least one cross-section to be removed from each sample tree for future lab-based processing and data collection which will be discussed in detail in the Laboratory Operations section. A cross-section was cut from the top of each sample tree stump (stump height) after the tree was felled which fulfilled the requirement that each sample tree have at least one cross-section removed for further analysis. A cross-section was also cut from the small end of any logs the Master Logger bucked from the merchantable portion of the tree's stem and retained for upcoming processing and data collection (Figure 26). A cross-section from the large end of bucked sawlogs was not necessary because the large end of one log is also the small end of the log (or stump) that precedes it provided they are cut from the same stem. Figure 26 provides the reader with a visual explanation of this notion.

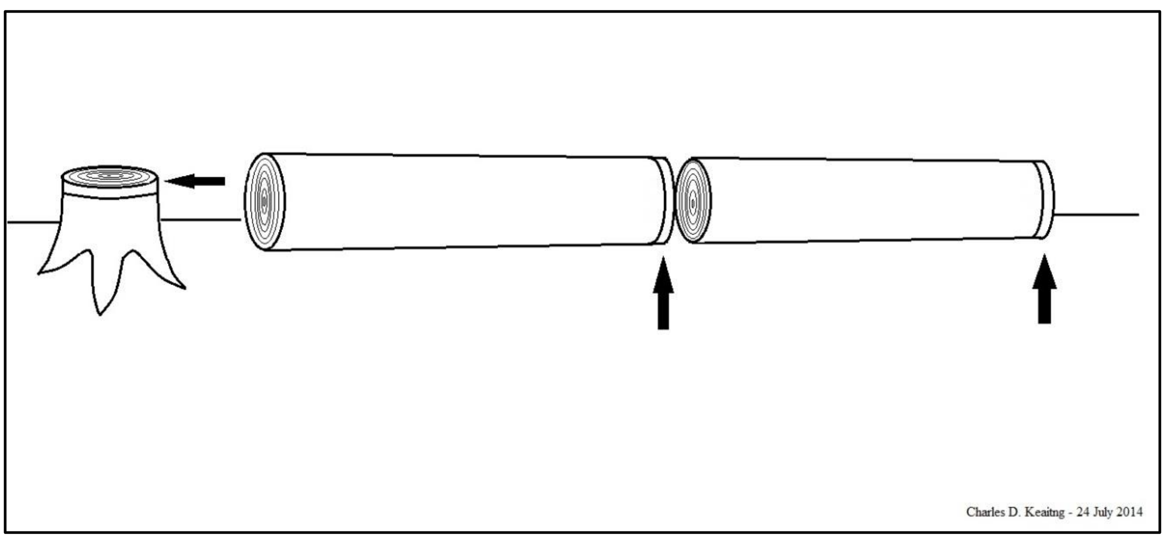

Figure 26. A diagram showing an example of a felled sample tree. The black arrows indicate the points at which cross-sections would be removed after topping and bucking the merchantable portion of the stem.

Cross-sections were gathered as they were cut and marked with the sample tree number and the log number (if applicable) so they could be identified later for data collection purposes. They were also marked to indicate the position of magnetic north in case the painted portion of the bark fell off as the disk dried. The tree stumps were marked with the sample number in case the stumps needed to be located at a later time. Figure 27 displays the author marking an example cross-section as described.

After harvesting operations had secured for the day the cross-sections were all weighed to gather the green weights. The Pesola® PHS100 digital suspension scale mentioned in the Weight Scales sub-section was used to collect the green weights. The clamp on the wheel loader’s combi-fork was left in the open position after the day’s harvest operations had concluded and the scale was suspended from the clamp using a heavy log chain. Large plastic trash bags (30 gallon size (113.56 liters)) worked well to suspend the cross-sections from the scale. A knot was tied in the bag opening that was large enough to be unable to pass through the scale hooks. The scale’s “tare” function was used to zero out the weight of the bag and a slit was then made in the side of the bag. Cross-sections were suspended in the trash bag as shown in Figure 17 and the green weight was recorded.

The outside bark diameter was also recorded for each disk. A total of 347 cross-sections were amassed from the harvest site for later processing and data collection. The collection of disks was stored in a well-ventilated building where they could air dry naturally without being exposed to the elements. The disks were allowed to air-dry for a period of approximately eight months from July 2011 to March of 2012.

Figure 27. A photograph showing the author marking a cross-section for later identification and data collection. Cross-sections were marked with the sample tree number, log number (if applicable), and the position of magnetic north in the event that the paint marked bark came loose from the cross-section. The tree stumps were also marked with the sample number in case the need to locate them later arose.

Laboratory Operations

With harvest operations completed the study focus shifted to the laboratory where much work still remained. As was previously mentioned, all 347 cross-sections were transported from the research site near Potosi, Missouri to the University of Missouri campus in Columbia, Missouri where they were allowed to air dry in preparation for the next phase of data collection and analysis.

Cross-Sections

The green cross-sections were left untouched from August 2011 until April of 2012 (~ eight months) to allow them to fully air-dry. Initial data collection in the laboratory setting was similar to that for the cross-sections at the harvest site. All cross-sections were weighed once more to obtain the air-dried weights using nearly the same method employed at the harvest site. The exception to this was the suspension scale being clamped to a support beam instead of chained to the wheel loader. As the disks dried the bark began to loosen and fall off of the cross-sections. Although this was anticipated very little could be done to prevent it from occurring or to keep the bark that had fallen off with its parent cross-section so the loss of bark is not accounted for in the air-dry cross-section weights.

Transect Removal

The cross-sections would ultimately be sawn into smaller sections so photographs were taken of each one prior to sawing for later reference. Transects 1.25 inches (3.18cm) wide were marked on all cross-sections at each cardinal direction (north, south, east, and west). Transect placement was determined by finding the mark indicating the position of magnetic north on the disk that was marked during harvest operations. A ruler was centered over that mark and the pith of the cross-section creating a stencil that would allow for a straight, even-width transect from the north face of the cross-section, over the pith and on to the south face of the disk. While being firmly held in place the sides of the ruler were traced with a construction pencil creating guidelines for the bandsaw blade. This same process was repeated for the east-west transect. However, there were no markings to indicate the position of east or west on the cross-section so the ruler had to be placed over the pith perpendicular to the north-south transect. The resulting transects formed a “plus” on the cross-section surface (Figure 28).

The length from the pith to the cambium, along with the widths of the heartwood and sapwood, were recorded in inches for each of the four cardinal directions and for every cross-section prior to sawing. On many occasions there was simply no wood to cut a transect from due to rot, checking, and/or breakage. In these instances as much data as possible would be collected but no transect would be drawn.

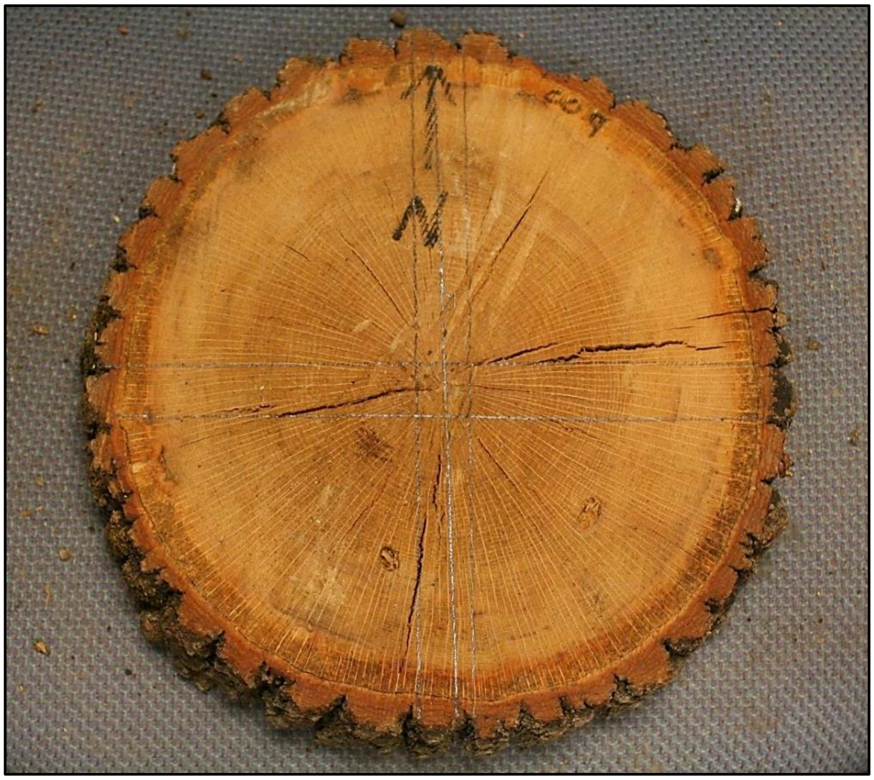

Figure 28. A photograph of a cross-section from sample tree number 009 with transects marked for removal.

A bandsaw with a 0.125 inch (0.317cm) or 1/8th inch saw blade was used to cut transects from the cross-sections. Even though the bandsaw was high powered and cut very well this was a slow process that required extreme caution. Hands and fingers were always in close proximity to the blade when sawing transects out of the cross-sections. The noise level of the saw and the sawdust vacuum system made the use of hearing protection absolutely necessary. Eye protection was also a necessary safety item along with a dust mask to avoid inhaling dust particles produced by the saw.

The north-south transect was usually the first to be sawn from the disk but the order was not important as all of the transects had to be cut out eventually. Whichever transect was started first was sawn all the way through so that the pith remained with that transect. The surface of the transects were rough and uneven having been cut with a chainsaw so once it was sawn free of the cross-section the transect was flipped 90° degrees to the left so that it was resting on a freshly sawn side. The transect was then “faced” by passing it through the saw once more removing a small amount of wood but leaving the upper surface of the transect smooth and flat and the breadth of the transect uniform throughout its length. This would aid in counting the rings and dividing the transects into even smaller pieces later on. Figure 29 provides a photo of a cross-section with the northwestern portion sawn free as an example of the sawing process. Removing sections from the cross-section in this manner was atypical and was performed for demonstrative purposes only.

Figure 29. A photograph of cross-section number 3 from sample tree 057 in the transect removal stage of processing. In this image the northwestern portion of the disk has been removed. This is an atypical method of removal meant for demonstrative purposes only.

The strip of wood removed while “facing” the transect was not discarded immediately for it retained the markings of where the pith was intersected by the remaining perpendicular transect. The strip was placed back on top of the transect from which it was cut and the existing guidelines were used to saw the pith free from the transect binding it. This method ensured the pith was cut free at the same points that were originally marked without having to re-measure or remark the guidelines on the new transect face. Upon completion of this task the author was left with two halves of a cross-section, each with a transect to be removed. The remaining transects, usually the eastern and western, were sawn free from each halve and were also faced in the manner the first transect was to produce a smoothed face and uniform thickness. Figure 30 provides an exploded view of what a cross-section would look with the transects cut from it.

Figure 30. A photograph of a cross-section from sample tree 009 after cutting the transects free and "facing" them with the bandsaw for a smoother surface and even breadth.

It was very important to mark the transects and pith cuboid immediately after cutting with whichever cardinal direction they corresponded to. By "facing" the sections to smooth their surfaces any markings originally made to distinguish the transect from its counterparts would be lost. If a problem was noticed soon after sawing the sections of wood left over from sawing the transects out of the cross-section could be placed back together, much like a puzzle, so the direction of the transect in question could be found. However, these sections were often discarded soon after cutting and it was not always possible to piece the transect back together if the position of each transect was called into question. It became standard procedure to mark each transect and the pith cuboid with a fine tipped marker direction it corresponded to. The top side of all transects and pith cuboids were also marked so that they would not be inadvertently flipped over while data were collected. All transects and pith cuboids were organized and stored in brown paper bags. The bags were marked with the sample tree number and the cross-section number for identification purposes.

Cuboid Processing

Transects that were sawn from the cross-section and placed in the paper bags would only remain in that form for a short while. To finish the collection of data the transect lengths would have to be processed into cuboids much like the pith cuboid that had already been made in the sawing process (Figure 30). The transects would be marked in one inch intervals starting at the end nearest the pith cuboid and continuing outward toward the cambium of the transect. It was unlikely that any of the transects would end on any one inch interval measured so the decision was made to leave the excess length attached to the last cuboid on the transect. The cuboids were then cut from each transect at every inch marked by a hammer and wood chisel. This produced a very clean cut in the wood without losing any material or growth rings due to saw kerf. The cuboids were marked very specifically with the sample tree number, the cross-section number, and the direction and sequence of the cuboid in its original transect. For example, marking the cuboid with “N5” indicated that that particular cuboid was the fifth cuboid from the pith on the north transect from that cross-section (Figure 19). This information would be needed later to identify the position of each cuboid in the cross-section prior to cutting. All cuboids were placed back into the paper bags that were originally holding the transects before dividing out the cuboids, for organizational purposes. Figure 31 provides a photograph of an example cross-section with the transects removed and the cuboids divided from the transects.

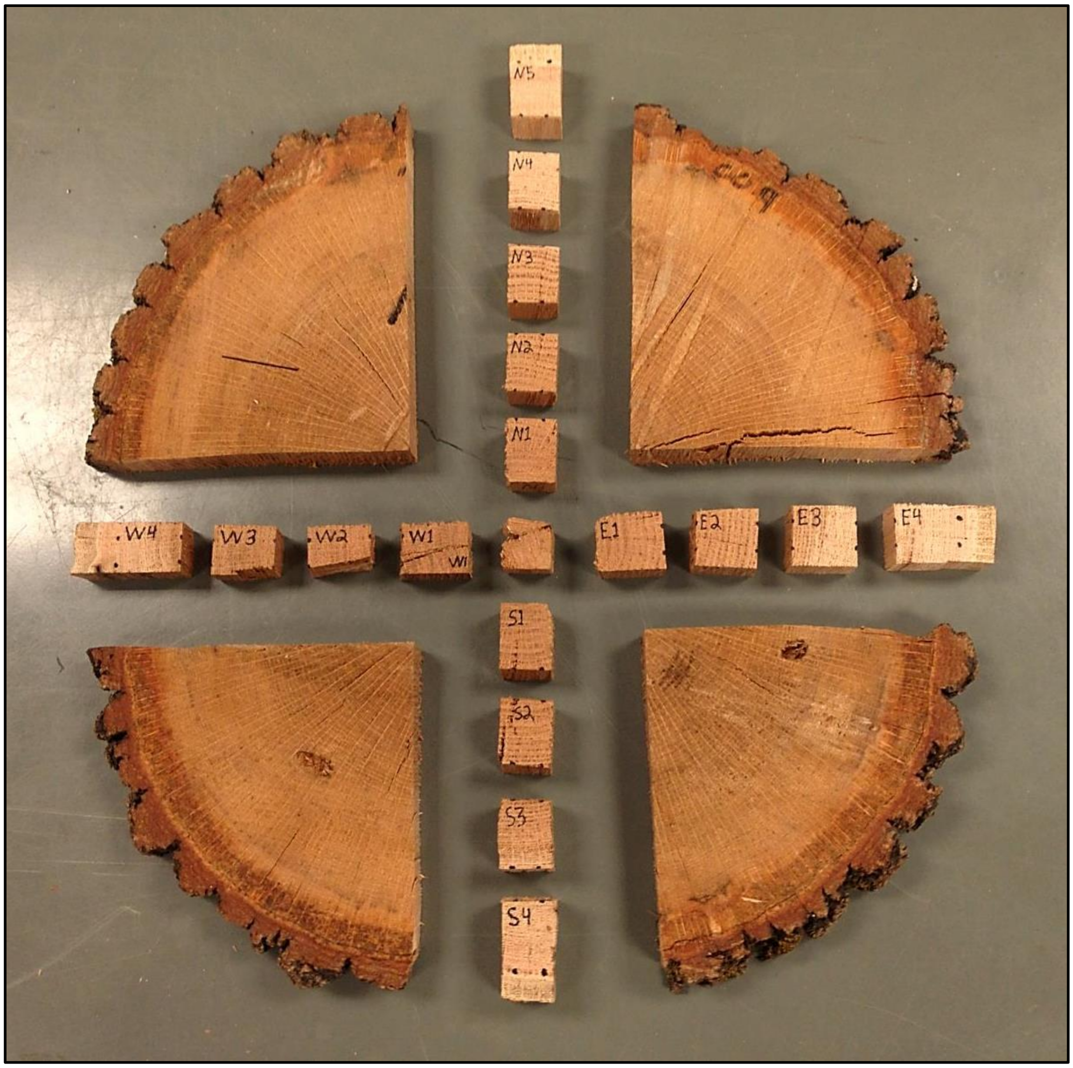

Figure 31. A photograph of a cross-section from sample tree 009 after cutting the transects free and dividing the cuboids from the transects.

Data Recorded

The extensive processing of the cross-sections into cuboids was necessary to obtain the air and oven-dried weights and volumes of each individual cuboid. The Ohaus Scout™ *Pro* Model SP401 table scale (Figure 18) was used to collect both the weight and volume of each cuboid, in grams (g) and grams per cubic centimeter (g/cm^3) respectively. While the air and oven-dried weights of each cuboid were easily obtained from the scale, obtaining the air and oven-dried volume required a slightly more difficult process.

Though there are many ways to obtain the volume of an object, the best option for this study was determined to be through measuring the water displacement (Bowyer *et al.*, 2007) of each cuboid. This is a common method used for determining the volume of irregularly shaped objects where a container of fluid is placed on a scale and the scale is then “tared” or “zeroed-out” so that the weight of the fluid and the container are no longer showing on the scale display. The object is then immersed in the fluid and the amount of that fluid displaced is registered by the scale as a weight that can be divided by the known density of the fluid used to obtain the object’s volume (Bowyer *et al.*, 2007).

The author used the Ohaus Scout™ *Pro* Model SP401 scale (Figure 18) and a glass beaker of water that had been allowed to warm to room temperature to measure the volumes of the cuboids. The object must be fully immersed in water for this method to work correctly so the author used a flexible style desk lamp affixed with a sharp dissecting needle to hold the cuboid underwater thus ensuring a stable reading of the cuboids volume (Figure 32). Holding the cuboid underwater with the dissecting needle in hand was attempted in the beginning but was not a stable enough method to produce an accurate reading of cuboid volume.

The density of water is assumed to be 1.00 g/cm^3 in this research and because the scale was measuring the weight of the displaced water in grams, the weight shown by the scale mirrored that of the cuboid volume. For instance, if the scale read 2.32 grams that meant that the volume of the cuboid being sampled was 2.32 cm^3.

It should be noted that Bowyer *et al.* (2007) mentions the water displacement and/or immersion method of obtaining volume and the need to seal dried wood samples with paraffin wax prior to submerging the sample in water to avoid erroneous reading caused by the sample absorbing water post-immersion. Expert advice was obtained from faculty members regarding the paraffin wax method and it was subsequently deemed unnecessary for this study as the cuboids were only submerged in water for a very short period of time (≤ 3-4 seconds). Also, the coating of each cuboid in paraffin wax would have added even more time to an already extremely time consuming and laborious task. It was also important to note that all cuboids created during this research were to be retained for future research projects and data collection. Coating the cuboids with paraffin wax may have made future projects and data collection impossible. Thus no effort to seal the cuboids was made.

Figure 32. An image showing the apparatus used by the author to determine the volume of the cuboids used in this study. The flexible arm of the desk lamp served well in stabilizing submerged cuboids so an accurate volume could be determined. Here a cuboid of known volume is being used to test the accuracy of this method.

Data Entry and Storage

All data produced from these operations were organized and carefully entered into Excel spreadsheets for data processing. Since computers typically do not fare well in the field due to dust, rain, and other hazards typically encountered during field work, the data collected during field operations were recorded on paper to be entered at a later date. This required careful data entry and rigorous checking for errors. In the event that data were found to be erroneous and a correction could no longer be obtained via other methods, the data were discarded and an annotation was recorded as to the reason why.

Data collection in the laboratory offered the advantage of direct entry as the data were produced. This undoubtedly led to error reductions from having to enter the data at a later time. It also allowed for changes to be made in the organization of the datasheets as the need was encountered. Once data entry was complete backup copies were made through several different methods to ensure that the work would not be lost.

Data Computations

Sample Tree and Log Weight

As one purpose of this research was to test the accuracy of the purchase of logs by weight it was necessary to calculate the volume of merchantable stems and sawlogs. The volumes produced were used to compare purchasing logs by weight to the traditional method of scaling and grading logs for purchase and also to determine if current assumptions of lbs. per board feet were accurate. Microsoft Excel was relied upon heavily to accomplish this task.

While the weights recorded in the field for the trees, merchantable stems, and sawlogs were already complete and ready for analysis, these weights were recorded while the logs were freshly cut and therefore still “green”. The air and oven-dried weights were still required for the study to continue as it was originally planned. Waiting for the logs to air-dry would have required an unreasonable amount of time to pass before the logs could be weighed again and oven drying an entire sawlog, while not impossible, would have required an immense amount of time, money, and energy. Thus, it was determined that the air and oven-dried weights of the logs would have to be calculated using data recorded from the cross-sections and cuboids.

Air-Dried (AD) Weights

To calculate the AD weights of all trees, merchantable stems, and sawlogs the green and AD weights recorded from the cross-sections were used to establish a percentage of weight lost through the drying process for each individual tree. This was achieved by dividing the AD weight of the cross-section by the green weight of the cross-section recorded at the harvest site (Equation 1). This percentage was calculated for every cross-section removed from each individual sample tree.

Equation 1:

$$\textbf{Percent Weight Change }(\%\boldsymbol{\Delta}\textbf{Wt}) = \frac{\textbf{Air Dried Weight }(\textbf{lbs.})}{\textbf{Green Weight }(\textbf{lbs.})}$$

The resulting percentages were then summed and averaged for each individual tree so that the resulting average could be multiplied by its respective percentage of weight change (Equation 2). This process was performed for every cross-section and sample tree for which data were available.

Equation 2:

$$\textbf{Average }(\%\boldsymbol{\Delta}\textbf{Wt}) = \frac{\sum \%\boldsymbol{\Delta}\textbf{Wt}}{\textbf{n}}$$

Where:

$\%\Delta Wt$ = percentage of weight change

$\sum\%\Delta Wt$ = sum of all weight change observations (observations of zero were omitted)

n = number of weight change observations

Once the total tree AD weight loss conversion factor was determined for each sample tree it was multiplied by that same tree's green weight (whole tree weight, merchantable stem weight, and the weight of the sawlogs removed from each merchantable stem, if any) to calculate what that tree would have weighed if given enough time to air-dry in the field.

Some instances were encountered where no cross-sections were available for a sample tree or where the data were corrupted or lost. Rather than exclude these instances from this study a separate average weight loss percentage was established for each of the four species (*Quercus velutina, Q. alba, Q. stellata, and Carya spp*.). The percentages of weight loss for each sample tree were separated into species groups and an average was generated from all sample trees for each of the four species. This average was then used in place of the missing data so that an estimated air-dry weight could be established for those trees missing the required cross-sectional data. Care was taken to utilize formulae that would exclude null values and zero values to avoid erroneous skewing of the data.

Oven-Dried Weights

Virtually the same process used in calculating the AD weight conversions was also used to calculate the oven-dried weight conversions for the trees, merchantable stems, and sawlogs. However, most of the cross-sections were too large to oven-dry and weigh again. Thus, the oven-dried weight conversion factors would have to be calculated using data recorded from the cuboids. This increased the amount of steps needed for calculating the oven-dried weights but the process was much the same.

The air and oven-dried weights were already recorded for the cuboids during earlier laboratory work. The percentage of weight loss for each cuboid during the oven-drying process was determined just as the percentage of weight loss, from green to AD weight, was for the cross-sections; by dividing the oven-dried weight by the AD weight (Equation 1). There were multiple cuboids within each cardinal transect and thus, an average would have to be produced for each transect. This same method of calculation was used to determine an average weight loss conversion for each sample tree in the previous section (Equation 2). Afterword the average percentages of weight loss for each cardinal transect would have to be summed and averaged once again to produce a conversion factor of weight loss for the cross-section as a whole.

The oven-dried weight loss percentage was then multiplied by the AD weight recorded for each cross-section to calculate what that cross-section would weigh if it were oven-dried. This process was repeated for each cross-section within each sample tree and an average weight loss percentage for each individual tree was produced. The whole tree, oven-dried weight loss percentage was then multiplied by the previously determined AD weight for that specific sample tree in order to calculate the oven-dried whole tree, merchantable stem, and sawlog weights.

This method was again applied to all specimens in the study and the resulting percentages were compiled into species groups (*Quercus velutina, Q. alba, Q. stellata, and Carya spp*.) and averaged. Once a species specific oven-dried weight loss average was determined for all four species, that average was applied to any sample tree that were missing the data required to produce an oven-dried weight loss percentage. Care was taken to utilize formulae that would exclude null values and zero values to avoid erroneous skewing of the data.

Volume Determination

Beers' (1964) equations for volume calculation were utilized to determine the volume of the merchantable stems and sawlogs. In order to use Beers' volume equations one must calculate three different factors using three different equations and data recorded from sample trees. These equations are very easily set up in Microsoft Excel and once the sample data are entered the volume of wood in a sample tree can be calculated in cords, cubic feet (both with and without bark), and board feet in International ¼ inch scale. The calculations in this research were limited to cubic feet without bark and International ¼ inch scale.

Once a good determination of volume is made an estimation of the amount of board feet are available can also be made. When one attempts to calculate the board feet found within a sawlog it is necessary to account for the slabbing or the removal of the side slabs of bark and wood to produce a cant from which boards or timbers can be cut. This action reduces the volume of wood available in the sawlog for lumber production. The saw kerf, or width of the cut made by the saw blade, and the shrinkage of wood through evaporation must also be taken into consideration when attempting to calculate the amount of board feet in the merchantable portion of the stem or bole. According to Husch *et al.* (2003, p. 219) it is generally acceptable to assume that six board feet can be produced from every one cubic foot of wood after accounting for saw kerf and evaporative shrinkage. Log rules and scaling methods such a Doyle, Scribner, and International ¼" are another option available and are often used to estimate the available board feet within a sawlog prior to actually sawing the log into boards.

Specific Gravity Determination

Many people incorrectly believe that specific gravity and density are one in the same. In reality, specific gravity is the ratio of the density of an object to the density of fresh water that object would displace (Equation 3) if submerged. Because it is a ratio, specific gravity data is recorded without units of measurement.

Equation 3:

$$\boldsymbol{Specific\ Gravity = \frac{Density\ of\ Object}{Density\ of\ Water\ (H_2O)}}$$

The specific gravity of the sample trees and logs while still in a "green" state were not collected in this study for several reasons. Finding the specific gravities would have required the immersion of each cross-section in water in both green and AD conditions. This was simply not feasible in the field setting because it would have required a large amount of water and because the temperature of the water needed to be kept somewhat constant for accurate recordings. This also presented a problem in the laboratory setting as many of the cross-sections were too large to immerse in water intact. Also, debris from such large samples would have contaminated the water in both the field and the laboratory settings and would have led to erroneous data recordings. It was decided early on in the data collection phase that specific gravities would only be collected from the cuboids since they were much smaller and cleaner samples to work with. This would mean that specific gravities would only be collected for the air and oven-dry stages of the samples.

The procedure for calculating the specific gravities of the individual sample trees is similar to that for calculating the air-dry and oven-dry weight conversion factors. Data collected during the cuboid processing and measurement were already available. Of this data that were already collected were the densities of each cuboid. The density of each cuboid was determined using equation 4. Since the density is measured using grams per cubic centimeter, and the density of water in this study is assumed to be 1 gram per cubic centimeter (1 g/cm^3), the density of each cuboid and its specific gravity are congruent.

Equation 4:

$$\boldsymbol{\rho\ (g/cm^3) = \frac{M\ (g)}{V\ (cm^3)}}$$

Where:

ρ = Density in grams per cubic centimeter

M = Mass in grams

V = Volume in cubic centimeters

The density/specific gravity data for the cardinal transects of each cross-section, as well as the data for each cross-section’s individual pith, were compiled into Excel spreadsheets for processing and analyzing. The density/specific gravity values for each cuboid were summed and averaged with the data from the other cuboids in the transect much like the percentages of weight change were (see equation 2) to determine an average for each transect. The averages for each transect were then combined into an average value for each cross-section as a whole.

Once an average was obtained for each cross-section the data were sorted into species groups (*Quercus velutina, Q. alba, Q. stellata, and Carya spp*.) and further combined to obtain a good average for each species group for both AD and oven dried specific gravity. Once the species averages were obtained missing data were supplemented on a per species basis with the newly calculated averages from each cross-section. Whenever an average specific gravity was used the cell containing that data was filled in with a color to designate it as an average value in case the removal or sorting of the averages used was deemed necessary.

The data generated up to this point were for one cross-section only and thus, the data for multiple cross-sections from within one tree would have to be combined. To facilitate this, the "VLOOKUP" function found in Excel was used to compile the data efficiently and to minimize error. Once all specific gravity values were amassed into one row for one sample tree the specific gravities were averaged again on a per tree basis. Once again the values produced from these calculations were sorted by species groups (*Q. velutina, Q. alba, Q. stellata, and Carya spp*.) so that an average of air-dry and oven dry specific gravity was available for all the species sampled in this study. Care was taken to utilize formulae that would exclude null values and zero values to avoid erroneous skewing of the data.

CHAPTER 3: RESULTS

Figure 33 displays the frequency of occurrence of the sample trees from which the data in this research were collected based upon diameter class and species. A tabled compilation of this data may also be reviewed in Table 4. Summary statistics such as minimum and maximum values along with mean, median and the range of the computations of the resultant weight-based calculations are compiled in Table 5. Much of the data collected, of which the calculations in Table 5 are based upon, may be reviewed in the appendices of this research. The highest frequency of samples occurs in the smaller diameters from the 8 inch (7.1 – 9.0 inches) to the 18 (17.1 – 19.0 inches) inch diameter classes. Sample trees in the larger diameter classes were very difficult to find at the research site and more samples were taken in the 8 to 18 inch diameter classes than originally planned for in order to reach the target goal of 220 trees.

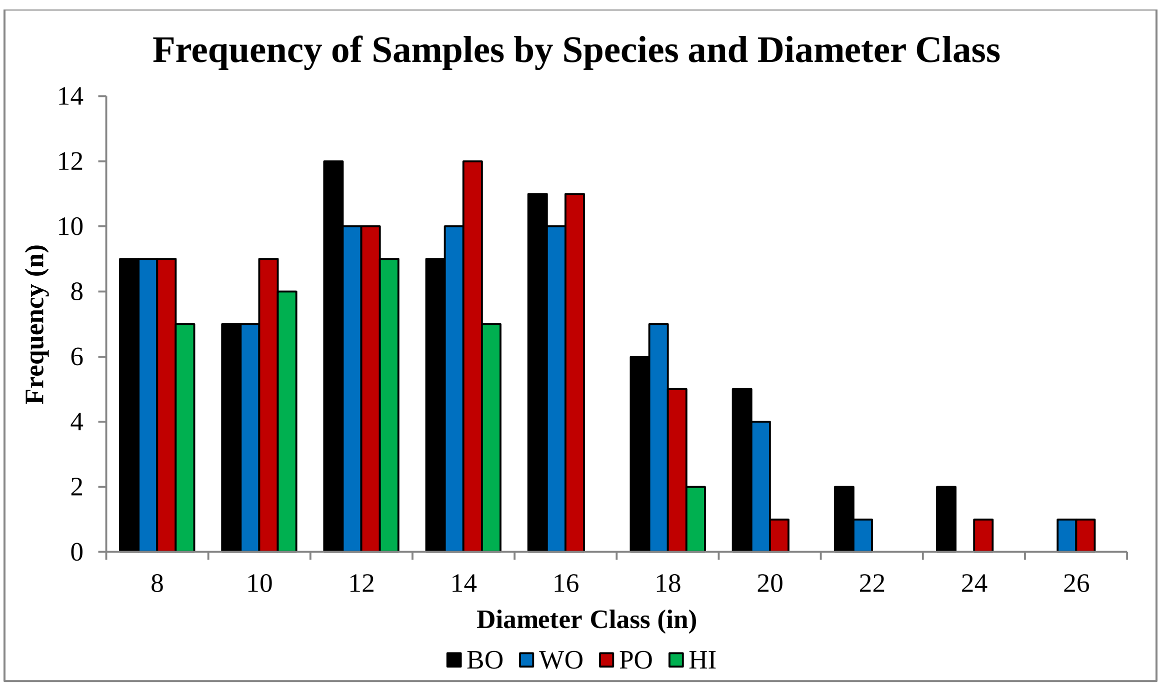

Figure 33. Sample tree frequency based upon two-inch diameter classes and species groups.

Figure 34 illustrates the average weight of the whole trees for each species and is separated into diameter classes. The weights presented are those of the whole tree following felling and no portion of the sample tree had been removed at the time the sample was weighed. Comparisons to whole tree weight and actual merchantable weight will be made on a per species basis in later sections of this research.

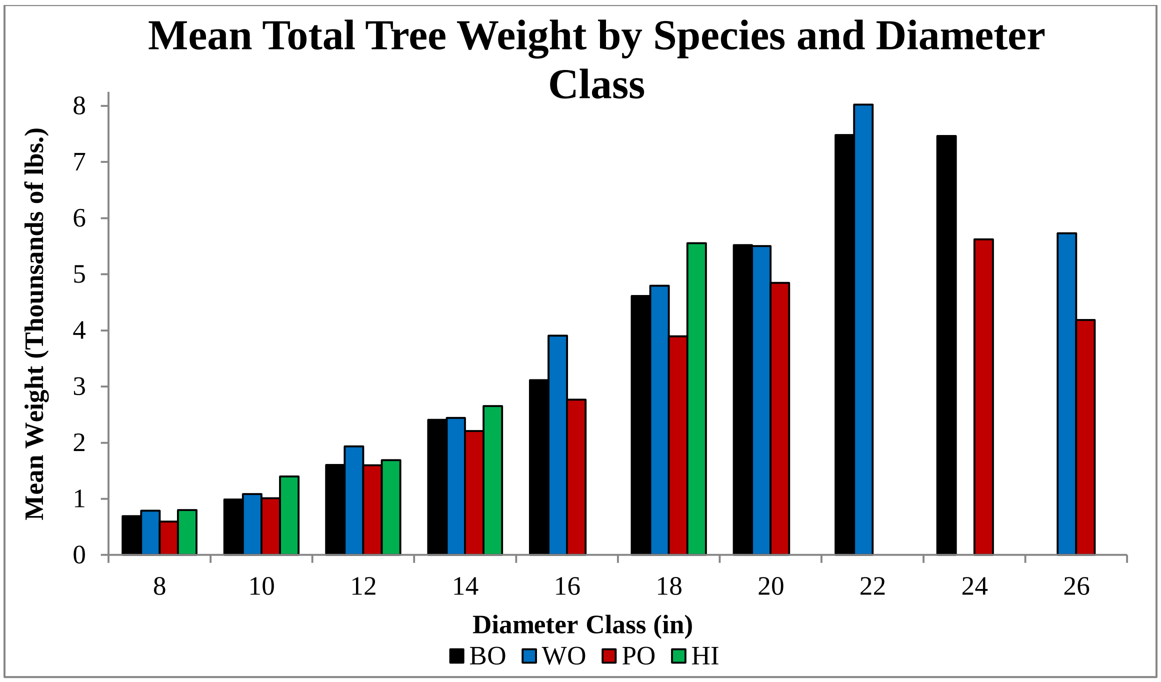

Figure 34. Mean whole tree weights of all species separated into diameter classes.

Weight & Density Computations

An important aspect of this research was to ascertain an accurate average green weight to assign, on a board feet (bf) basis, to the four species groups in this investigation. Figure 35 presents the data calculated regarding this aspect of the study. Green weight averages are 11.36 lbs./bf for black oak, 11.17 lbs./bf for white oak, 11.23

lbs./bf for post oak, and the average for hickories was 11.22 lbs./bf. Air-dried and oven-dried averages are presented in Figure 35 and the specific values are listed in Table 5. Arriving at the averages posted in Figure 35 required many other calculations to be made based on the field data collected. Cubic volumes, wood density, and a reduction factor for each species (to calculate weights based on different moisture classes) are just a few of the calculations that had to be made prior to presenting the board foot averages. The results for these areas are discussed in the species specific section of this chapter.

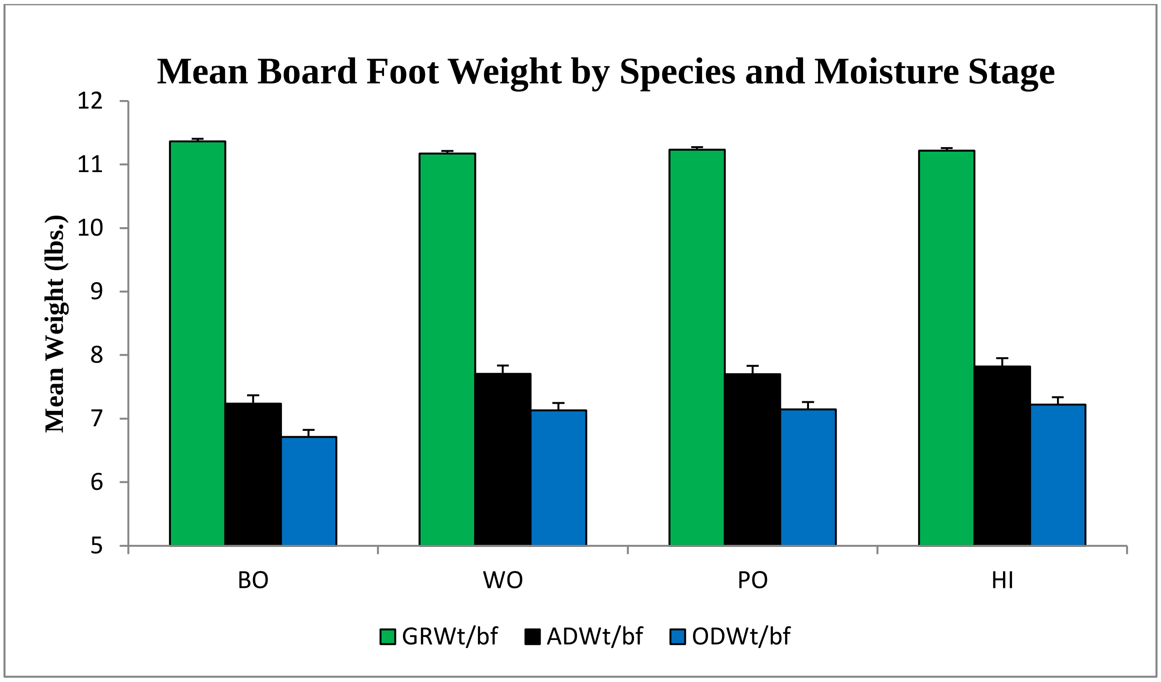

Figure 35. A histogram representing the average weight per board foot in pounds (lbs.) computed for each species in green (GRWt/bf), air-dried (ADWt/bf), and oven-dried (ODWt/bf) moisture classes.

Figure 36 displays the average weight computed per cubic foot for the study species. Green weight averages are 61.51 lbs./ft^3 for black oak, 59.83 lbs./ft^3 for white oak, 59.41 lbs./ft^3 for post oak, and the average for hickories was 60.09 lbs./ft^3. Air-dried and oven-dried averages are also presented in Figure 36 and the specific values are listed in Table 5. A more specific account of the data recorded and calculated can be found in the species specific sub-sections of this chapter.

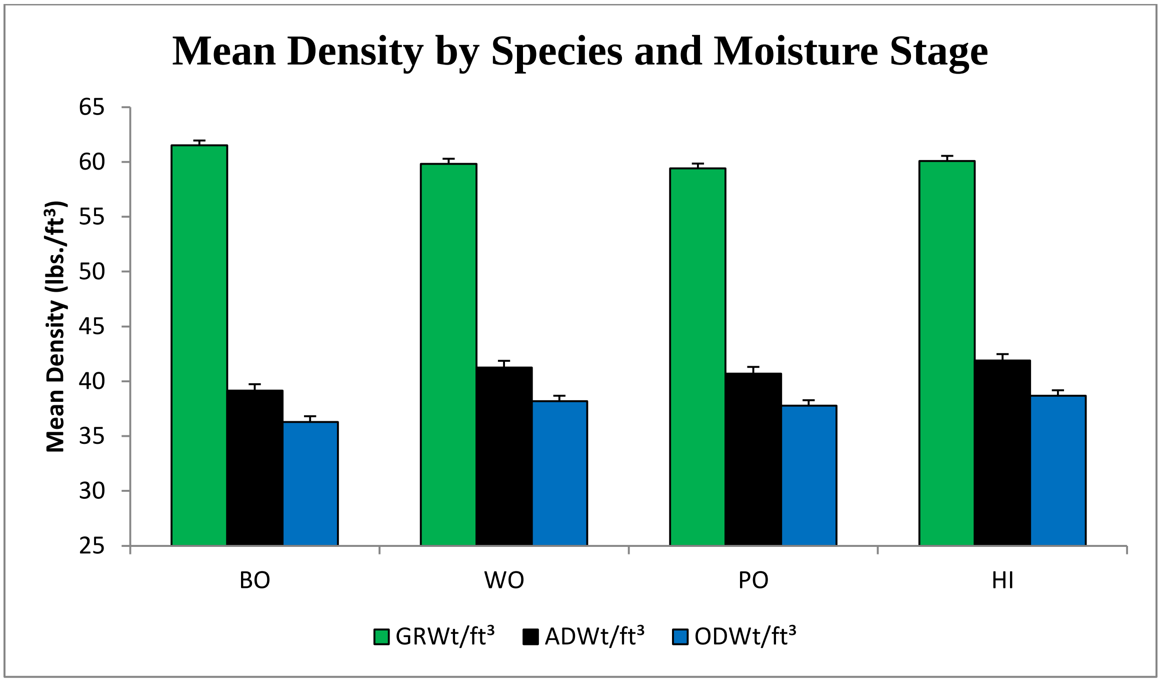

Figure 36. A histogram representing the average weight per cubic foot in pounds (lbs.) computed for each species in green (GRWt/ft^3), air-dried (ADWt/ ft^3), and oven-dried (ODWt/ ft^3) moisture classes.

Table 5. Summary statistics of computed weight information for various characteristics of the species focused on in this research.

	SPP	DBH	THt(ft)	MHt(ft)	TGrWt(lbs.)	MGrWt(lbs.)	%ΔWt	TADWt(lbs.)	MADWt(lbs.)	%ΔWt	TODWt.(lbs.)	MODWt.(lbs.)	Vol-IB(ft³)	Vol-EB(ft³)	VolBF(Int. ¼)	GRWt/ft³	ADWt/ft³	ODWt/ft³	GRWt/bf	ADWt/bf	ODWt/bf
Quercus velutina (black oak) n = 58																					
Min	BO	7.30	40.02	16.90	573.00	352.00	0.467	298.20	164.27	0.903	275.41	151.71	4.77	3.73	24.99	42.58	27.04	25.09	7.74	4.70	4.38
Max	BO	24.00	84.64	64.40	9347.00	5665.00	0.727	5173.05	3135.26	0.944	4847.14	2937.74	110.89	86.78	658.27	91.56	55.45	51.35	17.21	10.42	9.65
Mean	BO	14.03	57.28	30.82	2754.37	1701.00	0.635	1734.85	1067.75	0.928	1609.47	990.45	28.90	22.62	159.90	61.51	39.14	36.29	11.36	7.23	6.71
Median	BO	13.60	56.37	28.00	2314.00	1455.00	0.635	1494.45	982.80	0.928	1406.05	912.87	22.41	17.54	122.02	61.58	39.49	36.54	11.47	7.40	6.87
Range	BO	16.70	44.62	47.50	8774.00	5313.00	0.261	4874.85	2971.00	0.041	4571.74	2786.03	106.11	83.05	633.29	48.98	28.41	26.26	9.47	5.72	5.28
Quercus alba (white oak) n = 56																					
Min	WO	7.10	34.13	12.30	352.00	176.00	0.570	242.88	121.44	0.857	226.03	113.02	3.87	3.03	20.25	27.19	19.52	18.22	4.91	3.52	3.29
Max	WO	25.10	79.25	44.40	8024.00	4276.00	0.808	5711.13	3043.47	0.944	5359.45	2856.06	98.07	76.75	543.29	101.54	70.64	65.41	19.13	13.31	12.33
Mean	WO	13.78	58.46	27.10	2804.25	1389.58	0.690	1930.88	953.99	0.926	1790.97	884.43	24.38	19.08	131.57	59.83	41.26	38.18	11.17	7.71	7.13
Median	WO	13.35	57.86	26.81	2424.50	1223.00	0.690	1609.68	839.10	0.926	1485.21	780.55	20.16	15.78	107.02	59.10	40.53	37.59	10.93	7.56	7.01
Range	WO	18.00	45.12	32.10	7672.00	4100.00	0.238	5468.25	2922.03	0.088	5133.41	2743.04	94.21	73.73	523.04	74.35	51.12	47.19	14.23	9.79	9.04
Quercus stellata (post oak) n = 50																					
Min	PO	7.30	28.25	10.85	330.00	220.00	0.550	220.00	150.48	0.902	203.04	143.14	3.02	2.37	15.71	25.89	17.26	16.21	4.91	3.27	3.07
Max	PO	25.20	65.11	36.50	5621.00	3659.00	0.778	3816.73	2495.38	0.951	3541.92	2315.72	63.42	49.63	346.76	80.71	55.20	51.07	15.30	10.46	9.68
Mean	PO	13.29	50.71	21.78	2060.49	1074.03	0.684	1416.95	736.85	0.928	1314.64	683.72	18.52	14.49	98.28	59.41	40.71	37.77	11.23	7.70	7.14
Median	PO	13.30	50.21	21.45	1829.00	947.00	0.684	1245.28	663.48	0.928	1155.13	615.71	15.74	12.32	83.53	60.13	41.48	38.47	11.49	7.79	7.18
Range	PO	17.90	36.86	25.65	5291.00	3439.00	0.228	3596.73	2344.90	0.050	3338.88	2172.57	60.39	47.26	331.06	54.82	37.94	34.86	10.39	7.19	6.61
Carya spp. (hickories) n = 26																					
Min	HI	7.20	35.94	15.10	551.00	208.00	0.571	386.25	145.81	0.904	356.90	134.73	3.59	2.81	18.76	32.09	22.49	20.78	6.12	4.29	3.96
Max	HI	17.90	84.33	43.05	6814.00	2050.00	0.950	5046.81	1396.38	0.943	4730.43	1317.19	34.28	26.83	182.65	79.85	52.15	48.16	15.08	9.94	9.12
Mean	HI	11.46	54.96	27.01	1868.97	964.48	0.701	1309.61	673.87	0.923	1212.59	623.43	16.37	12.81	88.18	60.09	41.90	38.68	11.22	7.82	7.22
Median	HI	11.00	54.57	25.45	1565.00	859.00	0.701	1106.18	643.85	0.924	1021.66	594.91	14.74	11.54	79.35	61.24	42.93	39.67	11.24	8.11	7.50
Range	HI	10.70	48.39	27.95	6263.00	1842.00	0.379	4660.56	1250.57	0.040	4373.53	1182.46	30.69	24.02	163.89	47.77	29.65	27.38	8.96	5.65	5.16

Species Specific Results

Quercus velutina – black oak

Sample Weights

Black oaks were easily the most prevalent of the sample species found at the research site and account for 65 of the 220 (29.55 %) trees harvested and sampled for this research. Whole tree and merchantable weights in pounds are displayed graphically for the specimens in green, AD, and OD states in Figure 37 and Figure 38. Summary statistics for data collected on the specimens in this study are displayed in Table 5.

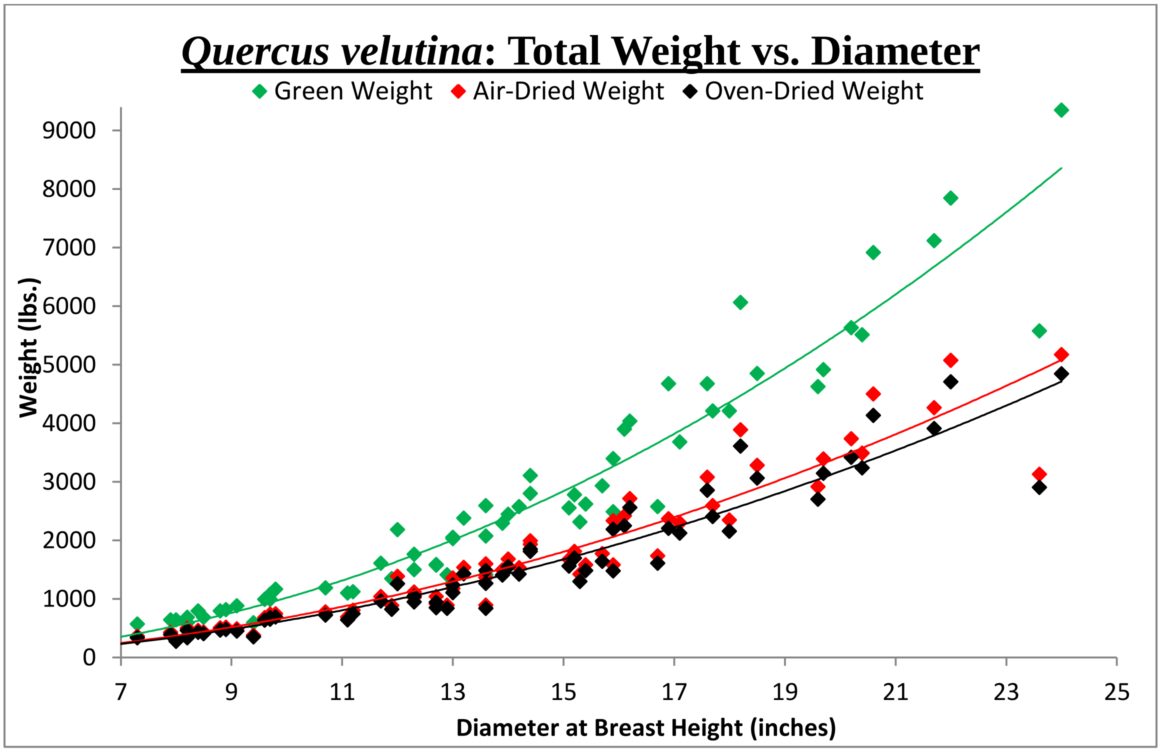

Figure 37. A graphical comparison of *Q. velutina* total weights in various stages of moisture loss. This graph displays the diameter and weight of each *Q. velutina* sample tree in green, AD, and oven-dried stages.

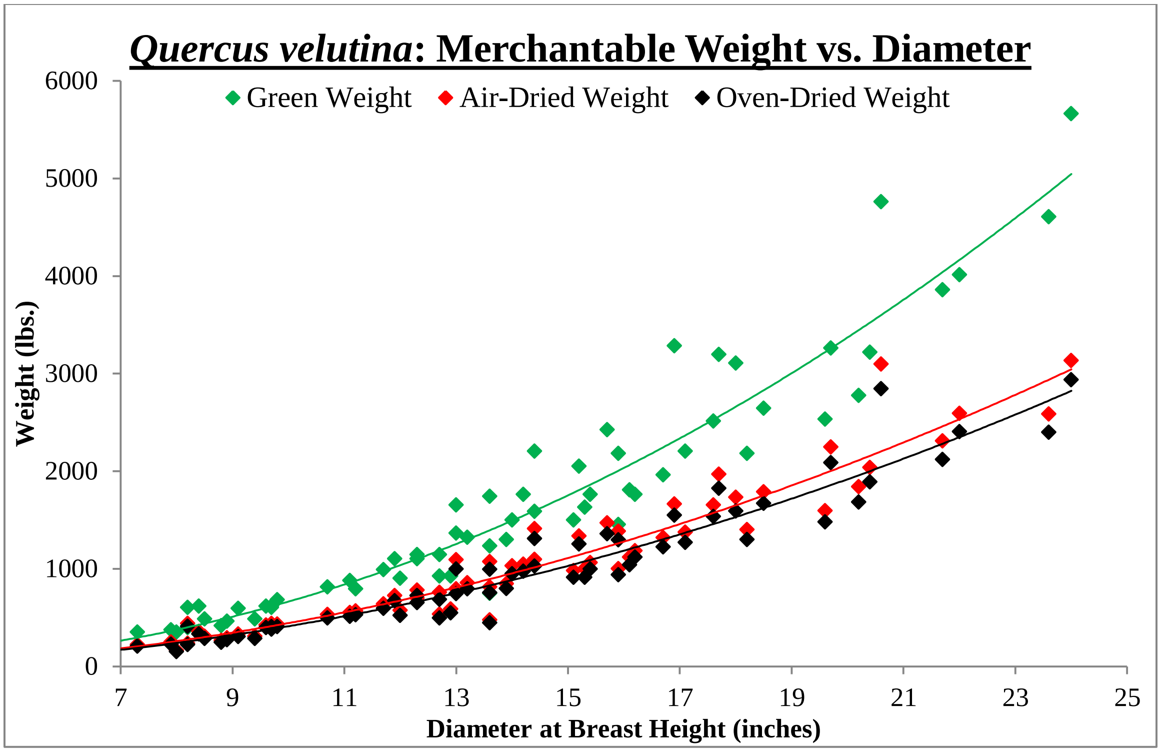

Figure 38. A graphical comparison of *Q. velutina* merchantable weights in various stages of moisture loss. This graph displays the diameter and weight of each *Q. velutina* sample tree in green, AD, and oven-dried stages.

Minimum and maximum black oak total tree weights were 537 lbs. (243.58 kg.) and 9,347 lbs. (4,239.73 kg.), respectively while removal of the tops and limbs reduced the maximum and minimum merchantable stem weights to 352 lbs. (159.66 kg.) and 5,665 lbs. (2,569.60 kg.), respectively. The average and median weights of whole tree black oak samples were 2,754.73 lbs. (1,249.52 kg.) and 2,314.00 (1,049.61 kg.), respectively and removal of the tops and limbs reduced the average and median weights of the merchantable stems to 1,701.00 lbs. (771.56 kg.) and 1,455.00 lbs (659.98 kg.).

The compilation of all data from the cuboids provided an average green-to-air-dried weight reduction factor of 0.635 (%ΔWt.= percent change in weight) for all black oak samples meaning that on average an AD black oak sample tree would weigh only

63.5 % of its original green weight. When the 0.635 reduction factor was applied, essentially subtracting 36.5% of the original weight, it reduced the minimum and maximum whole tree weights to 298.20 lbs (135.26 kg.) and 5,173.05 lbs. (2,346.46 kg.), respectively, with whole tree mean and median weights of 1,734.85 lbs. (786.91 kg.) and 1,494.45 lbs. (677.87 kg.), correspondingly. The maximum and minimum merchantable stem weights were reduced to 164.27 lbs. (74.51 kg.) and 3,135.26 lbs. (1,422.13kg.), respectively, and the merchantable mean and median weights to 1,067.75 lbs. (484.32 kg.) and 982.80 lbs. (445.79 kg.), respectively.

The weight reduction factor calculated for extrapolating the oven-dried weight for black oaks was 0.928 meaning that an oven dried sample of black oak would weigh 92.8% of that same sample in an AD state, a reduction of 7.2%. Factoring in the percentage further reduced the AD weight of the total trees to a minimum and maximum weight of 257.41 lbs. (116.64 kg.) and 4,847.14 lbs. (2,198.63 kg.) with whole tree mean and median weights of 1,609.47 lbs. (485.10 kg.) and 1,406.05 lbs. (637.77 kg.). Merchantable weights were reduced to a minimum of 151.71 lbs. (68.81 kg.) and a maximum of 2,937.74 lbs. (1332.38 kg.), with an arithmetic mean of 990.45 lbs. (449.26 kg.) and a median weight of 912.87 lbs. (414.07 kg.).

Figure 39 provides a visual of the differences in total tree weight and the merchantable weight of the stem that was produced after the top and limbs were removed by the logger. Figure 40 displays the differences in mean board foot weights in green, AD and OD moisture classes. Both of the following graphs are separated into the diameter classes that the sample trees were collected by in this research.

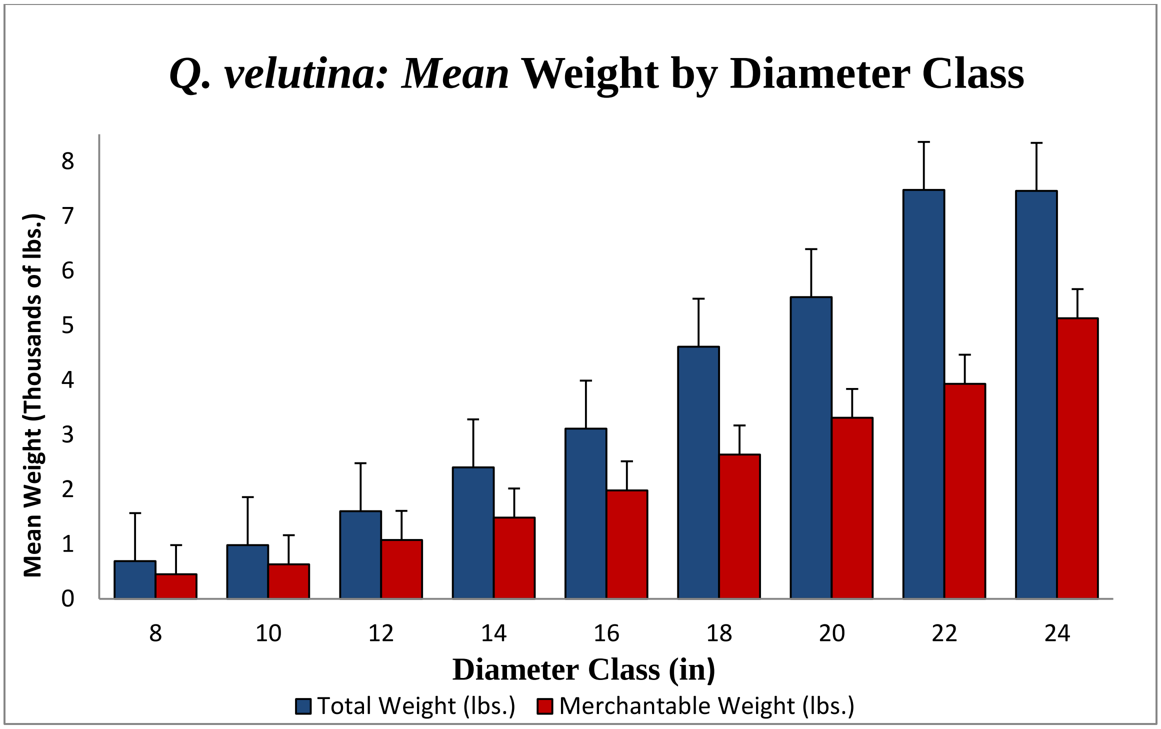

Figure 39. A histogram displaying the differences in mean total tree weight and mean merchantable stem weight for *Q. velutina* sample trees.

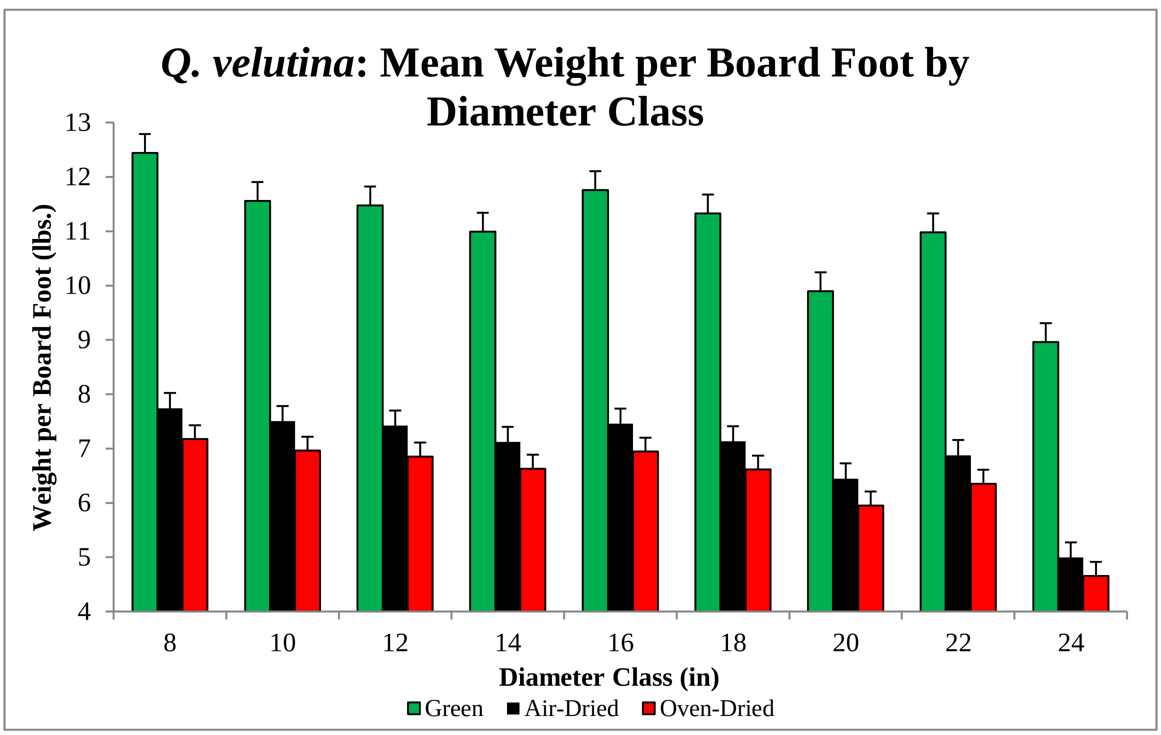

Figure 40. A visual representation of the mean board foot weight of *Q. velutina samples* by moisture and diameter classes.

Sample Volumes

Summary statistics for volume data can also be found in Table 5 and the full data set can be reviewed in Appendix A. All volumes were calculated using Beers' (1964) formula for volume estimation. The smallest volume for a black oak sample tree was calculated to be 4.77 ft^3 (0.14 cubic meters (m^3)) whereas the largest volume was 110.89 ft^3 (3.14 m^3). Arithmetic mean and median volumes were 28.90 ft^3 (0.82 m^3) and 22.41 ft^3 (0.63m^3), respectively. These volumes are calculated with tree bark included but volumes without the bark can be reviewed in Table 5. Merchantable volumes of sample black oaks were also calculated in terms of board feet using Beers' (1964) formulas which estimates board feet based on International ¼" log scale. There is no comparable metric unit in respect to the board foot and thus no metric conversion is listed following the board foot volumes. Minimum board foot volumes were 24.99 bf on the smallest volume sample with 658.27 bf contained within the largest volume sample tree. Mean board foot volume for the black oaks was 159.90 bf with a median of 122.02 bf.

Sample Density

Densities for the black oaks sampled in this research were also calculated and were recorded in green, AD, and OD states (Table 5). The minimum and maximum green density for black oak was 42.58 lbs. /ft^3 and 91.56 lbs. /ft^3, respectively. Mean and median green densities were 61.51 lbs. /ft^3 and 61.58 lbs. /ft^3, correspondingly. The minimum and maximum AD density for black oak was 27.04 lbs. /ft^3 and 55.45 lbs. /ft^3, respectively. Mean and median AD densities were 39.14 lbs. /ft^3 39.49 lbs. /ft^3, correspondingly. The minimum and maximum OD density for black oak was 25.09 lbs. /ft^3 and 51.35 lbs. /ft^3, respectively. Mean and median OD densities were 36.29 lbs. /ft^3

and 36.54 lbs. /ft^3, correspondingly. Figure 41 shows the mean densities for all moisture and diameter classes sampled in this research.

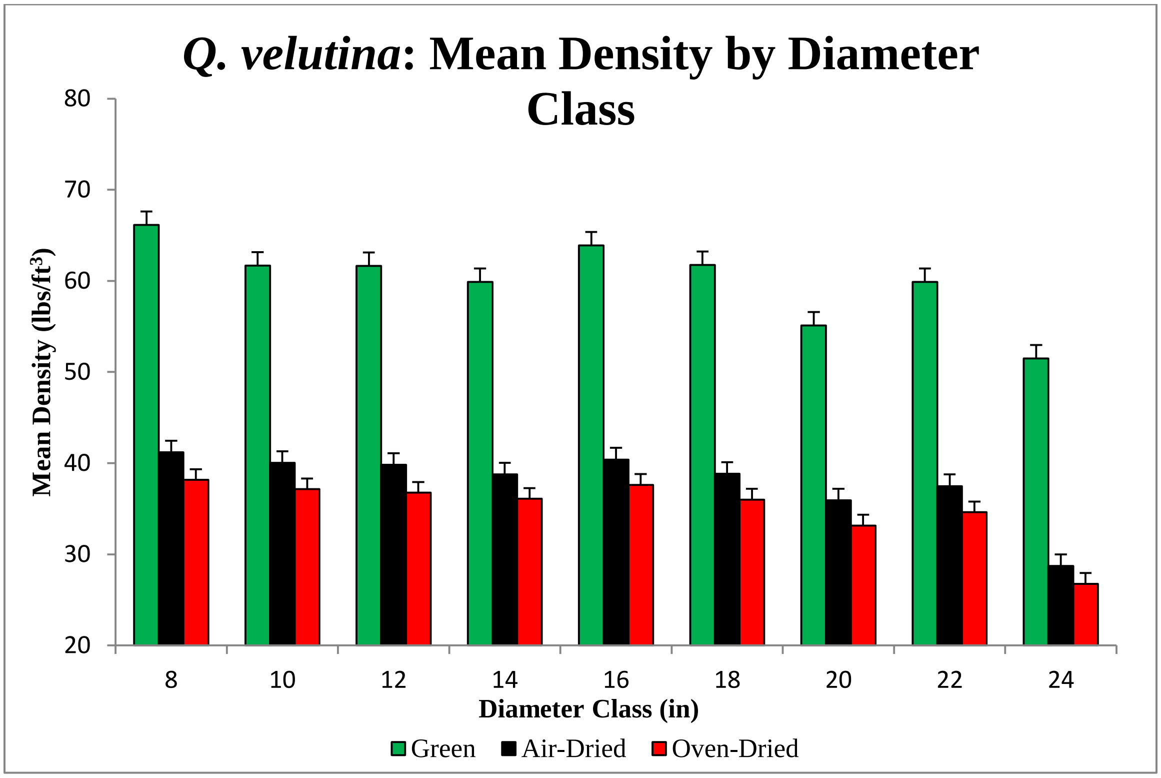

Figure 41. A histogram displaying the mean density of *Q. velutina* wood in pounds per cubic foot (lbs./ft^3). Averages are shown for all three moisture classes and are separated by diameter classes.

Quercus alba – white oak

Sample Weights

White oaks were the second most prevalent of the sample species found at the research site and accounted for 60 of the 220 trees harvested (27.27%) and sampled for this research. Whole tree and merchantable weights in pounds are displayed graphically for the specimens in green, AD, and oven dried states in Figure 42 and Figure 43. Summary statistics for data collected on the specimens in this study are displayed in Table 5.

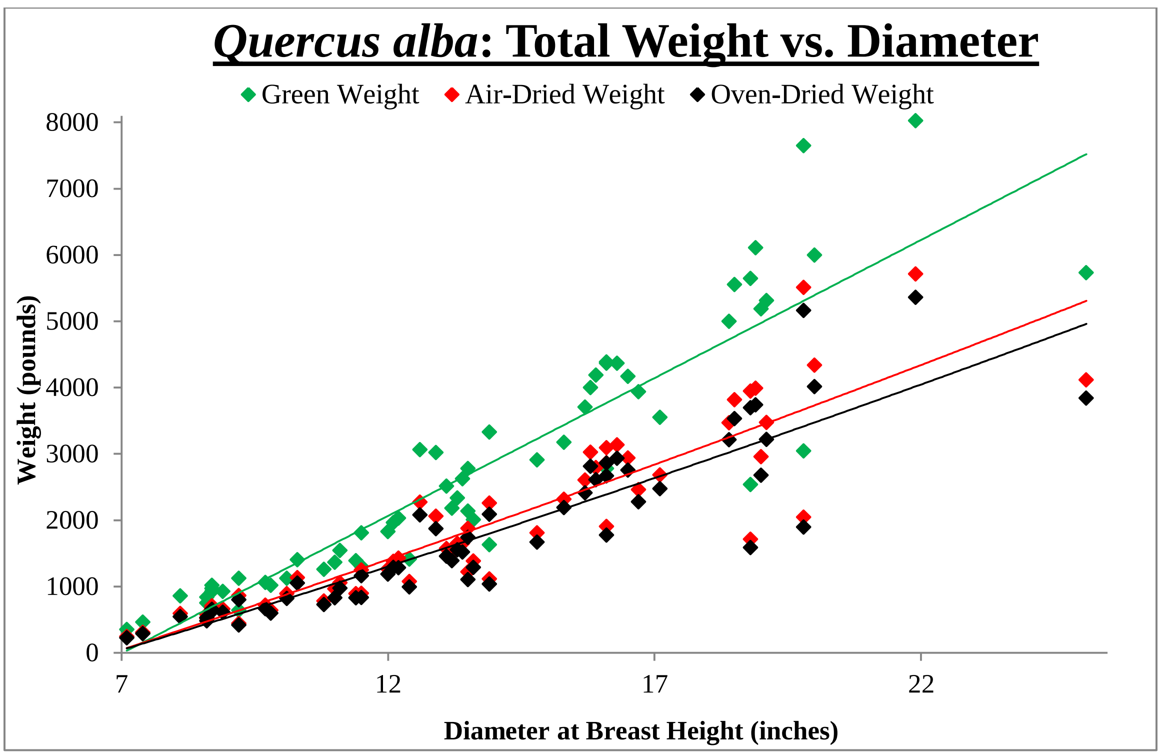

Figure 42. A graphical comparison of Q. alba total weights in various stages of moisture loss. This graph displays the diameter and weight of each Q. alba sample tree in green, AD, and oven-dried stages.

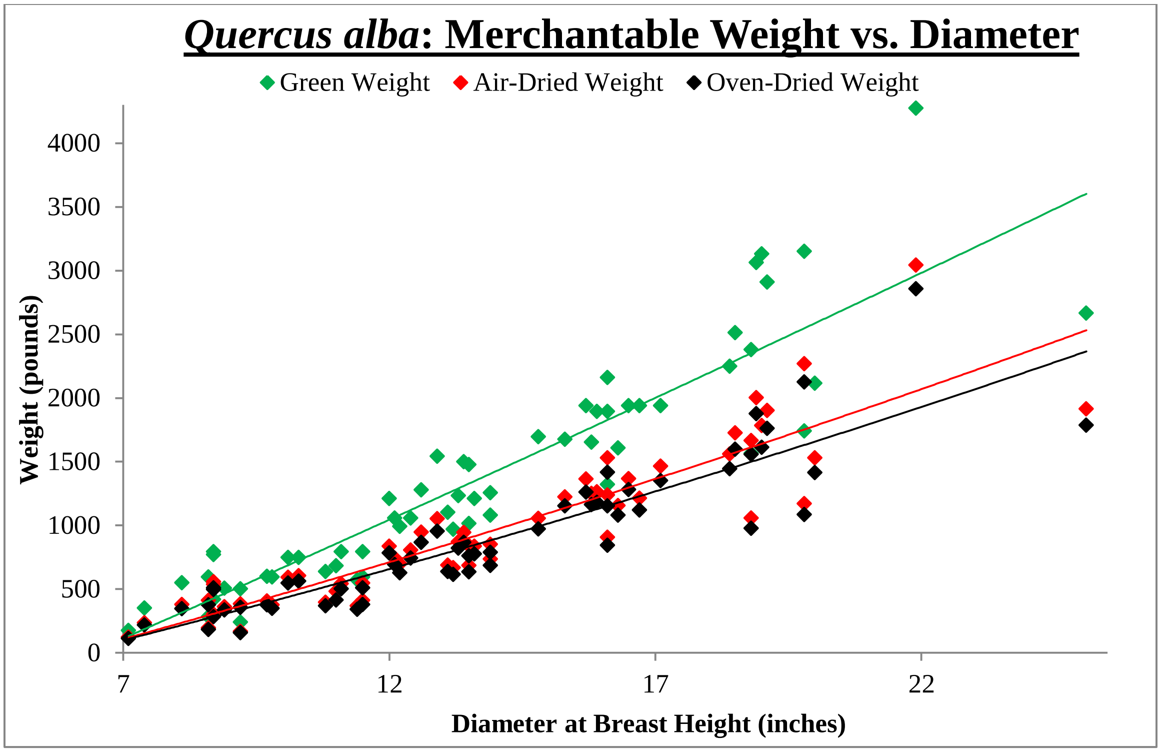

Figure 43. A graphical comparison of Q. alba merchantable weights in various stages of moisture loss. This graph displays the diameter and weight of each Q. alba sample tree in green, AD, and oven-dried stages.

Minimum and maximum white oak total tree weights were 352.00 lbs. (159.66 kg.) and 8,024.00 lbs. (3,639.63 kg.), respectively while removal of the tops and limbs reduced the maximum and minimum merchantable stem weights to 176.00 lbs. (159.66 kg.) and 4,276.00 lbs. (1,939.56 kg.), respectively. The average and median weights of whole tree white oak samples were 2,804.25 lbs. (1,271.99 kg.) and 2,424.50 (1,099.73 kg.), respectively and removal of the tops and limbs reduced the average and median weights of the merchantable stems to 1,389.58 lbs. (630.30 kg.) and 1,223.00 (554.74 kg.).

The compilation of all data from the cuboids provided an average green-to-air-dried weight reduction factor of 0.690 (%ΔWt.= percent change in weight) for all white oak samples meaning that on average an AD white oak sample tree would weigh only

69.0 % of its original green weight. When the 0.690 reduction factor was applied, essentially subtracting 31 % of the original weight, it reduced the minimum and maximum whole tree weights to 242.88 lbs. (110.17 kg.) and 5,711.13 lbs. (2,590.52 kg.), respectively, with whole tree mean and median weights of 1,930.88 lbs. (875.83 kg.) and 1,609.68 lbs. (703.14 kg.), correspondingly. The maximum and minimum merchantable stem weights were reduced to 121.44 lbs. (55.08 kg.) and 3,043.47 lbs. (1,380.49 kg.), respectively, and the merchantable mean and median weights to 953.99 lbs. (432.72 kg.) and 839.10 lbs. (380.61 kg.), respectively.

The weight reduction factor calculated for extrapolating the oven-dried weight for white oaks was 0.926 meaning that an oven dried sample of white oak would weigh 92.6% of that same sample in an AD state, a reduction in weight of 7.4%. Factoring in the percentage further reduced the AD weight of the total trees to an oven-dried minimum and maximum weight of 226.03lbs. (102.53 kg.) and 5,359.45 lbs. (2,431.01 kg.) with whole tree mean and median weights of 1790.97 lbs. (812.37 kg.) and 1,485.21 lbs. (673.68 kg.). Merchantable weights were further reduced to a minimum of 113.02 lbs. (51.27 kg.) and a maximum of 2,856.06 lbs. (1,295.49 kg.), with an arithmetic mean of 884.43 lbs. (401.17 kg.) and a median weight of 780.55 lbs. (354.05 kg.). Figure 45 displays the differences in mean board foot weights in green, AD and OD moisture classes. Both of the following graphs are separated into the diameter classes that the sample trees were collected by in this research.

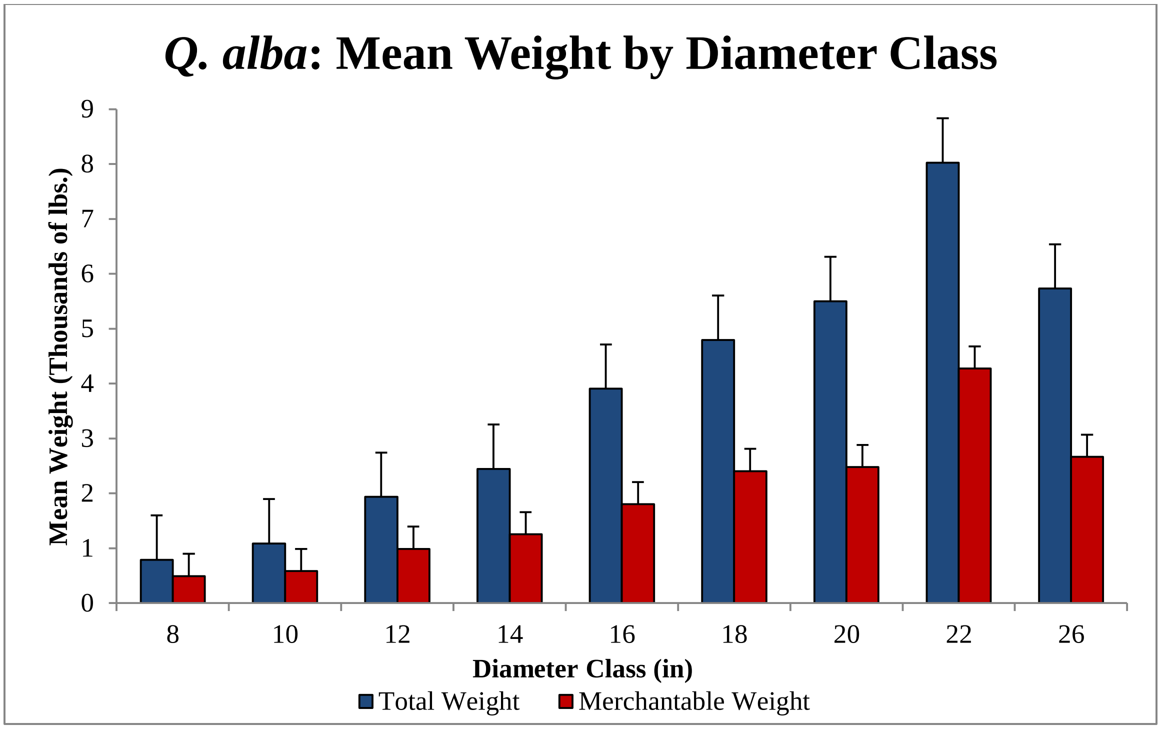

Figure 44. A histogram displaying the differences in mean total tree weight and mean merchantable stem weight for *Q. alba* sample trees.

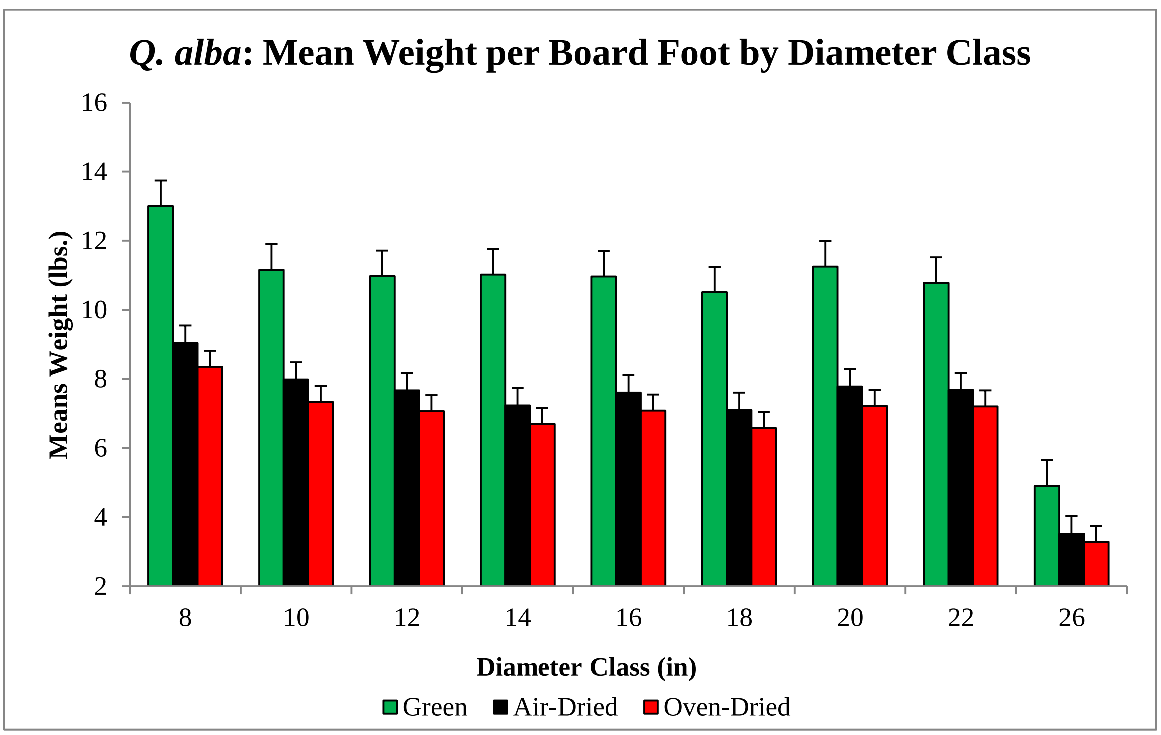

Figure 45. A visual representation of the mean board foot weight of *Q. alba* samples by moisture and diameter classes.

Sample Volumes

Summary statistics for volume data can also be found in Table 5 and the full data collection can be reviewed in Appendix A. All volumes were calculated using Beers' (1964) formula for volume estimation. The smallest volume for a white oak sample tree was calculated to be 3.87 ft^3 (0.11 m^3) whereas the largest volume was 98.07 ft^3 (2.78 m^3). Arithmetic mean and median volumes were 24.38 ft^3 (0.69 m^3) and 20.16 ft^3 (0.57 m^3), respectively. These volumes are calculated with tree bark included. Volumes without the bark included can be reviewed in Table 5. Volumes of sample white oaks were also calculated in terms of board feet using Beers' (1964) formulas which estimates board feet based on International ¼" log scale. There is no comparable metric unit in respect to the board foot and thus no metric conversion is listed following the board foot volumes. Minimum board foot volumes were 20.25 bf on the smallest volume sample with 543.29 bf contained within the largest volume sample tree. Mean board foot volume for the white oaks was 131.57 bf with a median of 107.02 bf.

Sample Density

Densities for the white oaks sampled in this research were also calculated and were recorded in green, AD, and OD states (Table 5). The minimum and maximum green density for white oak was 27.19 lbs. /ft^3 and 101.54 lbs. /ft^3, respectively. Mean and median green densities were 59.83 lbs. /ft^3 and 59.10 lbs. /ft^3, correspondingly. The minimum and maximum AD density for white oak was 19.52 lbs. /ft^3 and 70.64 lbs. /ft^3, respectively. Mean and median AD densities were 41.26 lbs. /ft^3 and 40.53 lbs. /ft^3, correspondingly. The minimum and maximum OD density for white oak was 18.22 lbs. /ft^3 and 65.41 lbs. /ft^3, respectively. Mean and median OD densities were 38.18 lbs. /ft^3

and 37.59 lbs. /ft^3, correspondingly. Figure 46 shows the mean densities for all moisture and diameter classes sampled in this research.

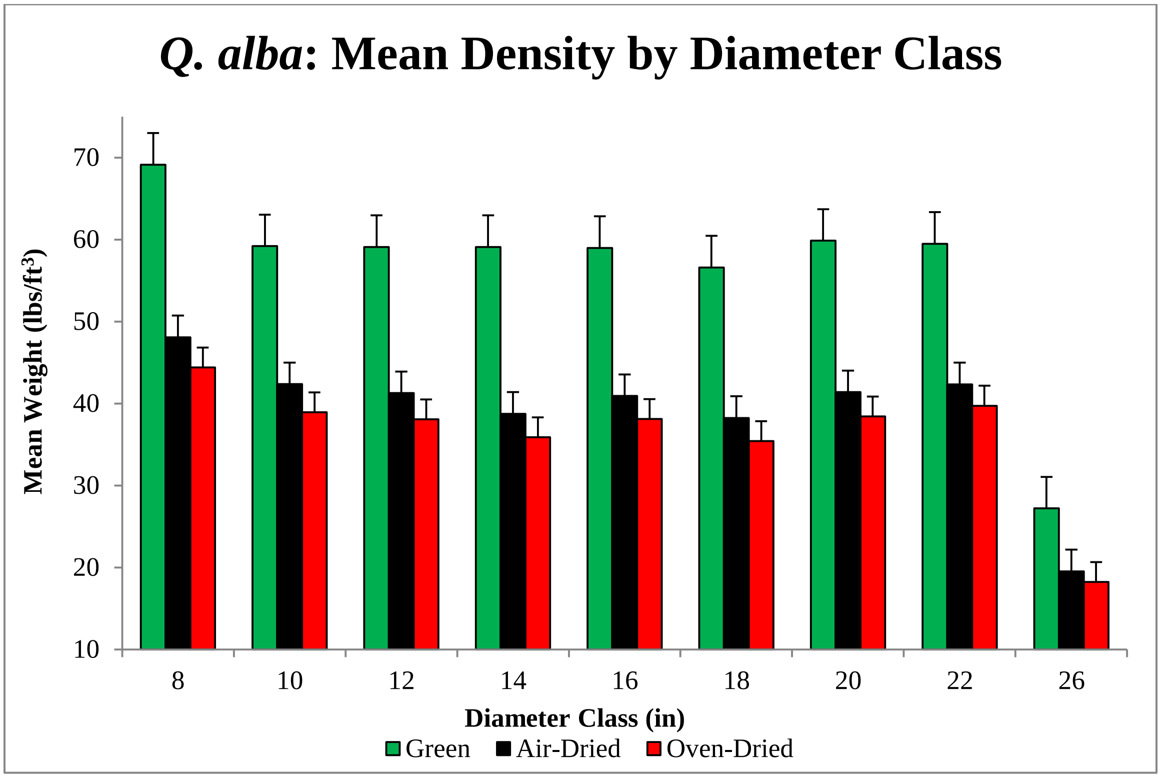

Figure 46. A histogram displaying the mean density of *Q. alba* wood in pounds per cubic foot (lbs./ft^3). Averages are shown for all three moisture classes and are separated by diameter classes.

Quercus stellata – post oak

Sample Weights

Post oaks found at the research site account for 59 of the 220 (26.82%) trees harvested and sampled for this research. Whole tree and merchantable weights in pounds are displayed graphically for the specimens in green, AD, and oven dried states in Figure 47 and Figure 48. Summary statistics for data collected on the specimens in this study are displayed in Table 5.

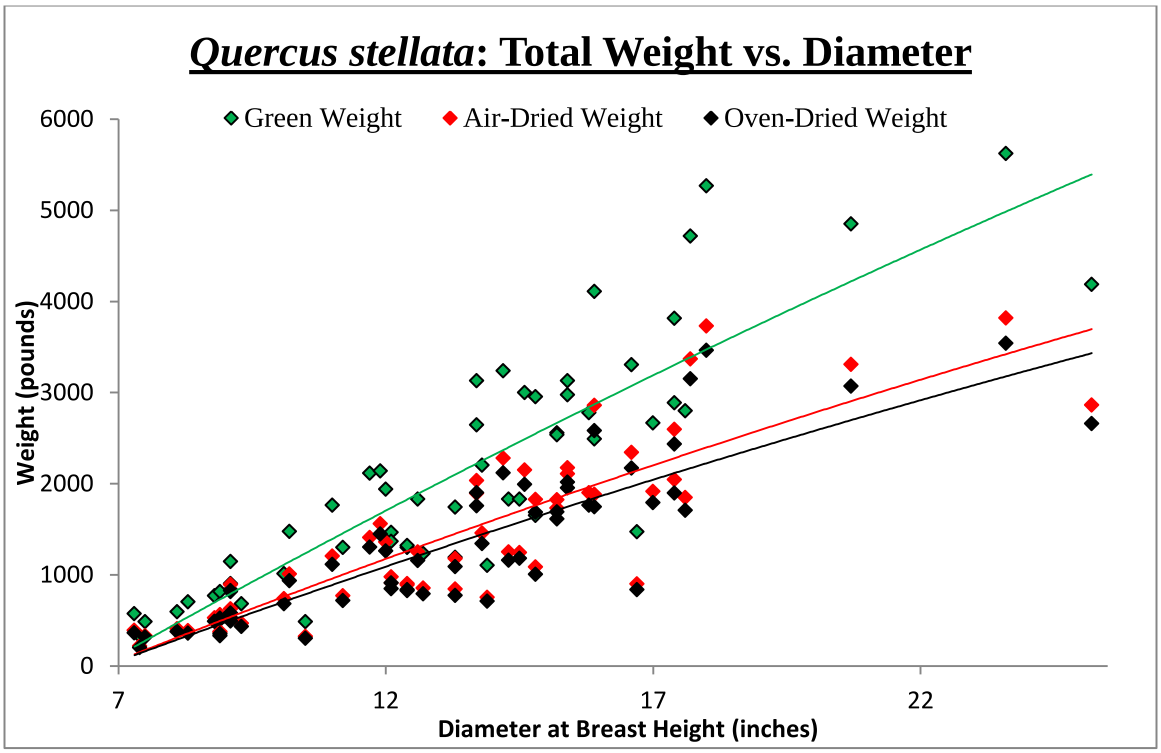

Figure 47. A graphical comparison of Q. stellata total weights in various stages of moisture loss. This graph displays the diameter and weight of each Q. stellata sample tree in green, AD, and oven-dried stages.

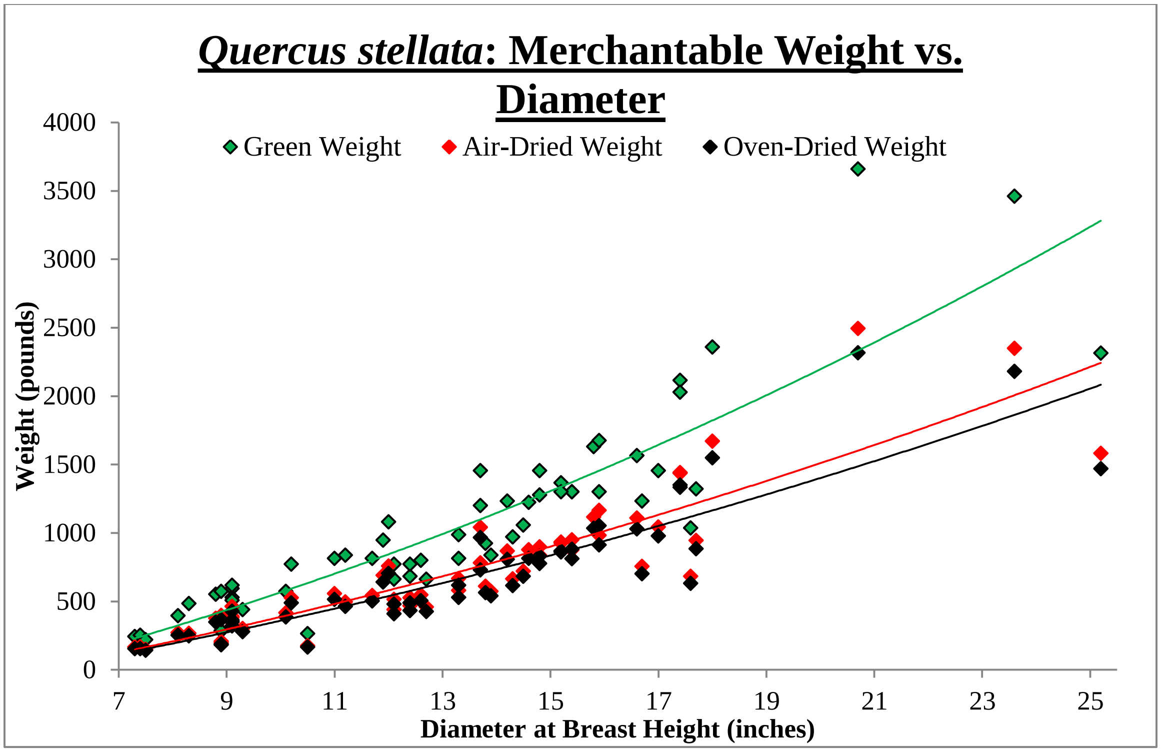

Figure 48. A graphical comparison of Q. stellata merchantable weights in various stages of moisture loss. This graph displays the diameter and weight of each Q. stellata sample tree in green, AD, and oven-dried stages.

Minimum and maximum post oak total tree weights were 330.00 lbs. (149.69 kg.) and 5,621.00 lbs. (2,549.64 kg.), respectively while removal of the tops and limbs reduced the maximum and minimum merchantable stem weights to 220.00 lbs. (99.79 kg.) and 3,659.00 lbs. (1,659.69 kg.), respectively. The average and median weights of whole tree post oak samples were 2,060.49 lbs. (934.62 kg.) and 1,829.00 (829.62 kg.), respectively and removal of the tops and limbs reduced the average and median weights of the merchantable stems to 1,074.03 lbs. (487.17 kg.) and 947.00 lbs (429.55 kg.).

The compilation of all data from the cuboids provided an average green-to-air-dried weight reduction factor of 0.684 (%ΔWt.= percent change in weight) for all post oak samples meaning that on average an AD post oak sample tree would weigh only 68.4 % of its original green weight. When the 0.684 reduction factor was applied, essentially subtracting 31.6% of the original weight, it reduced the minimum and maximum whole tree weights to 220.00 lbs (99.79 kg.) and 3,816.73 lbs. (1731.24 kg.), respectively, with whole tree mean and median weights of 1,416.95 lbs. (642.72 kg.) and 1245.28 lbs. (564.85 kg.), correspondingly. The maximum and minimum merchantable stem weights were reduced to 150.48 lbs. (68.27 kg.) and 2,495.38 lbs. (1131.89 kg.), respectively, and the merchantable mean and median weights to 736.85 lbs. (334.23 kg.) and 663.48 lbs. (300.95 kg.), respectively.

The weight reduction factor calculated for extrapolating the oven-dried weight for post oaks was 0.928 meaning that an oven dried sample of post oak would weigh 92.8% of that same sample in an AD state, a reduction of 7.2%. Factoring in the percentage further reduced the AD weight of the total trees to a minimum and maximum weight of 203.4 lbs. (92.26 kg.) and 3541.92 lbs. (1606.59 kg.) with whole tree mean and median weights of 1314.64lbs. (596.27 kg.) and 1155.13 lbs. (523.96 kg.). Merchantable weights were reduced to a minimum of 143.14 lbs. (64.93 kg.) and a maximum of 2315.72 lbs. (1050.39 kg.), with an arithmetic mean of 683.72 lbs. (310.13 kg.) and a median weight of 615.71 lbs. (279.28 kg.).

Figure 49 provides a visual of the differences in total tree weight and the merchantable weight of the stem that was produced after the top and limbs were removed by the logger. Figure 50 displays the differences in mean board foot weights in green, AD and OD moisture classes. Both of the following graphs are separated into the diameter classes that the sample trees were collected by in this research.

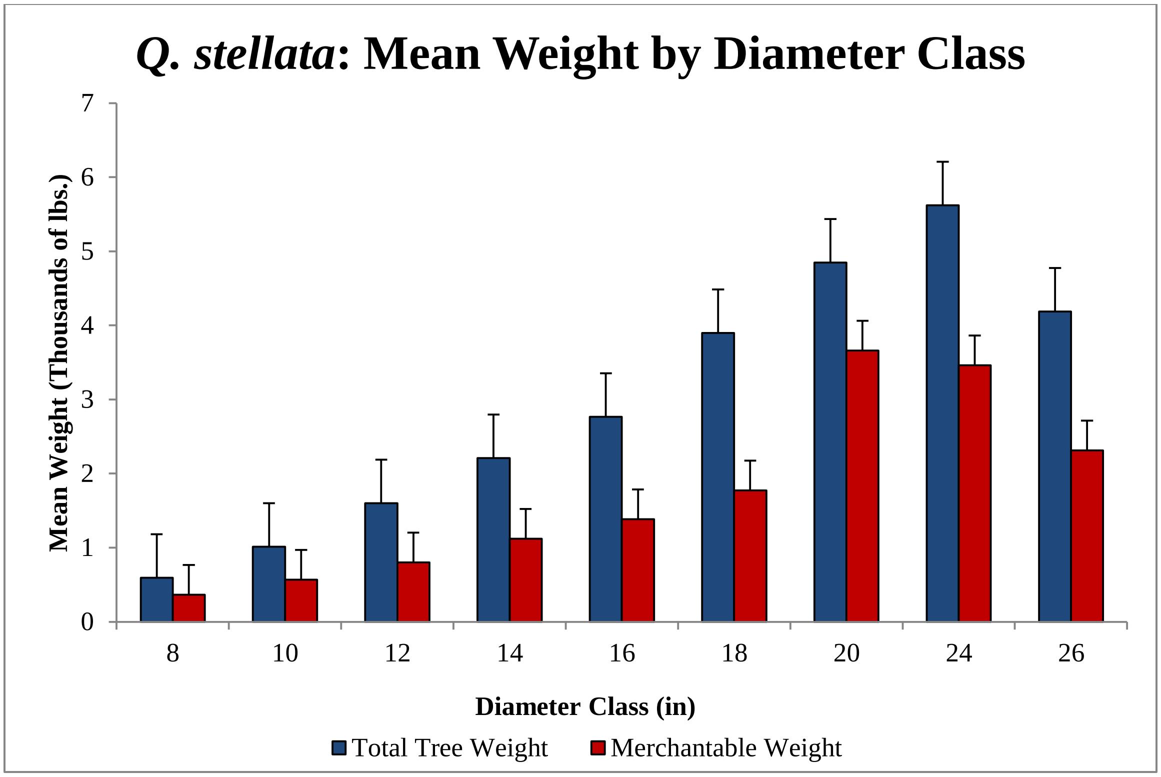

Figure 49. A histogram displaying the differences in mean total tree weight and mean merchantable stem weight for *Q. stellata* sample trees.

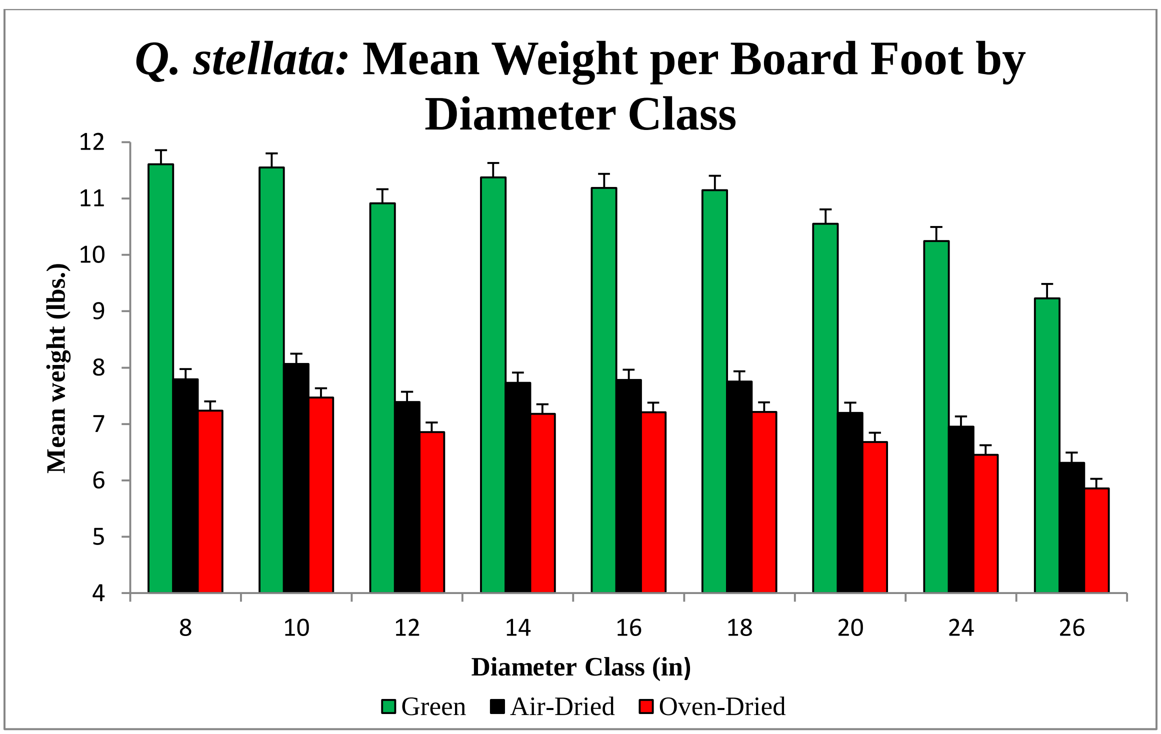

Figure 50. A visual representation of the mean board foot weight of *Q. stellata* samples by moisture and diameter classes.

Sample Volumes

Summary statistics for volume data can also be found in Table 5 and the full data collection can be reviewed in Appendix A. All volumes were calculated using Beers' (1964) formula for volume estimation. The smallest volume for a post oak sample tree was calculated to be 3.02 ft^3 (0.09 m^3) whereas the largest volume was 63.42 ft^3 (1.80 m^3). Arithmetic mean and median volumes were 18.52 ft^3 (0.52 m^3) and 15.74 ft^3 (0.45 m^3), respectively. These volumes are calculated with tree bark included but volumes without the bark can be reviewed in Table 6. Volumes of sample post oaks were also calculated in terms of board feet using Beers' (1964) formulas which estimates board feet based on International ¼" log scale. There is no comparable metric unit in respect to the board foot and thus no metric conversion is listed following the board foot volumes. Minimum board foot volumes were 15.71 bf on the smallest volume sample with 346.76 bf contained within the largest volume sample tree. Mean board foot volume for the post oaks was 98.28 bf with a median of 83.53 bf.

Sample Density

Densities for the post oaks sampled in this research were also calculated and were recorded in green, AD, and OD states (Table 5). The minimum and maximum green density for post oak was 25.89 lbs. /ft^3 and 80.71 lbs. /ft^3, respectively. Mean and median green densities were 59.41 lbs. /ft^3 and 60.13 lbs. /ft^3, correspondingly. The minimum and maximum AD density for post oak was 17.26 lbs. /ft^3 and 55.20 lbs. /ft^3, respectively. Mean and median AD densities were 40.71 lbs. /ft^3 and 41.48 lbs. /ft^3, correspondingly. The minimum and maximum OD density for post oak was 16.21 lbs. /ft^3 and 51.07 lbs. /ft^3, respectively. Mean and median OD densities were 37.77 lbs. /ft^3 and 38.47 lbs. /ft^3, correspondingly. Figure 51 shows the mean densities for all moisture and diameter classes sampled in this research.

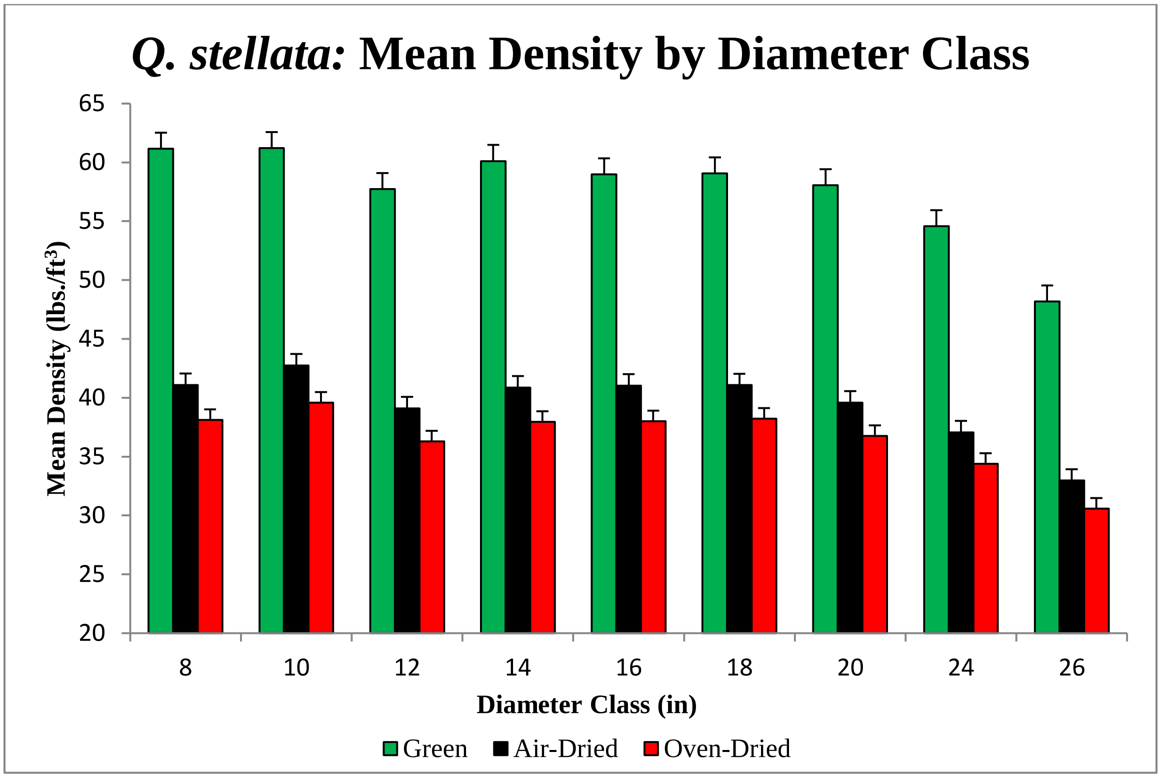

Figure 51. A histogram displaying the mean density of *Q. stellata* wood in pounds per cubic foot (lbs./ft3). Averages are shown for all three moisture classes and are separated by diameter classes.

Carya spp. – hickories

Sample Weights

Hickories comprised the smallest portion of the sample species found at the research site and account for 36 of the 220 (16.36 %) trees harvested and sampled for this research. Whole tree and merchantable weights in pounds are displayed graphically for the specimens in green, AD, and oven dried states in Figure 52 and Figure 53. Summary statistics for data collected on the specimens in this study are displayed in Table 5.

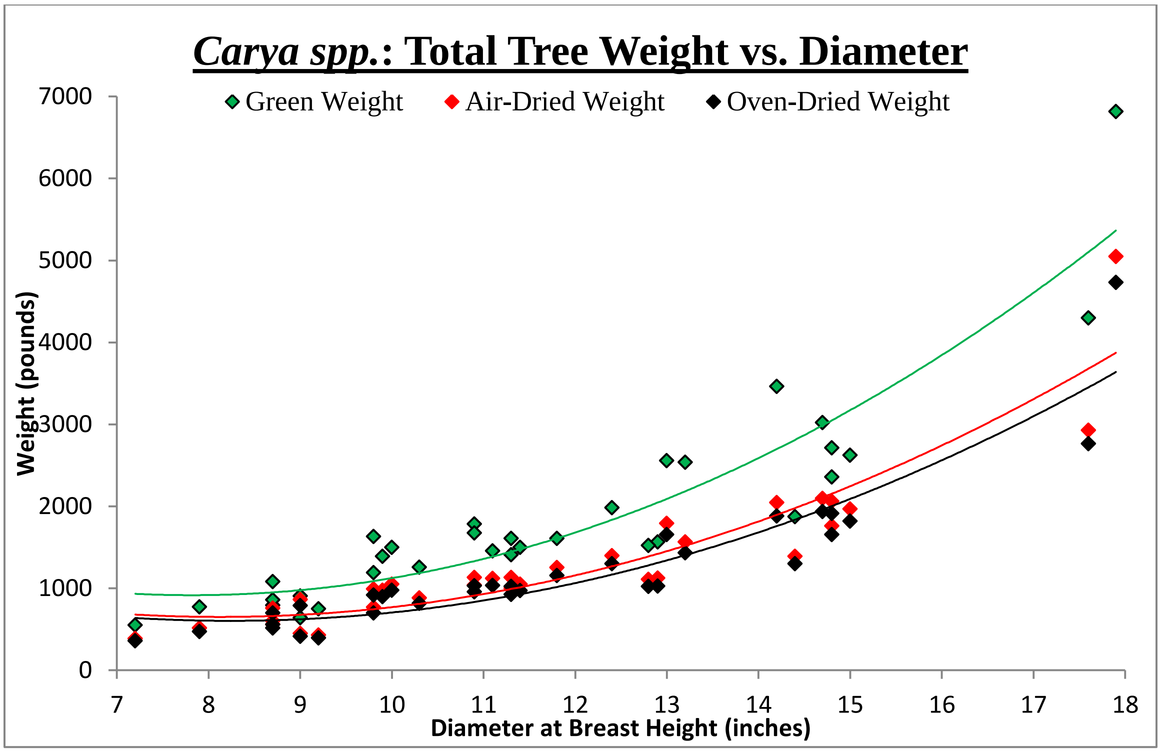

Figure 52. A graphical comparison of Carya spp. total weights in various stages of moisture loss. This graph displays the diameter and weight of each Carya spp. sample tree in green, AD, and oven-dried stages.

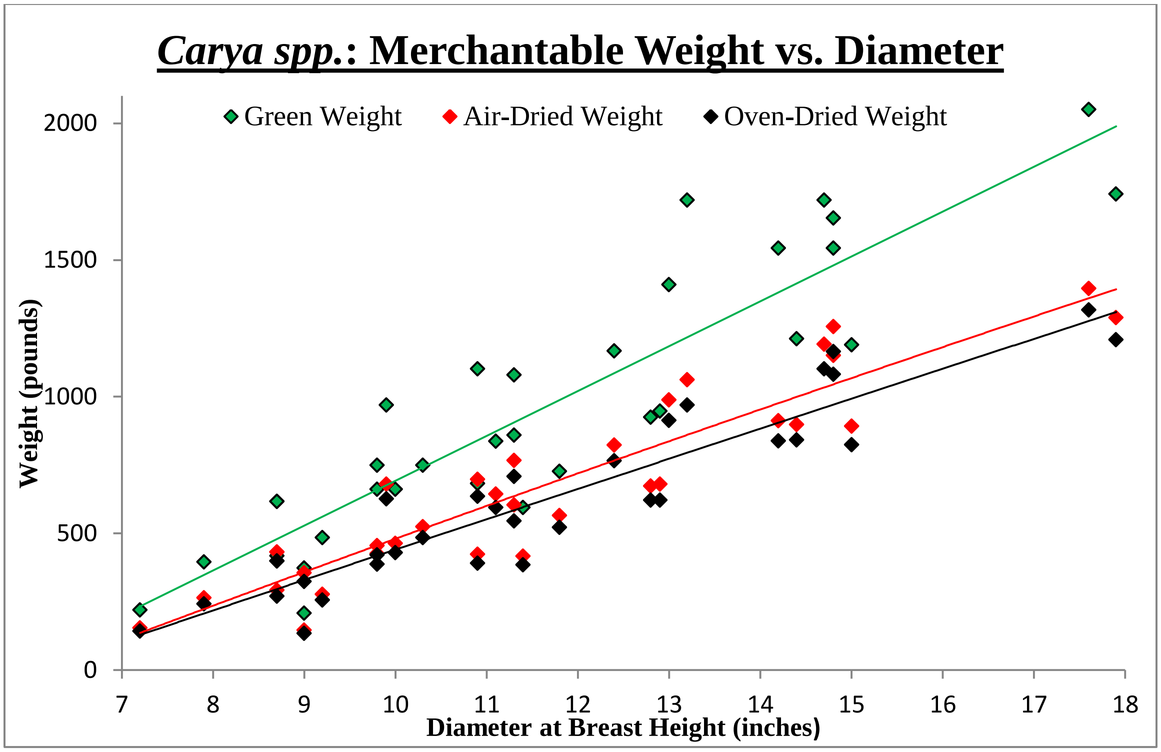

Figure 53. A graphical comparison of Carya spp. merchantable weights in various stages of moisture loss. This graph displays the diameter and weight of each Carya spp. sample tree in green, AD, and oven-dried stages.

Maximum and minimum hickory total tree weights were 551.00 lbs. (249.93 kg.) and 6814.00 lbs. (3090.78 kg.), respectively while removal of the tops and limbs reduced the maximum and minimum merchantable stem weights to 208.00 lbs. (94.35 kg.) and 2050.00 lbs. (929.86 kg.), respectively. The average and median weights of whole tree hickory samples were 1868.97 lbs. (847.75 kg.) and 1565.00 (709.87 kg.), respectively and the average and median weights of the merchantable stems was 964.48 lbs. (437.48 kg.) and 859.00 lbs (389.64 kg.).

The compilation of all data from the cuboids provided an average green-to-air-dried weight reduction factor of 0.701 (%ΔWt.= percent change in weight) for all hickory samples meaning that on average an AD hickory sample tree would weigh only 70.1 % of its original green weight. When the 0.701 reduction factor was applied essentially subtracting 29.9 % of the original weight, it reduced the minimum and maximum whole tree weights to 386.25 lbs (175.20 kg.) and 5046.81 lbs. (2289.19 kg.), respectively, with whole tree mean and median weights of 1309.61 lbs. (594.03 kg.) and 1106.18 lbs. (501.75 kg.), correspondingly. The maximum and minimum merchantable stem weights were reduced to 145.81 lbs. (66.14 kg.) and 1396.38 lbs. (633.39 kg.), respectively, and the merchantable mean and median weights to 673.87 lbs. (305.66 kg.) and 643.85 lbs. (292.05 kg.), respectively.

The weight reduction factor calculated for extrapolating the oven-dried weight for hickory was 0.923 meaning that an oven dried sample of hickory would weigh 92.3% of that same sample in an AD state, a reduction of 7.7%. Factoring in the percentage further reduced the AD weight of the total trees to a minimum and maximum weight of 356.90 lbs. (161.89 kg.) and 4730.43 lbs. (2145.69 kg.) with whole tree mean and median weights of 1212.59 lbs. (550.02 kg.) and 1021.66 lbs. (463.42 kg.). Merchantable weights were reduced to a minimum of 134.73 lbs. (61.11 kg.) and a maximum of 1317.19 lbs. (597.48 kg.), with an arithmetic mean of 623.43 lbs. (282.78 kg.) and a median weight of 594.91 lbs. (269.85 kg.).

Figure 54 provides a visual of the differences in total tree weight and the merchantable weight of the stem that was produced after the top and limbs were removed by the logger. Figure 55 displays the differences in mean board foot weights in green, AD and OD moisture classes. Both of the following graphs are separated into the diameter classes that the sample trees were collected by in this research.

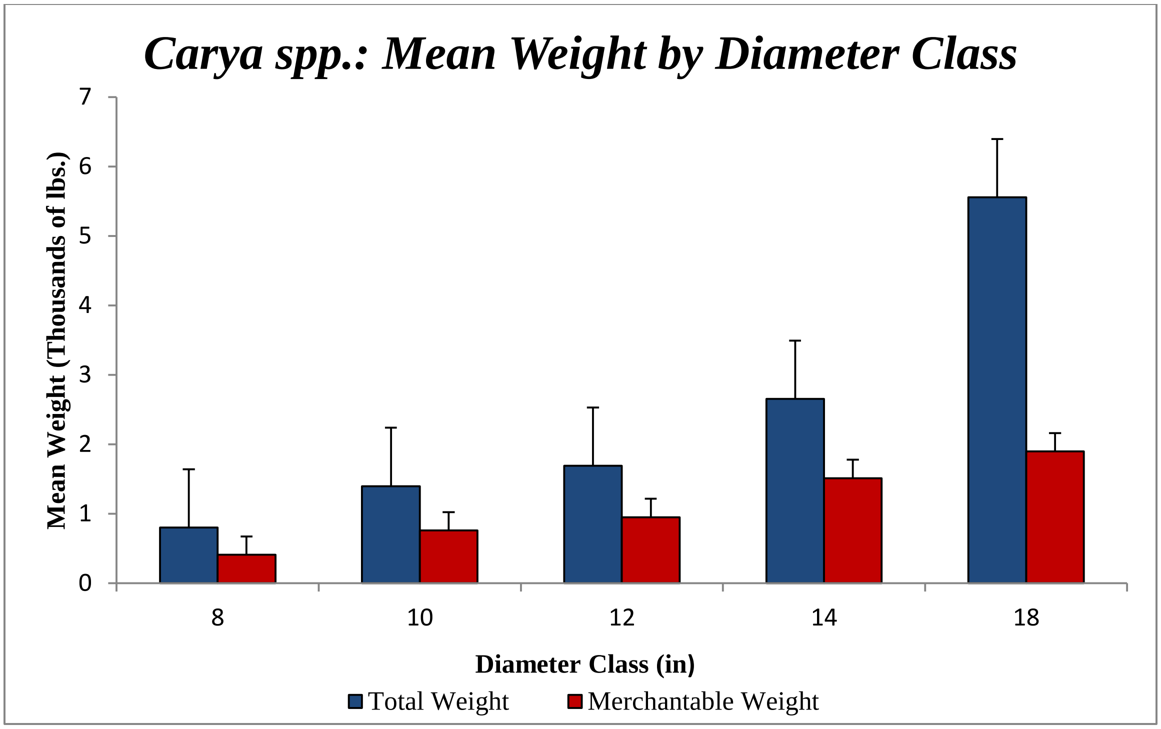

Figure 54. A histogram displaying the differences in mean total tree weight and mean merchantable stem weight for *Carya spp.* sample trees.

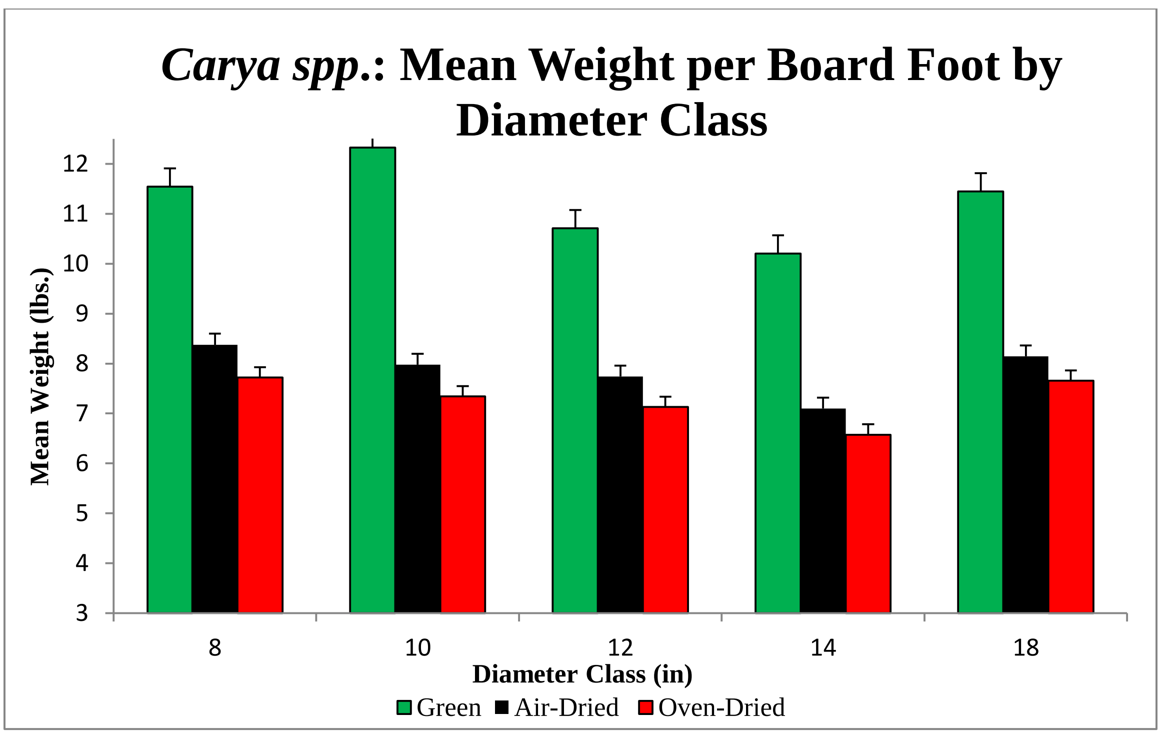

Figure 55. A visual representation of the mean board foot weight of *Carya spp.* samples by moisture and diameter classes.

Sample Volumes

Summary statistics for volume data can also be found in Table 6 and the full data collection can be reviewed in Appendix A. All volumes were calculated using Beers' (1964) formula for volume estimation. The smallest volume for a hickory sample tree was calculated to be 3.59 ft^3 (0.10 m^3) whereas the largest volume was 34.28 ft^3 (0.97 m^3). Arithmetic mean and median volumes were 16.37 ft^3 (0.46 m^3) and 14.74 ft^3 (0.42m^3), respectively. These volumes are calculated with tree bark included but volumes without the bark can be reviewed in Table 6. Volumes of sample hickories were also calculated in terms of board feet using Beers' (1964) formulas which estimates board feet based on International ¼" log scale. There is no comparable metric unit in respect to the board foot and thus no metric conversion is listed following the board foot volumes. Minimum board foot volumes were 18.76 bf on the smallest volume sample with 182.65 bf contained within the largest volume sample tree. Mean board foot volume for the hickories was 88.18 bf with a median of 79.35 bf.

Sample Density

Densities for the hickories sampled in this research were also calculated and were recorded in green, AD, and OD states (Table 6). The minimum and maximum green density for hickory was 32.90 lbs. /ft^3 and 79.85 lbs. /ft^3, respectively. Mean and median green densities were 60.09 lbs. /ft^3 and 61.24 lbs. /ft^3, correspondingly. The minimum and maximum AD density for hickory was 22.49 lbs. /ft^3 and 52.15 lbs. /ft^3, respectively. Mean and median AD densities were 41.90 lbs. /ft^3 42.93 lbs. /ft^3, correspondingly. The minimum and maximum OD density for hickory was 20.78 lbs. /ft^3 and 48.16 lbs. /ft^3, respectively. Mean and median OD densities were 38.68 lbs. /ft^3 and 39.67 lbs. /ft^3, correspondingly. Figure 56 shows the mean densities for all moisture and diameter classes sampled in this research.

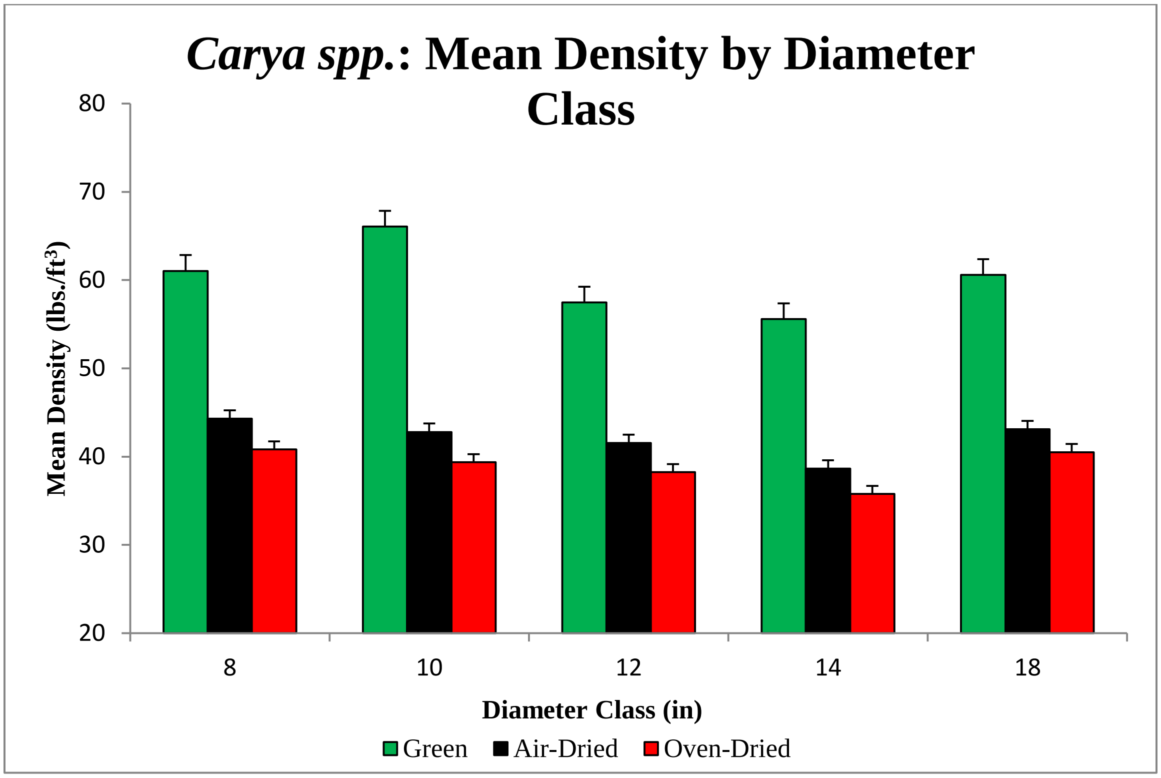

Figure 56. A histogram displaying the mean density of *Carya spp.* wood in pounds per cubic foot (lbs./ft3). Averages are shown for all three moisture classes and are separated by diameter classes.

Specific Gravity Computations

The specific gravity of AD wood samples that are exposed to atmospheric humidity are in a continuous state of flux as the samples' moisture contents increase and decrease with the relative humidity of the atmosphere. Because of this the specific gravity of a wood sample is only considered valid when obtained from OD samples. Therefore, only OD results will be presented in this research with the exception of Figure 57 which is being presented to demonstrate the difference in AD versus OD specific gravity among the species in this research.

It should also be noted that the measurements of weights and volumes collected from the cuboids in this study are in grams (g) and cubic centimeters (cm^3). Thus, the density of the samples is measured in grams per cubic centimeter (g/cm^3). Because the density of water in this research is assumed to be 1.00 g/cm^3 it effectively makes the density values and the specific gravities of the cuboids congruent. Consequently, the graphs and tables in this section can be perceived as both the specific gravity and the density of the wood in the selected species groups. Average values of OD specific gravities along with simple summary statistics can be viewed in Table 6.

Table 6. A listing of computed average specific gravities for the selected species groups in this research.

Whole Tree AVG Oven-Dried Specific Gravity by Species							
SPP	n	MIN	MAX	AVG	MED	VAR	MSE
BO	58	0.532	0.888	0.769	0.774	0.0046	0.0001
WO	56	0.654	0.906	0.788	0.779	0.0036	0.0001
PO	50	0.618	0.993	0.801	0.805	0.0074	0.0001
HI	26	0.235	1.046	0.782	0.772	0.0204	0.0008

Figure 57 visually displays the differences in average AD and average OD specific gravity and demonstrates why specific gravity determination requires OD wood samples. Average specific gravity for the black oaks (*Q. velutina*) sampled in this research computes to 0.769, the lowest specific gravity value, while the white oaks (*Q. alba*) averaged out to 0.788. The greatest average specific gravity value (0.805) occurred in the post oaks (*Q. stellata*) while the value for the hickories (*Carya spp*.) averaged to 0.782.

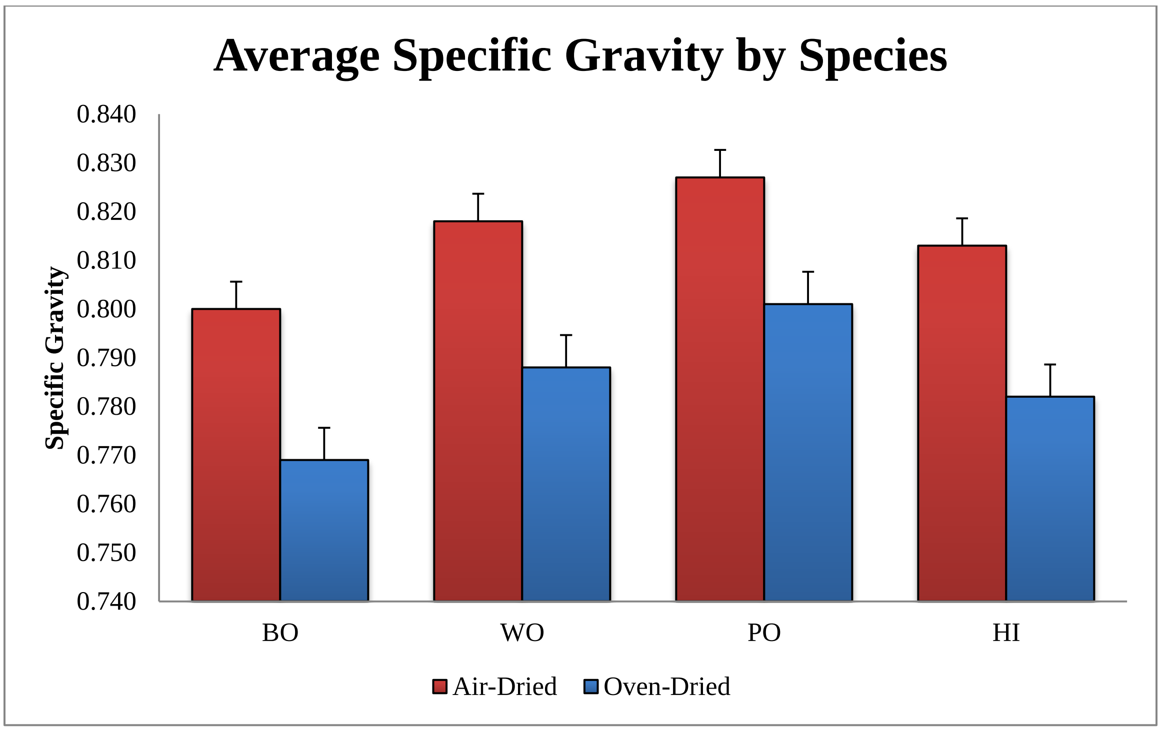

Figure 57. A histogram displaying the average air-dried (AD) and oven-dried (OD) specific gravity of each species group focused on in this research. Exact specific gravity values are listed in Table 8.

Figure 58 is a graphical representation of averaged specific gravity values for each of the selected species groups by pith sample and by cardinal direction. Referring to Figure 19 may aid the reader in visualizing where the average values exist within a cross-section of a sample tree. In most of the species the highest SG values occurred in the pith of the sample tree with the exception of the black oaks (*Q. velutina*) where the highest overall average occurred in the southern transect. Excluding the pith samples from this figure shows that the greatest variation in SG, on directional basis, occurred in the hickories (*Carya spp.*) sampled in this research. The black oaks (*Q. velutina*) had the lowest overall variation of all selected species groups. Table 7 lists the actual average values for the reader to examine.

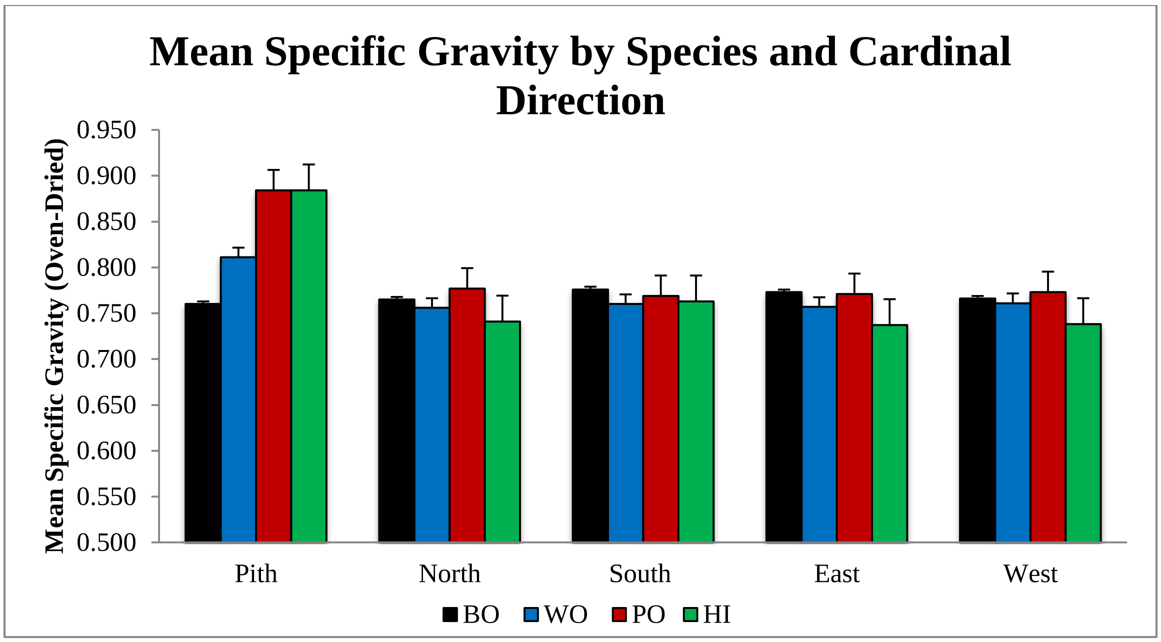

Figure 58. A graphical representation of average specific gravity by cardinal direction and by species groups.

Table 7. Listing of average SG values calculated and sorted by species group and cardinal direction and pith.

Species Average Oven-Dried SG by Pith and Cardinal Transect							
BO (n=116)		WO (n=99)		PO (n=63)		HI (n=31)	
Pith	0.760	Pith	0.811	Pith	0.884	Pith	0.884
N	0.765	N	0.756	N	0.777	N	0.741
S	0.776	S	0.760	S	0.769	S	0.763
E	0.773	E	0.757	E	0.771	E	0.737
W	0.766	W	0.761	W	0.773	W	0.738
Average	0.768		0.769		0.795		0.773

Figure 59 is based off of data from trees that yielded multiple logs during harvest operations. Cross-sections were taken at different heights from these multi-log sample trees and the data from the cuboids removed from the cross-sections provides a display of how the SG changed from the samples tree's base log (BL) upward log by log (L1, L2, *etc.*) through the merchantable stem. The graph shows that the SG of the white oaks (*Q. alba*) and the post oaks (*Q. stellata*) shared very similar SG values moving from the sample tree bases to the merchantable top. The black oaks followed a trend that was opposite of the white and post oaks. The hickories started out with higher SG values in the base compared to the other species but those values quickly declined in the respect to the others and resulted in lower SG values in the upper portions of the stem.

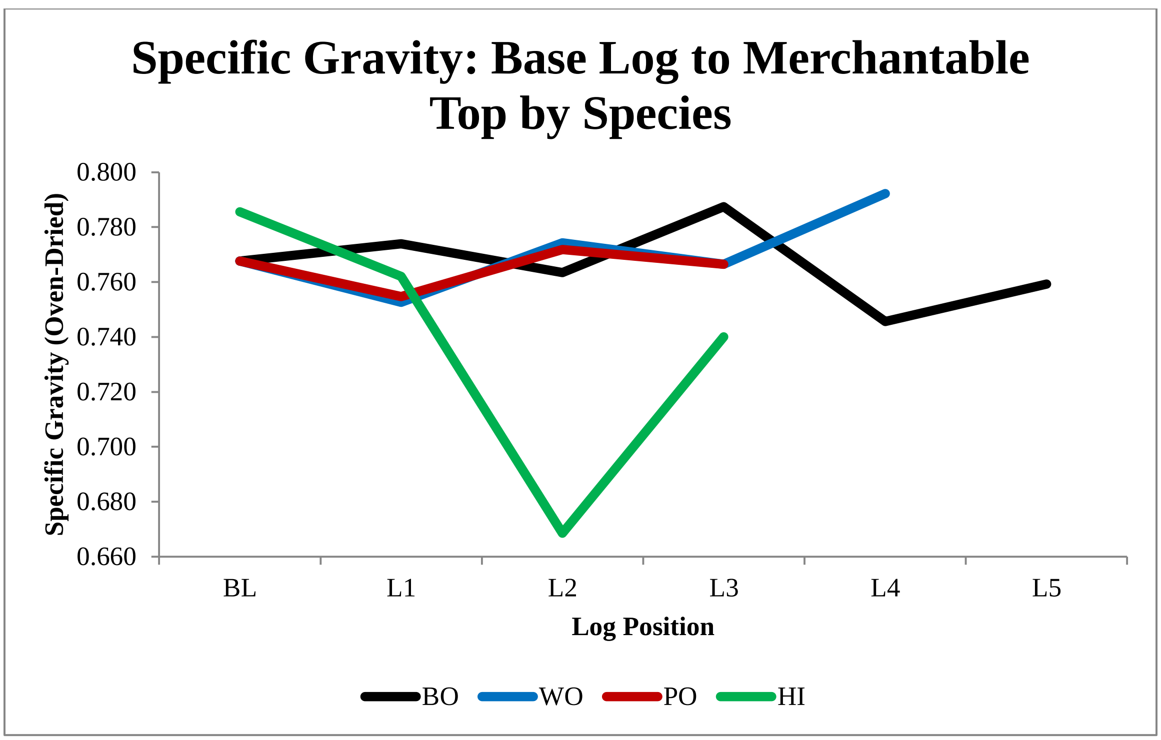

Figure 59. A graphical explanation of average OD SG values by species at differing heights within the merchantable stem of the sample trees.

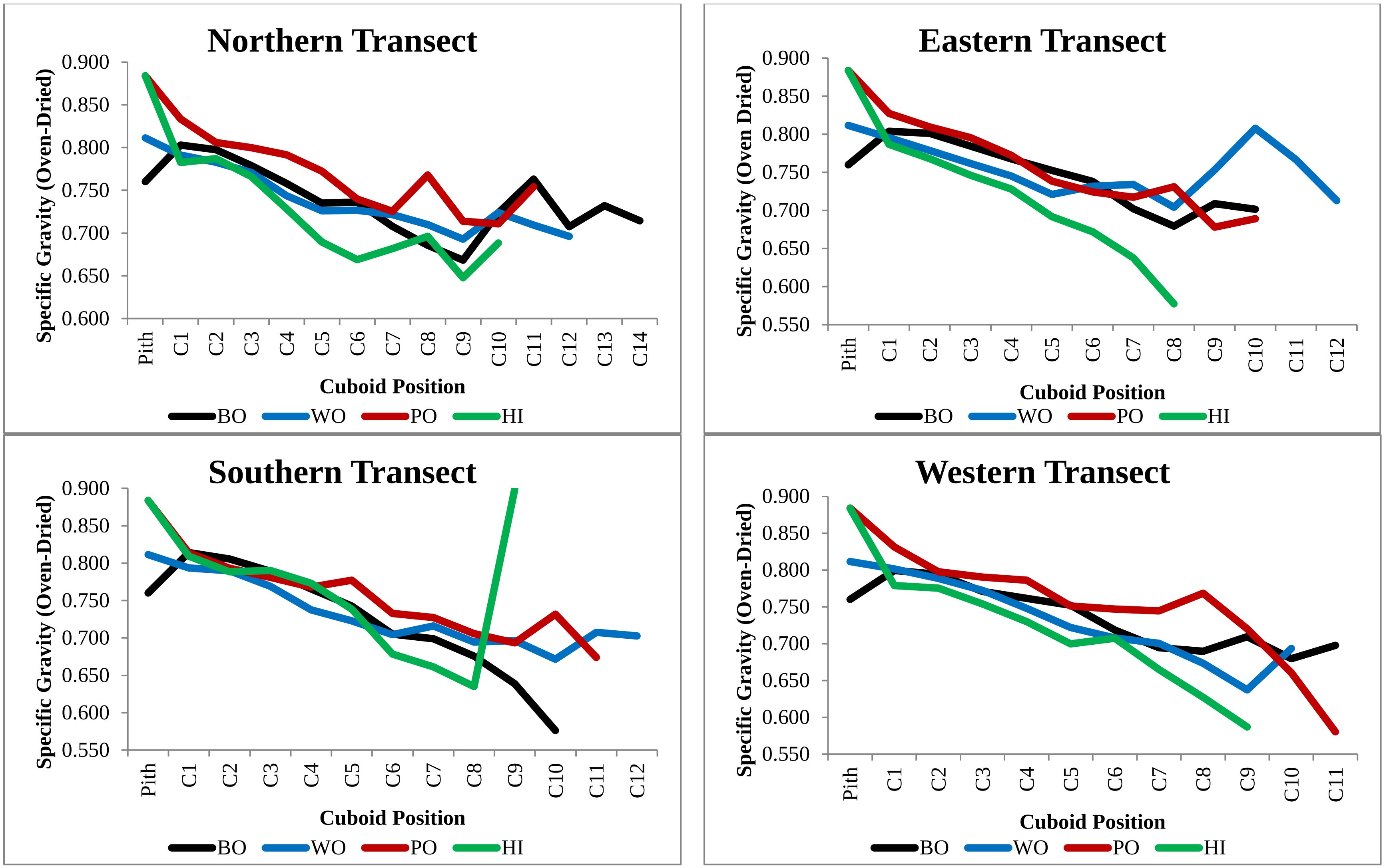

Figure 60. A graphical representation showing the trends of average OD SG, in each cardinal direction, for each of the selected species from pith to cambium.

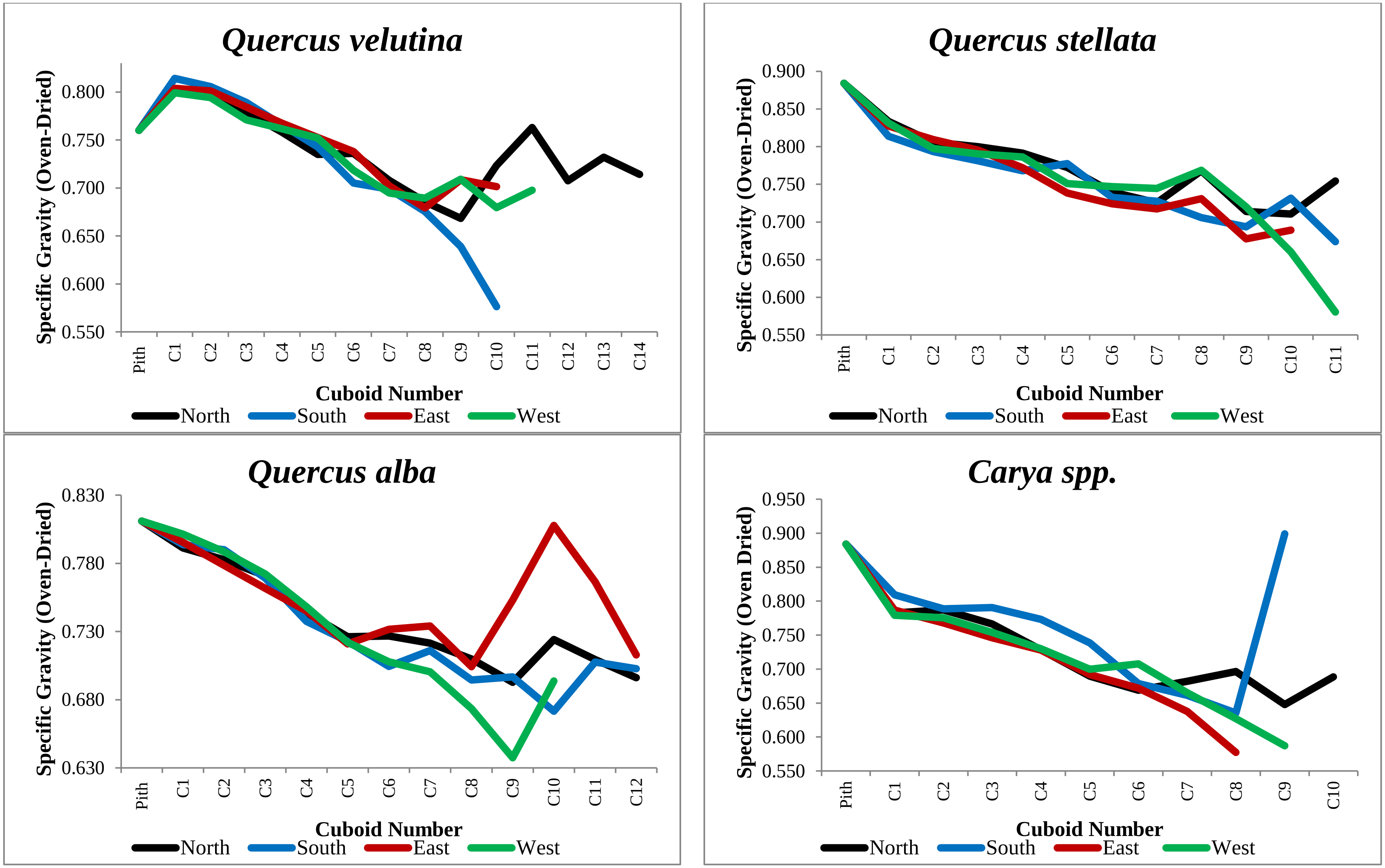

Figure 61. A graphical representation showing the trends of average OD SG for each cardinal direction within each species group.

Figure 60 contains a series of graphs explaining how the SG values change within the tree moving outward from the pith of the tree toward the cambium. With the exception of the hickories (*Carya spp*.) in the southern transect and the white oaks (*Q. alba*) in the eastern transect, all SG values follow a declining trend as they move outward from the center of the tree.

Figure 61 displays a series of graphs similar to those in Figure 46. However, these graphs are instead separated into species groups and display the changes in SG of all four cardinal directions for that particular species. While the trends displayed in this graph are similar to those in Figure 60 there are some slight differences that are worth noting. The SG values for both black oaks (*Q. velutina*) and white oaks (*Q. alba*) both follow a generally decreasing trend until about the C6 cuboid where they begin to level off or even increase in some cases such as the northern, eastern, and western transects of the black oak (*Q. velutina*) graph and the eastern and western transects in the white oak (*Q. alba*) graph. It is also worth noting that the black oaks (*Q. velutina*) were the only species to see an increase in SG immediately outside the pith in all cardinal directions.

CHAPTER 4: DISCUSSION

Primarily, the goals of this research included collecting, analyzing, and assessing the whole tree and merchantable stem weights. However, there were ancillary objectives for this research as well. The purchasing of wood by weight is becoming more common for both sawlogs and pulpwood (Oderwald and Yaussy, 1980) and a determination of an average weight per board foot was desired for each of the species of interest so that the resultant weights could be made available to those that may benefit from such information. Often wood is purchased by green weight in today's markets but the green weight of wood can have tremendous variation regionally, seasonally, and within different species (Miles and Smith, 2009). The majority of the timber found in the state of Missouri is located in the southeastern section of the state (Massengale, 2008). Having an average weight per board foot for the oaks and hickories in this research that is region specific is important because most of Missouri's timber harvesting is also in the southeastern region.

Weight and Densities

Board Feet Averages

Finding the average weight per board foot for each of the selected species was important to this research. The averages for each species, along with the summary statistics, can be reviewed in Figure 35 and Table 5. It is interesting to see that all of the study species have similar average green weights on a board foot basis. However what is most important is how the averages are all below the 12 lbs. /bf mark that are commonly assumed to be correct for Missouri. This means that the purchasing of sawlogs by weight is leading to incorrect to incorrect calculations of board foot volumes per load of logs. For instance, an example on an earlier page of this research provided a scenario of a load of logs weighing 144,000 pounds. If an estimate of board feet is made for that particular load at 12 lbs. /bf, the estimate should equate to 12,000 bf (or 12 MBF). However if the load was entirely made up of black oak logs, which according to this study average to 11.36 lbs. /bf, that load should contain approximately 12,676 bf of lumber meaning that the logger and the landowner missed out on being paid for 676 bf of their timber. If the aforementioned situation were altered and the load was made entirely of white oak (11.17 lbs./bf), post oak (11.23 lbs./bf), or hickory (11.22 lbs./bf) logs the number of board feet unaccounted for at the mill would equate to 892 bf, 823 bf, and 834 bf, respectively. Timber prices fluctuate rapidly so an estimate of monetary loss will not be made but it is easy to see that over time this could equate to substantial losses for loggers and landowners.

Merchantable Weight

The merchantable weight is another important aspect of this study. The recorded merchantable weight data can be converted into a percentage of whole tree weight that yield information on where the majority of the weight is held in standing timber or how much of the tree is being left behind as residue and not utilized. This information could also be used to estimate the weight of residues left at the harvest site. Figure 62 shows the mean merchantable weights for each species as a percentage of mean whole tree weight. All of the averages are over 50 percent meaning that at least half, and

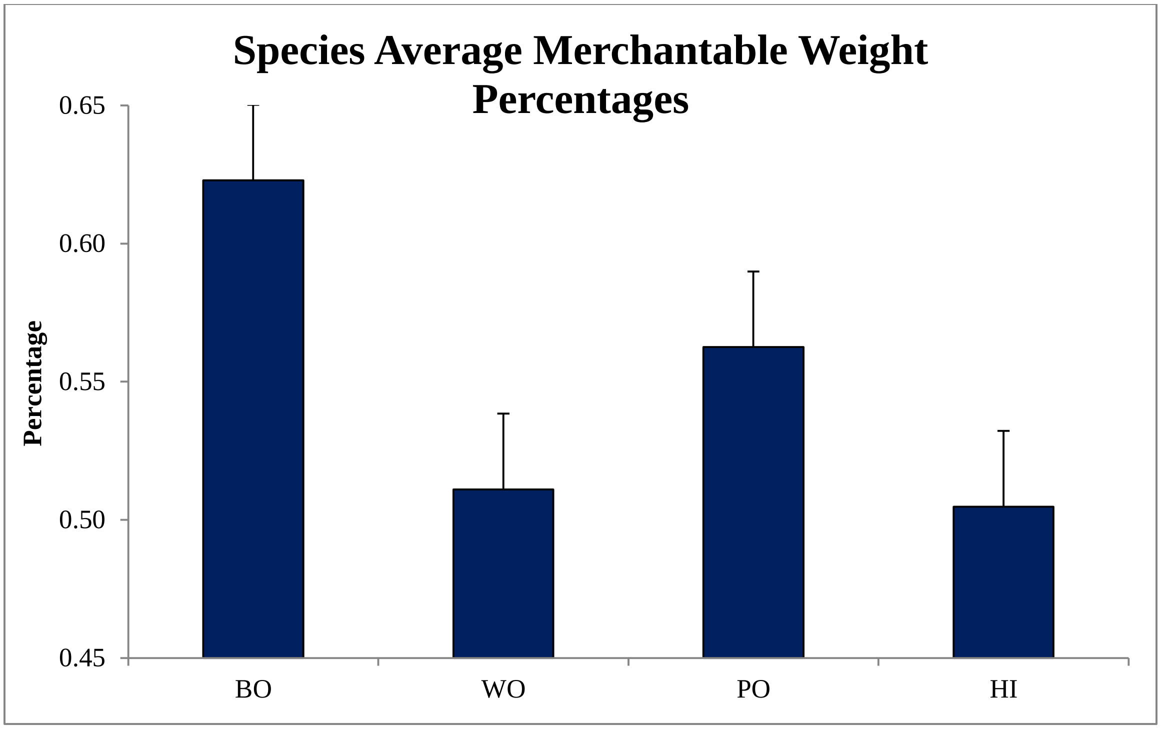

Figure 62. The mean merchantable weight percentages for each of the species of interest. The data are show as a percentage of mean whole tree weight.

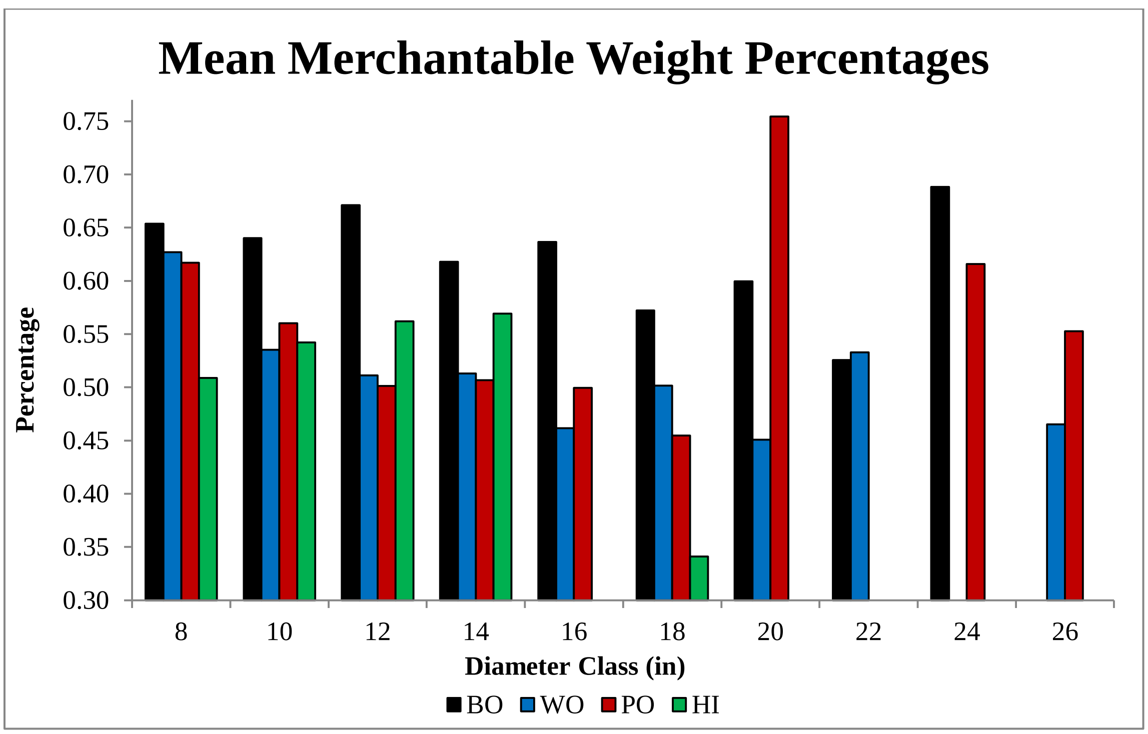

Figure 63. The mean merchantable weight of each species separated into diameter classes.

in some instances much more, of the weight in each of the species of focus is contained within the merchantable portion of the stem. Figure 63 shows the average merchantable weight for each species separated into diameter classes. *Q. velutina* and *Q. stellata* had the highest percentages of the study species and the lowest values occurred in the *Q. alba* and *Carya spp.* specimens.

Total Tree Weights

Many methods are currently available for use in estimating the weight of standing trees based upon diameter and height and by the geographical region that the species is located in. Hahn (1975) and Goerndt *et al.* (2013) are examples of authors that have equations for estimating weight and volume that are specific to Missouri. During the research phase of this work it was discovered that Myer *et al.* (1975) had produced equations and predicted weight tables for black oaks (*Q. velutina*), white oaks (*Q. alba*), red oaks (*Q. rubra*), and hickories (*Carya spp.*) from sample trees harvested from the Shawnee National Forest in southern Illinois.

The work by Goerndt *et al.* (2013) is produced from the very same data set that was collected for this thesis and Hahn's (1975) equations are produced from Forest Inventory Analysis (FIA) data collected from many areas within the state of Missouri. It was decided that the predicted weights made by Myers *et al*. (1975) were the best choice to make comparisons to the data in this research because of the similarities of the studies and data collection and the proximity of both studies in relation to each other. Figure 64 compares the predicted weights of white oaks made by Myers *et al*. (1975) to the total tree weights of white and post oaks collected in this research. A similar trend is

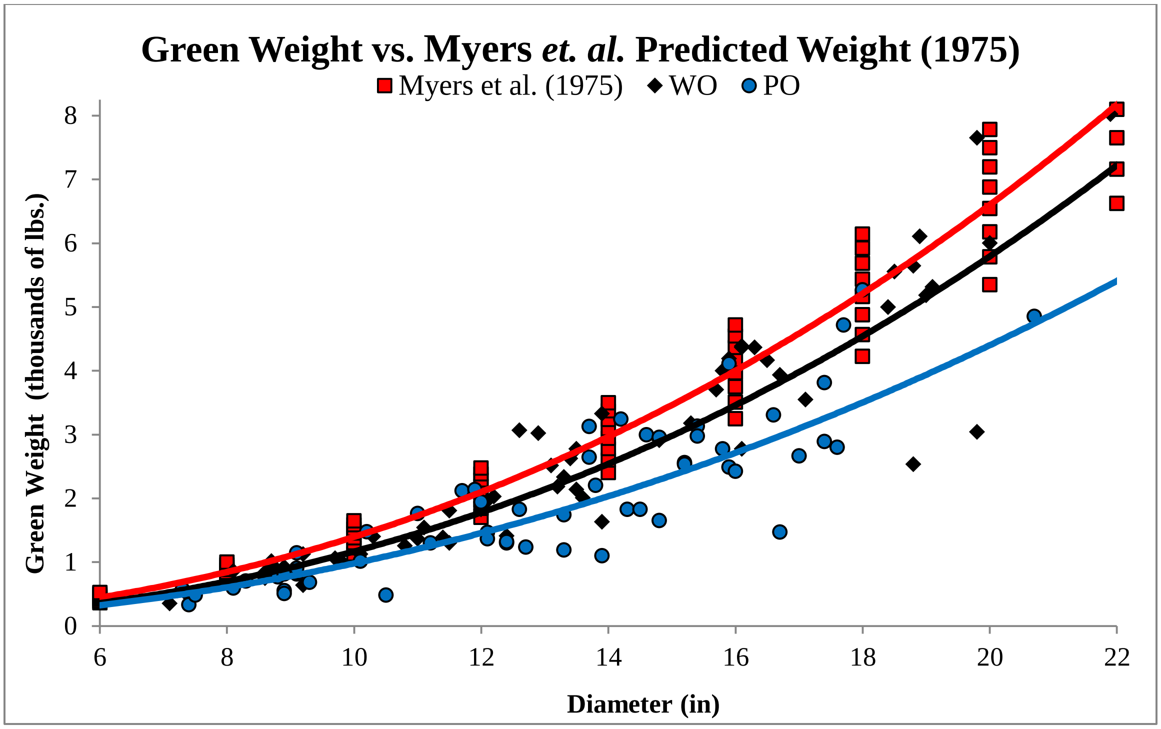

Figure 64. A comparison of the weight trends predicted for white oaks by Myers *et al.* (1975) and the actual trends produced from the data collected from white and post oaks in this study. Myers *et al.* (1975) did not sample any post oaks in their work thus post oak data from this study was compared to the predicted white oak group trends.

seen between the white oaks in both studies. The post oak curve is similar but the gap tends to widens as the tree diameter increases. This could be a resultant of the relatively small dataset recorded from larger diameter post oaks in this study.

Figure 65 compares the black oak data set from this research to Myers' predictions in a similar fashion as the white and post oaks were previously. The trends seen here are very similar with approximately 500 lbs. of difference at any given point along the curve. Figure 66 compares the hickory data from this research to Myers' predictions. Hickory data is also limited in the larger diameter classes of this research but it is interesting to see that the curves once again similar to Myers' work.

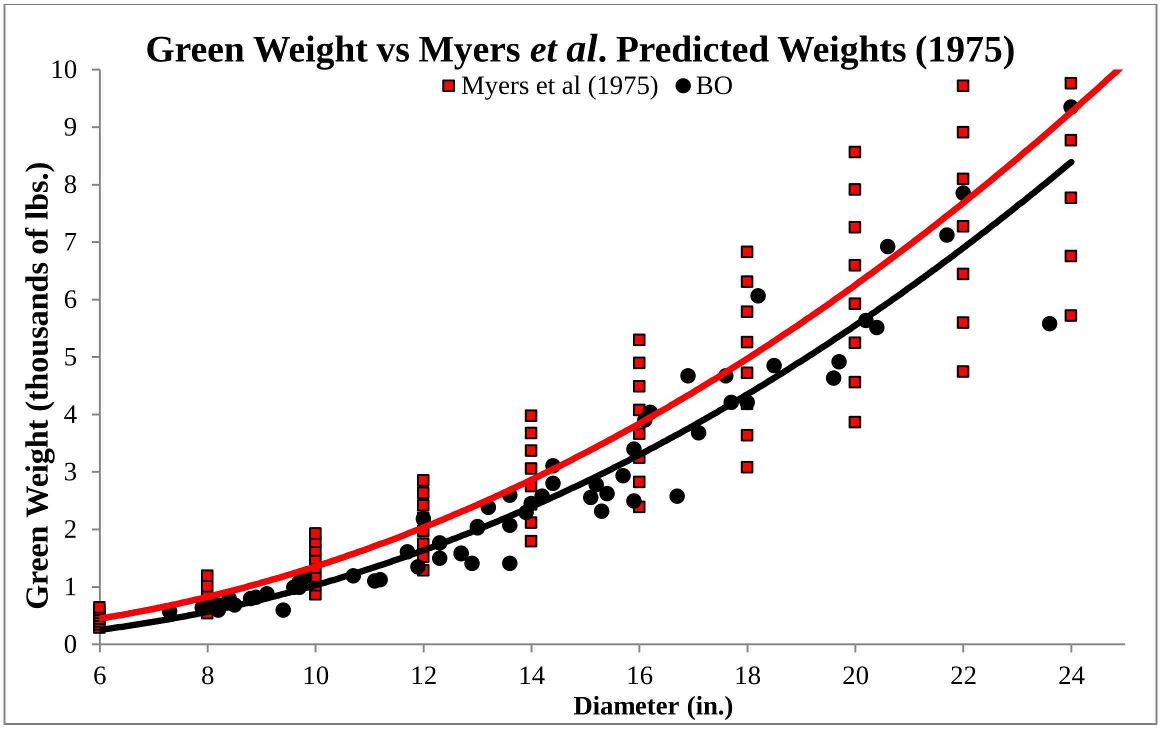

Figure 65. A comparison of the weight trends predicted for black oaks by Myers et al. (1975) and the actual trends produced from the data collected from black oaks in this study. A similar curve is notable.

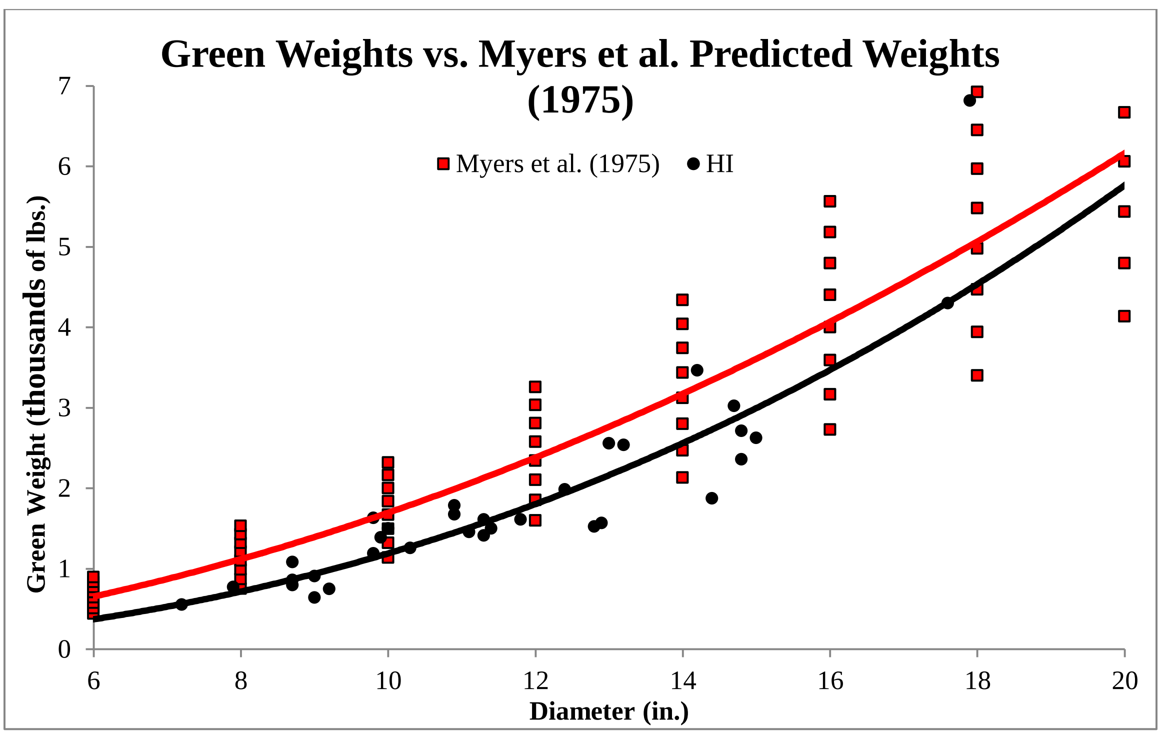

Figure 66. A comparison of the weight trends predicted for hickories by Myers et al. (1975) and the actual trends produced from the data collected from hickories in this study.

Density Averages

The density, or cubic weight, of wood is another dimension commonly encountered in forestry related research and the cubic weights of the species studied in this work were calculated so that comparisons to other research could be made. Cubic weight of a species is most often specified in either AD or OD moisture stages because the weight of water contained within green wood would greatly increase the weight per cubic foot initially but that would decrease quickly as the moisture evaporated post-harvest.

The green, AD, and OD cubic weights are available for review in Table 5 and in Figure 36. Figure 36 displays the dramatic drop in weight per cubic foot (ft^3) as the wood is allowed to dry and the smaller losses of weight going from the AD stage to the OD stage. Manwiller's (1979) study of 22 hardwood species in the southern U.S. produced green cubic weights of 63.7 lbs./ft^3 for black oak (*Q. velutina*), 65.0 lbs./ft^3 for white oak (*Q. alba*), 62.9 lbs./ft^3 for post oak (*Q. stellata*), and 59.7 lbs./ft^3 for hickories (*Carya spp.*). Manwiller's averages were taken from smaller diameter trees (5.5 – 6.5 inches DBH) than those sampled in this research and the densities are higher (Figure 67) than the average green cubic weights in this research with the exception of the hickories (*Carya spp.*).

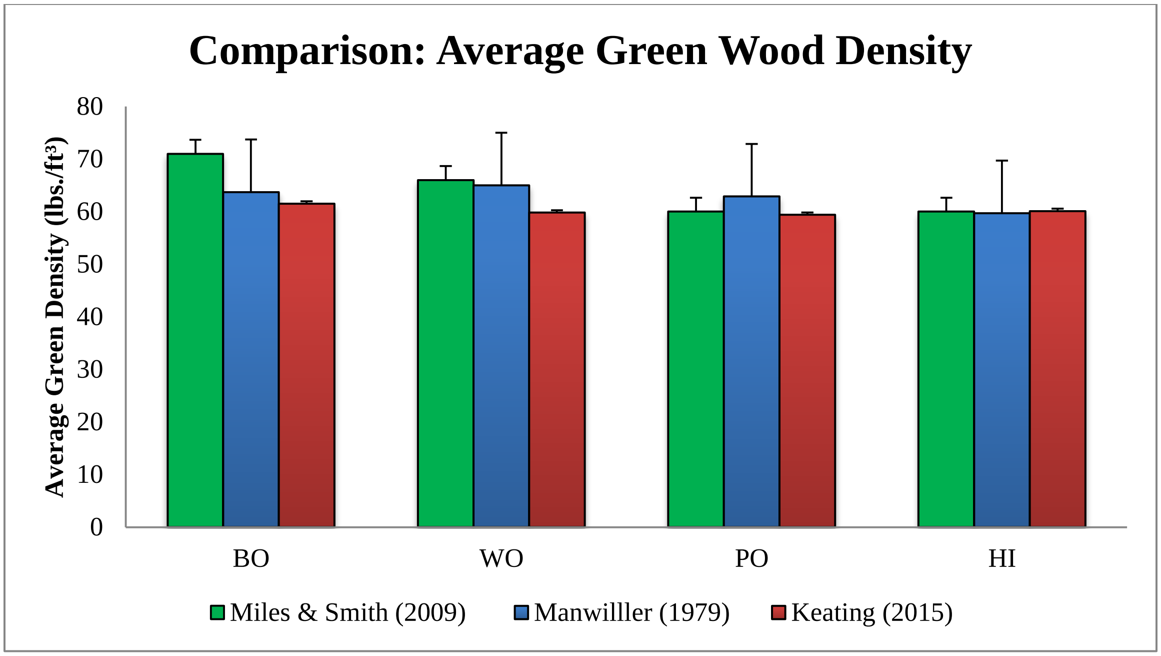

Figure 67. A comparison of average green density of this research to values produced by Miles and Smith (2009) Manwiller (1979).

The U.S. Forest Service's Forest Products Laboratory (FPL, 1999) displays the AD weight per cubic foot for the red and white oak groups as 44.0 and 47.0 lbs./ft^3 respectively and hickories as 51 lbs./ft^3. The AD cubic weights produced in this research were all lower than the figures from the FPL especially in the hickories (Carya spp.) which were nearly 10 pounds lighter on average in the AD stage. Research performed by Miles and Smith (2009) compiled data from various sources and displayed OD cubic weights for the species of focus in this research. Their findings listed the OD cubic weight for black oak at 42.0 lbs./ft^3, white oak at 43.0 lbs./ft^3, post oak at 44.0 lbs./ft^3, and hickories as 45.6 lbs./ft^3. These values are also higher than those recorded in this study. Another study by Hanks (1977) listed OD cubic weight for Appalachian black and white oaks at 34.9 lbs./ft^3 and 37.4 lbs./ft^3. These values are much closer to the values recorded in this research.

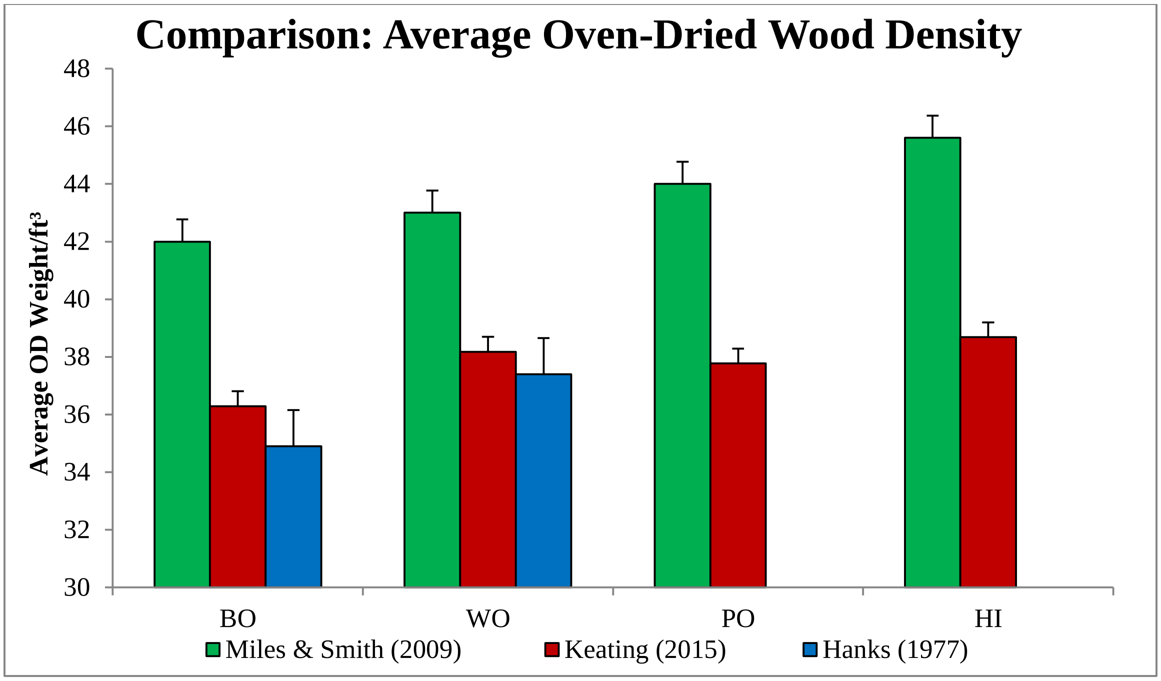

Figure 68. A comparison of average OD cubic weight of this research to values produced by Hanks (1977) and Miles and Smith (2009).

Specific Gravity

The specific gravity of wood has been extensively studied and is an important indicator in terms of physical wood properties such as wood strength and elasticity, density, *etc*. (Panshin and de Zeeuw, 1980). Thus, it stands to reason that specific gravity deserves mentioning in this research. Decreases in specific gravity values were expected when comparing AD and OD sample means and this trend can be seen in Figure 57. Table 8 lists the AD and OD specific gravity values for all species and the difference and percentage of decrease from oven-drying the samples. Black oak, white oak, post oak, and hickory specific gravity values decreased by 3.88 %, 3.67 %, 3.14 %, and 3.81 %, respectively.

Table 8. A categorical listing of average specific gravity values by species and by moisture content stage.

Average Specific Gravity				
	BO	**WO**	**PO**	**HI**
Air-Dried	0.800	0.818	0.827	0.813
Oven-Dried	0.769	0.788	0.801	0.782
Difference	0.031	0.030	0.026	0.031
Decrease (%)	3.88%	3.67%	3.14%	3.81%

Figure 58 displays the mean specific gravity values of the pith and for each cardinal direction. All of the species have higher specific gravity in the pith than in the rest of the wood, with the exception of the black oaks. This trend of decreasing specific gravity values is on par with Panshin and de Zeeuw's (p. 273, 1980) findings for post oak and for shagbark hickory (*Carya ovata*), which is one of the species combined into the hickory group in this study. Interestingly, they (Panshin and de Zeeuw) do not list any specific gravity trends for black or white oaks.

Figure 59 shows the mean OD specific gravity values for each species from the base of the tree and moving upward towards the top to the last sawlog harvested. Patterson and Wiant (1993) examined red oak (*Q. rubra*) logs in a similar fashion and found that specific gravity values were highest in the butt log of the stem. The data used to create Figure 59 shows that this pattern only occurred in the hickories sampled in this research. Black oak specific gravity increased from the base log to log one before decreasing in log two and then increasing again in log three. Black oak specific gravity then decreased greatly in log four and five. Interestingly, white oak and post oak follow almost the same pattern of increase and decreases up the stem until no more post oak data were available. Overall specific gravity trend for white and post oaks were increasing with increased height. The data for hickories in this graph show a great decrease in specific gravity at the second log followed a rapid increase in specific gravity. Please note that hickory data in this research is limited and more data would be required to estimate specific gravity trends in hickories confidently.

Figure 60 displays the specific gravity trends for all species on a cardinal direction basis. Overall trends show decreasing specific gravity values for all species except the black oaks which show a slight increase from pith to the first cuboid. This exception can also be noted in Figure 58. Figure 61 shows the same trends as those presented in Figure 60 but these are segregated into species. Note how much more similar the curves are in Figure 61 compared to those in Figure 60. It should also be noted that these graphs become erratic toward the ends of the trend lines. This is due to increased noise from smaller sample numbers. More data were available in the smaller diameter sample trees than in the larger diameters.

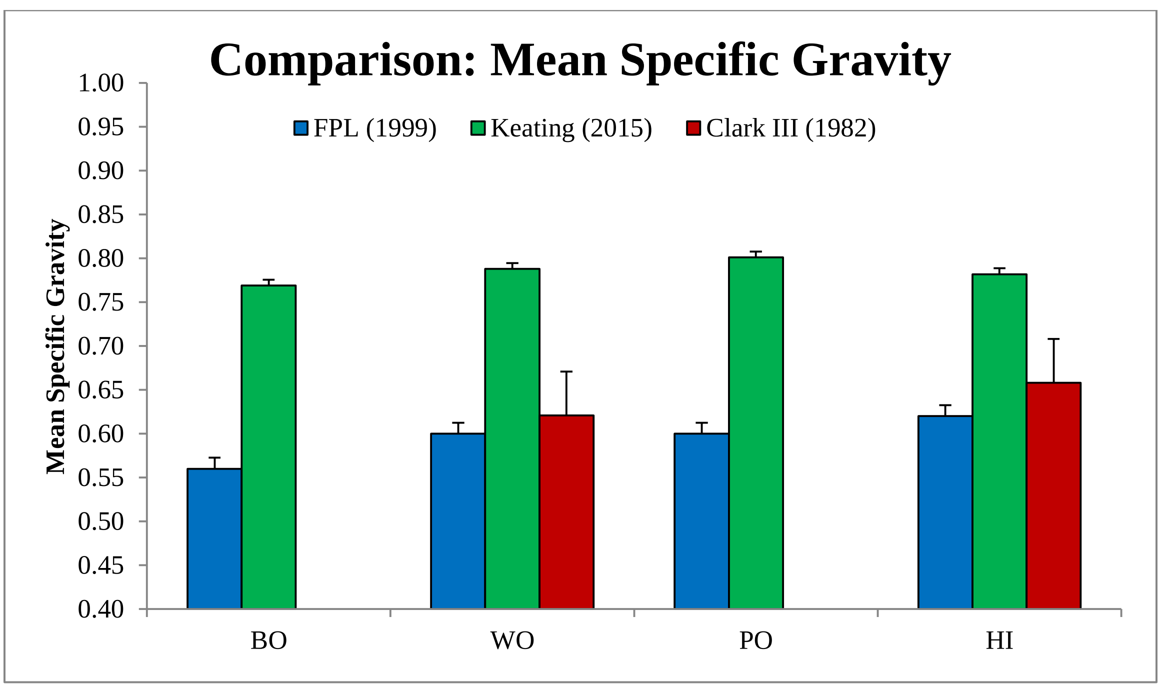

Figure 69. A graphed comparison of mean specific gravity values from this research (Keating 2015) compared to data from the U.S. Forest Service, Forest Products Laboratory (FPL 1999) and Clark III (1982).

Figure 69 displays the mean specific gravity values produced in this analysis and compares those values to other mean specific gravity values published by the U.S. Forest Service, Forest Products Laboratory (FPL 1999) and Clark III (1982). The specific gravity values computed in this research are all higher than those published by the FPL and Clark III (1982).

CHAPTER 5: CONCLUSIONS

This research has produced another set of data for black oaks (*Q. velutina*), white oaks (*Q. alba*), post oaks (*Q. stellata*), and hickories (*Carya spp.*). The species of focus in this work are commonly studied species in forestry related research and much research is available for them currently. While the computations of green and merchantable weights, wood density, and specific gravity are not new to the available research they are new in that they add data from another region that may or may not already have been studied.

This study should be replicated at other sites in Missouri to ensure accurate estimates can be predicted. Equations for regions of Missouri may be required to accurately predict the available biomass in oaks and hickories (i.e. these equations may work in southeastern Missouri but a different equation may be required for northern and western Missouri). Differing sites based upon soils mapping units, hydrologic conditions, elevation, aspect and even latitude may yield different data and thus different results. Combining equations from multiple and ecologically different sites within the state could be used to produce improved equations.

It should also be noted that the data collected during this experiment were collected during the summer months when trees are certain to weigh more due to increased moisture content percentages. A replication of this study during the late winter months when moisture percentages are at their lowest and again during early spring months when moisture percentages reach their highest percentages would supply improved data over that estimated through the conversion factors created on this thesis.

Another possibility for further research would be to incorporate the data from the sample trees in this study with those already logged into the FIA data. A blending of comparable data from both data sets would likely yield a better set of FIA regressions for the state of Missouri when estimations of biomass in the species studied are needed. The equations applicability may also extend into northern Arkansas, southern Illinois, Kentucky, and/or western Tennessee.

Any replication of this study should strive to obtain an increased amount of data on post oaks and hickories as we had hoped to achieve in the beginning of this research.

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Appendix: A

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
1	BO	14.20	62.55	38.60	2579	1763	0.594	1532.08	1047.33	0.930	1424.10	973.51
2	BO	13.00	64.55	39.60	2028	1366	0.581	1177.55	793.16	0.940	1106.54	745.33
3	WO	13.60	64.76	34.70	2006	1212	0.690	1384.14	836.28	0.929	1285.81	776.87
4	BO	15.70	62.10	24.80	2932	2425	0.606	1775.72	1468.66	0.926	1644.47	1360.11
5	BO	15.40	56.14	0.00	2623	1763	0.603	1580.53	1062.32	0.939	1483.39	997.03
6	WO	12.00	68.52	43.50	1829	1212	0.690	1262.01	836.28	0.938	1183.46	784.23
7	WO	11.50	63.50	29.53	1807	793	0.690	1246.83	547.17	0.929	1158.75	508.52
8	BO	12.30	40.25	0.00	1762	1102	0.635	1118.87	699.77	0.933	1043.44	652.59
9	BO	12.90	57.69	27.00	1410	925	0.635	895.35	587.38	0.935	836.95	549.07
10	BO	17.70	65.09	43.40	4210	3196	0.616	2591.54	1967.35	0.928	2404.95	1825.70
11	BO	15.90	57.34	43.95	2491	2182	0.635	1581.79	1385.57	0.935	1478.34	1294.95
12	WO	10.80	44.12	24.00	1256	639	0.620	778.37	396.00	0.931	724.31	368.50
13	BO	16.90	69.24	64.40	4673	3284	0.507	2369.60	1665.26	0.931	2206.10	1550.36
14	BO	13.60	59.60	21.02	1410	749	0.635	895.35	475.62	0.936	837.74	445.01
15	WO	9.20	35.94	15.05	639	242	0.690	440.91	166.98	0.943	415.71	157.44
16	BO	13.60	69.82	38.50	2591	1741	0.616	1596.78	1072.94	0.928	1481.81	995.69
17	WO	16.10	61.27	26.70	4387	1895	0.653	2865.04	1237.58	0.931	2668.30	1152.59
18	BO	24.00	74.23	55.10	9347	5665	0.553	5173.05	3135.26	0.937	4847.14	2937.74
19	BO	16.10	50.02	27.20	3902	1807	0.619	2415.52	1118.62	0.931	2249.33	1041.65
20	HI	10.60	52.57	0.00	0	0	0.701	0.00	0.00	0.924	0.00	0.00
21	BO	14.60	48.55	0.00	0	0	0.635	0.00	0.00	0.928	0.00	0.00
22	PO	12.40	56.38	29.45	1300	683	0.684	889.20	467.17	0.928	825.18	433.54
23	PO	8.90	50.21	22.22	551	286	0.684	376.88	195.62	0.930	350.61	181.99
24	PO	10.50	41.54	21.20	485	264	0.667	323.33	176.00	0.939	303.60	165.26
25	PO	15.80	51.28	24.45	2777	1631	0.684	1899.47	1115.60	0.928	1762.71	1035.28
26	HI	8.60	59.19	0.00	0	0	0.701	0.00	0.00	0.924	0.00	0.00
27	HI	8.70	41.65	0.00	0	0	0.701	0.00	0.00	0.938	0.00	0.00
28	PO	16.70	57.08	24.35	1471	1234	0.613	901.58	756.32	0.928	836.67	701.87
29	HI	13.00	66.77	33.00	2557	1410	0.701	1792.46	988.41	0.924	1656.23	913.29
30	HI	10.90	57.61	31.95	1785	1102	0.633	1130.50	697.93	0.911	1029.69	635.70
31	WO	19.00	65.39	36.85	5185	3130	0.570	2954.43	1783.48	0.905	2674.20	1614.32
32	HI	11.40	65.48	28.75	1498	595	0.701	1050.10	417.10	0.924	970.29	385.40
33	HI	9.00	44.60	17.87	639	208	0.701	447.94	145.81	0.924	413.90	134.73
34	WO	8.10	53.17	28.00	859	551	0.690	592.41	380.00	0.915	541.80	347.54
35	PO	8.30	49.52	26.80	705	485	0.550	387.75	266.75	0.928	359.83	247.54
36	WO	12.20	61.22	26.38	2028	992	0.705	1428.82	698.91	0.898	1283.35	627.75
37	WO	8.60	53.11	26.77	837	595	0.690	577.53	410.55	0.919	530.49	377.11
38	WO	8.70	55.83	26.00	970	793	0.704	682.59	558.04	0.913	623.18	509.47
39	BO	15.30	62.96	28.20	2314	1631	0.614	1421.67	1002.05	0.911	1295.14	912.87

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
40	BO	19.70	57.50	52.95	4916	3262	0.690	3389.74	2249.25	0.928	3145.68	2087.31
41	HI	10.90	48.62	25.00	1675	683	0.621	1039.66	423.93	0.921	957.63	390.48
42	BO	14.00	52.26	31.65	2447	1499	0.688	1682.31	1030.56	0.921	1549.96	949.49
43	BO	10.70	56.31	27.50	1190	815	0.652	776.09	531.52	0.930	721.77	494.32
44	WO	10.10	54.94	29.40	1124	749	0.792	889.83	592.96	0.921	819.92	546.37
45	WO	12.60	61.54	26.15	3064	1278	0.741	2269.63	946.67	0.916	2079.42	867.33
46	BO	9.70	48.83	29.30	1080	605	0.684	738.95	413.95	0.917	677.37	379.45
47	WO	12.40	62.06	31.33	1410	1058	0.763	1076.05	807.42	0.922	992.02	744.37
48	BO	13.00	64.68	33.27	2050	1653	0.662	1356.62	1093.90	0.912	1236.72	997.22
49	BO	20.60	84.64	54.55	6919	4761	0.651	4501.10	3097.23	0.918	4132.73	2843.76
50	WO	13.50	72.59	37.60	2138	1477	0.570	1218.70	841.92	0.905	1103.02	762.00
51	WO	15.90	65.55	29.50	4188	1895	0.667	2792.00	1263.33	0.934	2607.96	1180.06
52	WO	12.90	76.39	42.70	3020	1543	0.682	2059.09	1052.05	0.908	1868.70	954.77
53	HI	13.20	84.33	43.05	2536	1719	0.618	1566.35	1061.74	0.913	1430.31	969.52
54	WO	14.80	69.16	30.30	2910	1697	0.621	1807.73	1054.20	0.921	1665.43	971.22
55	WO	13.40	67.60	32.60	2623	1501	0.629	1648.74	943.49	0.919	1516.02	867.53
56	WO	16.70	70.32	29.50	3936	1940	0.625	2460.00	1212.50	0.925	2275.33	1121.48
57	BO	21.70	72.93	40.45	7120	3858	0.599	4263.17	2310.02	0.917	3909.33	2118.29
58	BO	18.00	80.35	38.50	4210	3108	0.557	2346.99	1732.64	0.918	2154.53	1590.57
59	HI	9.00	43.19	19.80	907	374	0.950	861.65	355.30	0.914	787.43	324.69
60	BO	8.00	48.25	22.10	639	352	0.467	298.20	164.27	0.924	275.41	151.71
61	HI	9.90	65.06	39.47	1389	970	0.701	973.69	679.97	0.921	896.58	626.12
62	PO	14.60	62.83	24.65	2998	1224	0.717	2148.57	877.20	0.927	1991.90	813.24
63	PO	14.80	62.71	30.95	2954	1455	0.618	1826.11	899.45	0.924	1687.53	831.20
64	HI	9.20	50.44	22.50	749	485	0.571	428.00	277.14	0.924	395.48	256.09
65	PO	13.70	55.85	20.30	3128	1201	0.650	2033.20	780.65	0.935	1901.81	730.20
66	HI	7.90	38.85	18.30	771	396	0.667	514.00	264.00	0.918	471.78	242.31
67	PO	10.20	52.30	21.05	1477	771	0.684	1010.27	527.36	0.925	934.61	487.87
68	PO	11.00	53.94	25.05	1763	815	0.684	1206.26	557.63	0.923	1112.97	514.50
69	PO	9.10	50.18	24.30	1146	595	0.778	891.33	462.78	0.925	824.59	428.12
70	PO	14.80	50.67	26.50	1653	1278	0.656	1084.78	838.69	0.925	1003.67	775.98
71	PO	14.20	52.47	22.50	3240	1234	0.704	2280.00	868.37	0.930	2119.85	807.38
72	PO	7.30	48.29	15.50	573	242	0.684	391.93	165.53	0.928	363.71	153.61
73	HI	9.80	54.76	22.80	1631	749	0.609	992.78	455.91	0.924	917.33	421.26
74	HI	14.20	65.07	28.85	3461	1543	0.591	2045.14	911.77	0.919	1880.09	838.19
75	PO	13.80	45.37	17.00	2204	925	0.661	1457.48	611.69	0.920	1341.08	562.84
76	BO	11.70	55.85	28.60	1609	992	0.645	1038.06	640.00	0.928	963.70	594.15
77	BO	15.10	40.02	26.95	2557	1499	0.656	1676.46	982.80	0.930	1558.65	913.73
78	BO	9.10	54.55	22.90	881	595	0.556	489.44	330.56	0.921	450.73	304.41
79	BO	10.30	47.96	0.00	0	0	0.635	0.00	0.00	0.923	0.00	0.00
80	BO	17.10	58.07	32.60	3681	2204	0.624	2296.58	1375.08	0.924	2122.04	1270.57

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
81	BO	12.00	55.28	24.30	2182	903	0.635	1385.57	573.41	0.908	1258.23	520.71
82	BO	12.70	54.43	26.40	1575	1146	0.662	1042.28	758.38	0.903	941.57	685.10
83	BO	20.20	63.63	26.10	5633	2777	0.663	3735.05	1841.33	0.915	3416.54	1684.31
84	BO	9.80	56.48	28.35	1168	683	0.636	743.27	434.64	0.933	693.36	405.45
85	WO	11.00	49.15	22.45	1366	683	0.706	964.24	482.12	0.857	826.13	413.06
86	PO	8.90	43.44	16.60	507	286	0.727	368.73	208.00	0.902	332.48	187.55
87	PO	8.80	50.41	25.45	771	551	0.684	527.36	376.88	0.927	488.84	349.35
88	PO	7.40	40.10	18.60	330	252	0.667	220.00	168.00	0.923	203.04	155.05
89	WO	13.20	47.96	21.30	2181	970	0.688	1499.44	666.88	0.924	1385.52	616.21
90	PO	15.90	60.51	24.45	4111	1675	0.696	2859.83	1165.22	0.903	2582.23	1052.11
91	BO	8.50	48.26	24.45	683	485	0.635	433.71	307.98	0.933	404.47	287.21
92	HI	9.80	48.95	23.55	1190	661	0.645	767.74	426.45	0.909	697.96	387.69
93	PO	13.30	48.35	20.00	1190	815	0.711	845.53	579.08	0.914	773.18	529.53
94	HI	11.30	47.46	23.20	1609	859	0.703	1130.65	603.62	0.904	1021.66	545.44
95	HI	12.90	46.49	23.30	1565	947	0.719	1124.84	680.66	0.914	1027.92	622.01
96	BO	7.90	45.12	17.00	639	374	0.667	426.00	249.33	0.909	387.34	226.71
97	BO	8.40	51.82	30.00	793	617	0.579	459.11	357.21	0.928	426.05	331.49
98	PO	15.40	52.03	18.55	3130	1300	0.673	2106.73	875.00	0.928	1955.05	812.00
99	PO	8.10	45.03	19.10	595	396	0.684	406.98	270.86	0.928	377.68	251.36
100	BO	22.00	69.99	28.00	7848	4012	0.647	5073.74	2593.76	0.928	4708.43	2407.01
101	HI	12.40	63.20	33.55	1984	1168	0.705	1397.82	822.91	0.930	1300.13	765.40
102	WO	16.10	67.31	29.75	4365	2160	0.708	3090.64	1529.39	0.926	2861.93	1416.22
103	BO	8.90	45.36	16.90	815	462	0.635	517.53	293.37	0.927	479.99	272.09
104	WO	8.70	45.96	26.85	925	418	0.727	672.73	304.00	0.930	625.44	282.63
105	BO	9.40	44.13	25.70	595	485	0.635	377.83	307.98	0.929	350.88	286.01
106	BO	11.90	55.05	28.00	1344	1102	0.659	885.82	726.32	0.928	822.04	674.02
107	BO	11.10	47.82	25.60	1102	881	0.625	688.75	550.63	0.928	639.16	510.98
108	WO	18.80	56.64	22.80	2535	1565	0.675	1711.13	1056.38	0.926	1584.50	978.20
109	WO	16.10	50.47	16.90	2777	1322	0.686	1905.78	907.25	0.930	1772.09	843.61
110	BO	8.20	51.16	33.50	683	605	0.727	496.73	440.00	0.933	463.67	410.72
111	BO	7.30	45.24	23.20	573	352	0.635	363.86	223.52	0.921	334.99	205.79
112	PO	11.20	46.96	24.90	1300	837	0.593	770.37	496.00	0.932	717.66	462.06
113	PO	10.10	45.70	20.25	1014	573	0.727	737.45	416.73	0.926	683.05	385.99
114	WO	17.10	58.53	27.10	3549	1940	0.755	2679.85	1464.90	0.923	2473.55	1352.12
115	BO	18.50	59.06	28.00	4850	2645	0.676	3279.90	1788.73	0.934	3063.43	1670.68
116	WO	19.80	58.50	18.10	3042	1741	0.673	2046.44	1171.22	0.926	1895.00	1084.55
117	WO	18.40	61.71	27.80	4996	2248	0.694	3469.44	1561.11	0.926	3212.71	1445.59
118	WO	13.90	42.39	24.00	1631	1080	0.682	1112.05	736.36	0.932	1036.56	686.38
119	PO	9.10	51.37	29.55	815	529	0.652	531.52	345.00	0.929	493.86	320.55
120	WO	15.80	61.56	29.80	3999	1653	0.756	3024.50	1250.19	0.930	2812.06	1162.38
121	WO	11.10	52.91	28.10	1543	793	0.683	1053.16	541.25	0.926	975.22	501.20

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
122	WO	10.30	50.59	26.00	1401	749	0.808	1131.58	604.96	0.929	1051.25	562.02
123	BO	14.40	59.61	54.10	3108	2204	0.641	1991.06	1411.94	0.928	1847.71	1310.28
124	PO	12.60	47.94	20.70	1829	801	0.684	1251.04	547.88	0.923	1155.13	505.88
125	BO	17.60	56.37	28.80	4673	2513	0.658	3076.95	1654.69	0.928	2855.41	1535.55
126	HI	14.80	63.46	29.75	2711	1653	0.760	2060.36	1256.28	0.928	1911.50	1165.51
127	HI	8.70	50.60	28.05	1080	617	0.701	757.08	432.52	0.924	699.66	399.72
128	HI	8.70	42.12	22.80	793	418	0.701	555.89	293.02	0.924	513.65	270.75
129	WO	13.10	54.63	23.20	2513	1102	0.625	1570.63	688.75	0.926	1454.40	637.78
130	HI	11.80	47.77	25.00	1609	727	0.778	1251.44	565.44	0.924	1156.33	522.47
131	PO	14.30	56.36	17.80	1829	970	0.684	1251.04	663.48	0.928	1160.96	615.71
132	PO	13.30	46.11	15.00	1742	987	0.676	1177.03	666.89	0.924	1088.10	616.51
133	WO	8.60	41.28	15.00	749	284	0.690	516.81	195.96	0.928	479.43	181.79
134	BO	13.20	62.56	29.10	2380	1322	0.647	1540.00	855.41	0.928	1429.12	793.82
135	WO	8.90	49.24	29.65	925	507	0.714	660.71	362.14	0.927	612.53	335.73
136	WO	9.70	50.18	21.40	1058	601	0.676	715.71	406.56	0.926	662.74	376.47
137	WO	8.70	51.08	23.75	1014	771	0.696	705.39	536.35	0.926	653.19	496.66
138	PO	9.10	45.60	21.00	837	507	0.750	627.75	380.25	0.923	579.48	351.01
139	WO	25.10	57.77	38.45	5731	2667	0.718	4113.65	1914.34	0.933	3838.91	1786.49
140	PO	17.00	55.00	18.00	2667	1455	0.718	1914.05	1044.22	0.935	1790.45	976.79
141	PO	12.70	46.85	14.35	1234	661	0.692	854.31	457.62	0.928	792.80	424.67
142	PO	16.60	56.44	21.30	3306	1565	0.708	2341.75	1108.54	0.928	2172.62	1028.48
143	WO	20.00	57.76	22.50	5998	2116	0.723	4336.53	1529.86	0.925	4013.06	1415.75
144	PO	15.20	53.81	22.20	2557	1366	0.678	1733.56	926.10	0.931	1613.56	862.00
145	BO	18.20	62.39	27.15	6062	2182	0.642	3889.32	1399.95	0.928	3609.29	1299.15
146	BO	19.60	66.99	35.60	4629	2535	0.630	2914.56	1596.11	0.928	2704.71	1481.19
147	HI	15.00	51.14	24.20	2623	1190	0.750	1967.25	892.50	0.924	1817.74	824.67
148	BO	20.40	72.06	27.40	5511	3218	0.633	3487.80	2036.61	0.928	3236.68	1889.97
149	PO	12.10	49.32	24.00	1466	771	0.667	977.33	514.00	0.931	909.74	478.45
150	PO	11.70	48.88	21.90	2116	815	0.667	1410.67	543.33	0.926	1305.60	502.86
151	PO	12.10	40.00	16.20	1366	661	0.667	910.67	440.67	0.930	847.09	409.90
152	HI	10.00	50.84	24.90	1499	661	0.701	1050.80	463.36	0.927	973.79	429.40
153	PO	12.40	45.02	23.80	1322	771	0.684	904.25	527.36	0.927	837.83	488.63
154	PO	17.60	47.75	12.30	2799	1036	0.660	1848.40	684.15	0.923	1706.56	631.65
155	PO	13.90	28.25	14.30	1102	837	0.684	753.77	572.51	0.942	709.89	539.18
156	BO	9.70	47.93	25.15	992	617	0.711	704.84	438.39	0.929	654.75	407.24
157	BO	8.20	42.15	21.00	595	396	0.600	357.00	237.60	0.938	334.90	222.89
158	PO	9.30	42.40	21.45	683	440	0.684	467.17	300.96	0.925	431.99	278.29
159	PO	7.50	39.92	10.85	485	220	0.684	331.74	150.48	0.951	315.56	143.14
160	HI	12.80	47.28	18.30	1521	925	0.727	1106.18	672.73	0.924	1022.11	621.60
161	WO	7.10	34.13	17.15	352	176	0.690	242.88	121.44	0.931	226.03	113.02
162	WO	13.90	56.89	22.10	3328	1256	0.678	2256.55	851.63	0.926	2089.57	788.61

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
163	WO	11.40	49.53	12.30	1388	573	0.643	892.29	368.36	0.926	826.26	341.10
164	HI	7.20	35.94	15.10	551	220	0.701	386.25	154.22	0.924	356.90	142.50
165	WO	11.50	53.46	24.60	1300	595	0.690	897.00	410.55	0.926	830.62	380.17
166	BO	11.20	44.01	21.90	1124	793	0.717	805.89	568.57	0.928	747.86	527.63
167	BO	12.30	51.61	29.85	1499	1146	0.682	1022.05	781.36	0.928	948.46	725.11
168	WO	9.20	51.25	20.00	1124	501	0.767	861.73	384.10	0.926	797.97	355.68
169	BO	16.70	53.66	27.80	2579	1962	0.672	1734.12	1319.25	0.928	1609.27	1224.27
170	BO	15.20	64.07	30.50	2777	2050	0.652	1809.69	1335.93	0.938	1697.49	1253.10
171	PO	14.50	52.97	21.00	1829	1058	0.681	1245.28	720.34	0.947	1179.72	682.42
172	PO	23.60	53.28	25.45	5621	3461	0.679	3816.73	2350.06	0.928	3541.92	2180.86
173	PO	11.90	56.12	21.55	2138	947	0.730	1560.16	691.05	0.928	1447.83	641.30
174	WO	15.30	56.91	44.40	3174	1675	0.730	2316.16	1222.30	0.944	2187.28	1154.28
175	WO	16.30	61.67	24.80	4365	1609	0.718	3134.93	1155.58	0.935	2931.26	1080.50
176	PO	15.90	51.25	18.90	2491	1300	0.756	1882.09	982.22	0.928	1746.58	911.50
177	WO	13.30	58.22	27.35	2336	1234	0.706	1648.94	871.06	0.943	1554.36	821.10
178	BO	13.90	66.99	22.50	2292	1300	0.652	1494.45	847.64	0.941	1406.05	797.50
179	WO	16.50	63.44	28.50	4166	1940	0.705	2935.59	1367.03	0.937	2752.02	1281.54
180	BO	14.40	58.76	27.20	2800	1587	0.690	1931.19	1094.57	0.937	1809.55	1025.63
181	HI	17.60	55.30	25.45	4298	2050	0.681	2927.62	1396.38	0.943	2761.60	1317.19
182	HI	14.40	59.09	31.85	1873	1212	0.741	1387.41	897.78	0.937	1300.37	841.46
183	PO	17.70	50.20	12.80	4717	1322	0.714	3369.29	944.29	0.935	3151.67	883.29
184	WO	18.80	61.55	27.70	5643	2380	0.700	3947.32	1664.83	0.936	3696.23	1558.93
185	PO	25.20	63.08	15.10	4187	2314	0.684	2863.91	1582.78	0.928	2657.71	1468.82
186	WO	19.80	78.04	28.60	7649	3152	0.720	5509.29	2270.27	0.937	5159.76	2126.23
187	HI	17.90	71.50	19.20	6814	1741	0.741	5046.81	1289.48	0.937	4730.43	1208.64
188	PO	18.00	61.29	29.40	5268	2358	0.708	3731.17	1670.10	0.928	3462.53	1549.86
189	HI	11.30	62.91	36.50	1410	1080	0.710	1000.65	766.45	0.924	924.60	708.20
190	HI	14.70	65.78	39.40	3020	1719	0.694	2094.52	1192.21	0.924	1935.33	1101.60
191	PO	17.40	58.00	27.40	3813	2116	0.681	2596.08	1440.68	0.938	2434.32	1350.91
192	PO	15.40	46.94	18.00	2976	1300	0.731	2174.55	949.90	0.928	2017.98	881.51
193	PO	20.70	65.11	36.50	4850	3659	0.682	3307.63	2495.38	0.928	3069.48	2315.72
194	HI	14.80	59.69	32.70	2358	1543	0.746	1759.57	1151.41	0.939	1652.92	1081.62
195	PO	17.40	51.19	27.40	2888	2028	0.708	2046.01	1436.74	0.928	1898.70	1333.30
196	BO	23.60	65.56	40.20	5577	4607	0.561	3130.32	2585.86	0.928	2904.93	2399.68
197	WO	19.10	69.80	26.40	5313	2910	0.654	3474.81	1903.20	0.926	3217.68	1762.36
198	WO	18.90	75.03	33.10	6106	3064	0.653	3989.43	2001.90	0.938	3740.61	1877.05
199	WO	21.90	72.55	37.20	8024	4276	0.712	5711.13	3043.47	0.938	5359.45	2856.06
200	WO	18.50	79.25	28.20	5555	2513	0.686	3813.42	1725.14	0.926	3531.23	1597.48
201	HI	11.10	58.81	29.35	1455	837	0.769	1119.23	643.85	0.924	1034.17	594.91
202	WO	15.70	73.56	29.50	3703	1940	0.703	2601.92	1363.14	0.926	2409.38	1262.27
203	WO	9.80	57.58	25.60	1014	595	0.633	642.20	376.83	0.926	594.68	348.95

Tree	SPP	DBH	THt	MHt	GrTW	GrMW	%ΔWt	AdTW	AdMW	%ΔWt	OdTW	OdMW
204	PO	9.10	48.32	24.75	903	617	0.632	570.32	389.68	0.928	529.25	361.63
205	PO	12.00	56.05	25.90	1940	1080	0.702	1361.40	757.89	0.928	1263.38	703.33
206	WO	13.50	57.94	22.40	2777	1014	0.676	1877.41	685.52	0.926	1738.48	634.79
207	HI	8.70	54.38	26.60	859	617	0.701	602.16	432.52	0.924	556.39	399.65
208	HI	10.30	57.81	27.10	1256	749	0.701	880.46	525.05	0.924	813.54	485.15
209	PO	13.70	61.22	29.20	2645	1455	0.716	1893.26	1041.47	0.928	1756.95	966.49
210	BO	13.60	60.29	28.20	2072	1234	0.659	1364.49	812.63	0.928	1266.24	754.12
211	PO	8.90	47.21	25.20	815	573	0.692	564.23	396.69	0.928	523.61	368.13
212	PO	15.20	48.77	20.10	2535	1300	0.719	1822.03	934.38	0.928	1690.85	867.10
213	BO	12.70	55.18	25.35	1587	925	0.578	916.93	534.44	0.928	850.91	495.96
214	BO	9.60	45.85	23.70	992	617	0.688	682.00	424.19	0.934	637.10	396.26
215	WO	7.40	46.74	20.70	462	352	0.667	308.00	234.67	0.932	286.91	218.60
216	BO	8.80	51.31	32.20	793	418	0.635	503.56	265.43	0.928	467.30	246.32
217	WO	12.10	57.16	24.15	1962	1058	0.702	1376.84	742.46	0.933	1285.12	692.99
218	PO	16.00	46.57	17.45	2425	1080	0.643	1558.93	694.29	0.928	1446.69	644.30
219	BO	15.90	54.49	18.20	3395	1455	0.688	2337.06	1001.60	0.936	2188.00	937.72
220	BO	16.20	66.49	25.30	4034	1763	0.673	2714.33	1186.26	0.944	2562.63	1119.96

SPP = Species

WO= white oak

BO= black oak

PO = post oak

HI = hickories

DBH = diameter at breast height (4.5 ft)

Gr = Green

Ad = Air-dried

Od = Oven-dried

TW = Total Weight (lbs.)

MW= Merchantable Weight (lbs.)

%ΔWt. = Percent change in weight (lbs.)

Note: The boxes in Appendix A that are shaded in grey are the average weight reduction factor (%ΔWt.) produced from this data set for that particular species. The averages were entered into the data set when a sample lacked enough data to produce its own reduction factor.