SPECIFIC GRAVITY AND ESTIMATED PHYSICAL PROPERTIES OF EMORY OAK IN SOUTHEASTERN ARIZONA

By

John Kaunda Maingi

A Thesis Submitted to the Faculty of the

SCHOOL OF RENEWABLE NATURAL RESOURCES

In Partial Fulfillment of the Requirements
For the degree of

MASTER OF SCIENCE
WITH A MAJOR IN WATERSHED MANAGEMENT

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 2

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: ______________________

APPROVAL BY THESIS COMMITTEE

This thesis has been approved on the date shown below:

Dr. Peter F. Ffolliott
Professor of Watershed Management
7/15/92
Date

Malcolm J. Zwolinski
Dr. Malcolm J. Zwolinski
Professor of Watershed Management
July 14, 1992
Date

Gerald Gottfried
Dr. Gerald J. Gottfried
Research Forester, USDA Forest Service
7/15/92
Date

ACKNOWLEDGEMENTS

I would like to thank Dr. Peter Ffolliott, my major advisor, thesis director and friend. He has been there for me throughout my whole course. I am grateful for his patience and support in developing this research up to the state it is in. His contributions in helping me develop a career in dryland forestry research has been immense.

I would also like to thank Dr. Malcolm Zwolinski for agreeing to serve in my committee and the many helpful comments and suggestions he made in the writing up of the thesis. Many thanks to Dr. Gerald Gottfried for his invaluable contributions to the quality of this thesis. I thank Dr. Steve Leavitt for the use of his laboratory and equipment during the study. I am grateful to all my friends who contributed in various ways to the sucessful completion of my program. I thank my family, and especially my mother for all the support they have given me.

I am very grateful to my employer Kenya Forestry Research Institute (KEFRI) for giving me this opportunity to pursue further studies. This study would not have been possible without the financial assistance of the Government of Norway, through the auspices of the Royal Norwegian Agency for International Development (NORAD). I am especially grateful to Ms. Kari Gronn-Nielsen of NORAD, Oslo who made sure that I received my scholarship funds in time throughout my study period.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Average specific gravity of Emory oak (*Quercus emoryi*) estimated from 115 increment cores was 0.567 ± 0.011 (95 percent confidence interval). Increment core specific gravity is a predictor of average tree specific gravity. Diameter breast height (dbh) and diameter root collar (drc) were correlated with increment core specific gravity, but the correlations were too low to be valuable for predictive purposes. Estimated physical properties of Emory oak wood were lower than those reported for Gambel oak (*Quercus gambelii*) but higher than those reported for alligator juniper (*Juniperus deppeana*).

INTRODUCTION

Trees in the oak woodlands of southeastern Arizona have been utilized longer and more intensely for fuelwood than for any other wood product (Bahre and Hutchinson, 1985). Wood is still a principal fuel used in many rural localities. In many areas, this has increased greatly in the past 10 years. The increase in the demand for oak fuelwood has been attributed to higher energy prices and increased population.

Until recently, relatively little attention has been directed toward intensive land and resource management in the oak woodlands. The main reason for this is the long rotation period that characterizes trees in these woodlands, and the poor form which precludes their widespread use. However, due to the increasing demands for fuelwood, as well as for other wood-based resources, systematic management plans are now being formulated by several land management agencies.

Much of the research in oak woodlands has concentrated on the quantification of woody biomass (Bahre and Hutchinson, 1985; Callison, 1989; Ffolliott and Leferve, 1988; Tongvichit, 1987; Touchan, 1986) and problems associated with natural recruitment (Borelli, 1990). The potential energy of woody biomass in Arizona has been investigated (McMurtray, 1978; Ffolliott et al., 1979; Patterson, 1980; and Tolisano, 1984).

Processing and utilization of wood resources in the oak woodlands has been restricted largely to the use for fuelwood. The tree species present a sizable wood fiber resource that could be useful in the manufacturing of wood products such as charcoal and extraneous compounds (Barger and Ffolliott, 1972). Extraneous materials, extractives, or infiltrations are the collective names for various organic substances found in the parenchyma cells of the heartwood. These materials may be crystals, silica and numerous amorphous materials of complex chemical nature, including gums, resins, tannins, oils, latex, coloring matter, and nitrogenous materials, such as alkaloids (Panshin et al., 1964). Other wood products that can be made from smaller, irregular stems and capitalize on unique physical characteristics (such as fragrance and color) offer processing and utilizational opportunities.

Determination of specific gravity of Emory oak, one of the most important woodland species in southeastern Arizona, is important as it would enable measurement of woodland productivity on a weight basis. Productivity of the oak woodlands has largely been measured in terms of volume units. Biomass assessments based on volume are often limited in value because from volume information there is no adequate indication as to the actual amount of wood substance available per unit volume. Volumetric measures of woodland productivity are particularly inappropriate when the wood is being grown for cellulose products. Measurement on a weight basis offers a logical solution to the problem of evaluating woodland productivity. Measuring wood by green weight is also a poor and inaccurate way of determining biomass, because green weight will vary with moisture content.

A knowledge of specific gravity and its variability in Emory oak would enable evaluation of the species for utilization possibilities. Specific gravity is correlated closely with the mechanical strength of wood, and determines, to a large extent, the yield of products such as pulp and charcoal. It provides a means of estimating strength, shock resistance, and hardness. The variability in specific gravity also indicates the variability to be expected in physical properties.

Specific gravity is usually expressed as the ratio of weight of a substance to the weight of an equal volume of water and is abbreviated as (sp gr) or (G). In the case of wood, oven-dry weight is used as basis and comparison is made with the weight of displaced water. Specific gravity will vary with moisture content of wood, because of the dimensional changes that occur in wood below the fiber saturation point. For this reason, it is necessary to specify the moisture content of the wood at which the volume was determined, when stating the specific gravity. Minimum specific gravity is obtained when green volume is used, and maximum when volume of wood is taken at the oven-dry condition in determining weight of displaced volume of water.

Specific gravity of wood based on green volume, or basic specific gravity, is one of the most useful and commonly cited values. The term basic is applied since both green volume and oven-dry weight are as nearly constant and reproducible measurements as can be obtained with wood.

Extraction of wood from the oak woodlands is for fuelwood. Knowledge of specific gravity of a species would enable the amount of energy a certain quantity of fuel would yield to be estimated more accurately. The higher the specific gravity of a species, the more solid wood substance per unit volume it contains and, thus, the more energy yield per unit volume. In addition, specific gravity and moisture content usually are negatively related to each other within a species, so the higher the specific gravity, the lower the moisture content (Zobel et al., 1968). This relationship of moisture content of wood substance is important in energy production, because net energy is largely a function of the amount of moisture that must be removed from the wood before it can be converted into usable energy (Zobel and van Buijtenen, 1989).

Objectives of this study were to:

1. Determine the unextracted specific gravity of Emory oak from a sample of increment cores.
2. Develop a relationship between average tree specific gravity (obtained from disks) and specific gravity estimated from increment cores.
3. Determine whether specific gravity varies with tree height.
4. Ascertain whether specific gravity estimated from increment cores varies with tree and stand variables.
5. Estimate physical properties of the tree species from knowledge of specific gravity.

LITERATURE REVIEW

Specific gravity is not a simple property, but is determined by characteristics such as cell size, wall thickness and other factors. In addition to cell characteristics, factors such as chemical deposits within and between the cell can affect specific gravity drastically. When such deposits are present, specific gravity must be categorized as extracted or unextracted. Relatively inflated specific gravity values can be obtained if there are unusual deposits of extractives, such as the resins in the heartwood of some conifers, around knots or near wounds resulting from insect attack, frost cracks, or ring shake. Some trees have chemical or crystalline deposited in, on, or between the cell walls. This situation is especially common for hardwoods such as oak species (Chudnoff, 1980). Although they are not part of the cell wall, these deposits greatly affect both the specific gravity of the wood and quality of the final product.

Woods with basic specific gravities (calculated on oven-dry weight and volume in green condition) of 0.36 or less are considered to be light; 0.36 to 0.50, moderately light to moderately heavy; above 0.50, heavy (Panshin et al., 1964).

The importance of specific gravity has been emphasized by many investigators. Van Buijtenen (1982), and Bamber and Burley (1983) showed that density is the most significant of all the wood properties in determining end-use. The strength and quality of solid wood products relate to specific gravity (Lewark, 1979; Pearson and Gilmore, 1980). Specific gravity values largely determine the energy yield from wood and the yields of such products as charcoal (Barger and Ffolliott, 1971; Boulding, 1977; Goldstein, 1980). Higher specific gravity wood contains more substance per unit volume and thus will yield more energy per unit volume than lower specific gravity wood.

Variability in Specific Gravity

It is common for specific gravity to vary significantly within a tree. In many species, butt logs (portion of the tree bole between ground and 16 feet) tend to have a higher density than logs cut from higher in the main stem. However, wood near the base of the tree can have a lower density in other species. Specific gravity decreases with increasing height and increases with distance from pith for most conifer species (Elliott, 1970; Zobel and van Buijtenen, 1989). In large softwood logs, the density increases outward from the pith and then reaches a fairly constant level.

Most hardwoods show only minor decreases in specific ravity with increasing height. Others, such as the trembling aspen (*Populus tremuloides*), show a high specific gravity at the base, a decrease for some distance up the tree followed by an increase towards the top. Some reports show an increase in density with height in *Eucalyptus* spp. and *Populus* spp (Zobel and van Buijtenen, 1989).

In a study on the variation of wood properties in southern red oak (*Quercus falcata*), Hamilton (1961) found that wood with the highest density and greatest percentage of latewood was found in a central core extending the length of the tree. This core was surrounded by shells of wood of lower specific gravity and percentage latewood. These findings were in agreement with those of earlier studies in ring porous hardwoods such as oaks (Myer, 1930; Paul, 1959).

Barger and Ffolliott (1964, 1965) determined the specific gravity of Arizona Gambel oak and alligator juniper in northern Arizona. They found that the mean specific gravity of the species was higher in saplings and small poles compared to larger poles. Effects of extractives on specific gravity of southwestern ponderosa pine (*Pinus ponderosa*) was studied by Barger and Ffolliott (1971). The results of the study indicated that the mean specific gravity of the species is reduced by 12 percent by the removal of alcohol-, benzene-, and water-soluble extractives.

Juvenile wood (wood formed in the region near the pith) development in most hardwoods is relatively small compared to softwoods and, therefore, the variation in wood with age of the tree is usually small, making it much simpler to categorize wood properties regardless of age (Zobel and van Buijtenen, 1989). With the exception of the eucalypts, work on the properties of hardwoods has been limited compared to that devoted to conifers.

Effects of Stand and Site Variables on Specific Gravity

Wood properties of hardwoods usually have the same overall pattern as conifers, varying greatly from tree to tree, within a species and sometimes also within the geographical range where the species originated, or where it was grown later as an exotic.

Stand density has an influence on the wood formed. Spacing among trees influences branching characteristics and rate of growth, both of which affect specific gravity (Bamber and Burley, 1983). Differences in stand densities influence specific gravity not only through crown development and growth rate, but also through their effect on the utilization of nutrients and water. In addition, the temperature of the soil, moisture availability from the soil, penetration of radiant energy, and illumination of the crown are affected and result in a changed growth pattern which, in turn, can affect specific gravity (Savina, 1956).

Larson (1962) points out the nature of wood produced in the tree stem can be most readily understood as a resultant of the crown activity. For stands with similar spacings and distribution of crown sizes, growth factors as available soil moisture or local temperatures affect the periods of shoot elongation and the total growing season between sites. Since early and latewood formation are dependent upon different stages in crown development, shifts in timing and length of these periods will result in differing structure of the growth rings between stands which are apparently similar. For example, decreases in specific gravity, tracheid length and latewood percentage can be related to long periods of active terminal growth. However, at the same time, the reason for the increased terminal growth may not be evident.

Many studies have been carried out in an attempt to determine the effects of the various growth factors on specific gravity, tree form, tracheid length, and other features of the tree. Few of these studies were planned to take the full set of interrelated growth conditions into account. In most studies only one or two variables were measured while others were ignored or assumed to be constant. As a result, there are many conflicting conclusions based on these incomplete studies.

Site related factors such as moisture, availability of sunlight and nutrients, wind and temperature can affect specific gravity. These factors are determined to a large extent by the elevation, aspect, slope, latitude, and soil type of a site, and the stand composition and spacing of trees. All these factors can affect the size and wall thickness of the cell, and as a consequence, the wood density of species differ, in their sensitivity to these factors. The variation of wood specific gravity resulting from the effects of site and climate are difficult to assess because of the unknown interrelation of the factors.

Tree species and position of tree within a stand also can have an effect on wood specific gravity. Lawton (1984) reported for a tropical montane forest that shade-intolerant species had less dense wood than shade-tolerant species from the same sites. A possible explanation for this observation is that the shade tolerant species continued to put on latewood under less than ideal growth conditions. The shade intolerant species on the other hand produced little growth under such conditions and, therefore, had a lower percentage of latewood compared to the shade tolerant species. Lawton also found that species growing on windy sites had denser wood than species characteristic of sheltered sites.

The amount of moisture available has limited influence on the specific gravity of the low density, diffuse-porous hardwoods, but has a major effect on the high density, ring-porous hardwoods. This effect is primarily through a change in the relative amount of vessels produced in the earlywood and latewood. Latewood continues to be produced when moisture is available, resulting in higher specific gravity wood (Zobel and van Buijtenen, 1989).

Site or soil differences within a given geographic area usually are not associated with significant differences in specific gravity, unless the sites or soils are diverse. Therefore, wood of a species tends to be relatively constant from site to site within a region when site differences are moderate (Zobel and van Buijtenen, 1989). Furthermore, large individual differences among trees within a site make it more difficult to detect differences caused by site or soil variability.

A major component of a site is soil. Wood properties often change with soil characteristics, although variations of soil with wood specific gravity usually are small within a given geographic area. Tree growth responses to soil occur when extreme differences in soil texture are present such as between sand and clay. Different soil types will have different moisture storage capacities. This may markedly alter the beginning, the end, or the total length of the growing season between sites. Therefore sites with different soil types are likely to cause a disproportionate formation of earlywood or latewood cell types.

Hamilton et al. (1978) found that soil parent material affected the specific gravity of northern red oak (*Quercus rubra*). Wood from trees on limestone soils had a specific gravities of 0.597 and 0.581 on sandstone soils. Wilde and Paul (1959) reported that aspen (*Populus tremuloides*) wood of highest specific gravity was produced on well-drained, fine textured soils, while lower specific gravity wood was produced on well-drained and nutrient deficient soils. This observation indicates that trees growing on well-drained, fine textured soils produced higher proportions of latewood than those on well-drained nutrient deficient soils.

Zahner (1968) concluded that the wood density of ring-porous species, such as oaks, is influenced by site, because these species grow in a variety of environments which affect latewood production. Since the size and proportion of large vessels in the earlywood are relatively constant at all sites, the variable production of high density latewood among sites can increase wood density on poor to good sites. Un-harvested sites with higher site index will not only yield greater volumes of wood, but also wood of greater density.

The effect that the environment has upon wood specific gravity of loblolly pine (*Pinus taeda*) in southern Illinois can be attributed almost entirely to the availability of moisture for growth (Gilmore et al., 1966). In regions that do not receive rainfall in the summer, soils become dry and only a limited quantity of water is available for tree growth. When the density of the stand is reduced, more moisture becomes available to each tree over a long period during the growing season, producing more earlywood. The effect of reducing stand density on loblolly pine was a decrease in wood density (Goggans, 1961). It is well established that early wood has a lower density than latewood.

Breast Height to Whole Tree Correlations in Specific Gravity

A major problem faced in the sampling of wood in a standing tree is to determine where the sample should be taken to represent the whole tree. Usually, sampling must be non-destructive and done in a convenient location to minimize cost and effort. The simplest method is to take a wood sample at breast height (4.5 feet above the ground surface) and relate it to the density of the whole tree.

A number of studies have shown that specific gravity of the merchantable portion of trees is correlated with that of samples taken at breast height (Christopher and Wahlgren, 1964; Maeglin, 1966; Taras and Wahlgren, 1963; USDA Forest Service, 1965; Wahlgren and Fassnacht, 1959; Wahlgren et al., 1966). These studies also have revealed that the addition of other tree characteristics, such as age, diameter, and height, can increase precision of the estimates.

Frequently, the specific gravity of increment cores at breast height to whole tree specific gravity relationships are better when only the mature wood (also known as outer wood is the wood produced in older trees by the mature cambium which is less subject to influences of the apical meristem) at breast height is compared to the whole tree values (Zobel et al., 1960). Problems are minimal when trees of the same age are sampled. Warren and Mirams (1963) stated that even a small sample of specific gravity values at breast height can provide a good indication of whole tree specific gravity values. Less satisfactory is the use of only juvenile wood specific gravity values to predict total tree specific gravity values. Zobel et al. (1960) found that in slash pine (*Pinus elliottii*) the correlations using juvenile wood were smaller than those for whole cores or mature wood only. Similar results were reported for radiata pine (*Pinus radiata*) by Harris (1965). Hardwoods usually show a better correlation between breast height and total tree specific gravity values than softwoods, largely because hardwoods produce mild juvenile wood and small longitudinal variations. Frequently, breast height specific gravity value is nearly the same as whole tree specific gravity.

Strength and Related Physical Properties of Wood

Strength includes all the properties that enable wood specimen to resist a variety of loads or forces. Strength properties can be determined directly through tests of small wood samples, or they can be estimated from specific gravity. Strength characteristics determined from actual mechanical tests are available for various species (Markwadrt, 1930). The test values may be used to calculate working stresses, load-carrying capacities, and similar values (Markwardt and Wilson, 1935). Index values describing major strength and physical properties may be useful in comparing the properties of one wood with another, or in choosing a wood outstanding in some particular property.

Many strength and associated physical properties of wood are closely related to specific gravity. Empirical equations expressing the relationship of specific gravity to other physical properties have been developed from available data by the Forest Products Laboratory (Markwardt, 1930 and USDA, 1956). Since the equations are based on a large volume of data, predicted strength values may be more reliable than actual strength tests on a small number of samples.

Definition of Some Strength Property Terms

There are three kinds of primary stresses that can act on wood. The force can be acting in compression if it shortens a dimension or reduces the volume of the wood. In this case there is said to be a **compressive stress**. If the force tends to increase the dimension, or volume, it is then a tension force, and a **tensile stress** is exerted on the wood. **Shear stress** results from forces which tend to cause one portion of the body to move with respect to another in a direction parallel to their plane of contact. **Bending stresses** result from a combination of all three primary stresses; they cause bending in the wood. The resistance of the body to the applied stress is known as the **strength of the wood** (Panshin et al., 1964).

Modulus of elasticity indicates the ability of wood to recover its original shape and size after a stress is applied. For any given piece of wood subjected to stress, the load-deformation curve reaches a **proportional limit**, beyond which the total deformation is nonrecoverable and some permanent set is imposed on the specimen. **Toughness** of wood is a reflection of the total amount of nonrecoverable strain that a piece of wood can absorb up to the point of complete failure. Wood samples which bend a great deal and break gradually with the absorption of much energy are tough. On the other hand, wood which breaks abruptly and completely with relatively small bending is brittle. The **maximum crushing strength** is a measure of the ability of a piece of wood to withstand loads in compression parallel to the grain up to the point of failure. In bending, the magnitude of the load required to cause failure is expressed by the **modulus of rapture**. **Resistance to impact bending** is another type of strength of wood, which is essentially a measurement of the energy absorption or work properties and toughness (Panshin et al., 1964).

DESCRIPTION OF STUDY

Study Area

This study was carried out in San Rafael Valley on the southwestern slopes of the Huachuca mountains (Figure 1). The area is part of Sierra Vista Ranger District on the Coronado National Forest of southeastern Arizona, approximately 80 miles southeast of the city of Tucson.

The area is the Mexican highland section of the Basin and Physiographic Province. The southern extremity of the range is intersected by the international boundary and from this point extends northwesterly about 20 miles, having a southeast-northwest axis (Wallmo, 1955).

The Huachuca mountains are one the highest and most isolated ranges in Southern Arizona, ranging from 3,500 to 9,400 feet in elevation. They consist essentially of a single, southeast-northwest ridge, approximately 25 miles long and 4.5 miles wide (Wallmo, 1955).

Soils on the area are predominantly a Casto-Martinez-Canelo soil association, generally occurring on dissected fans and piedmonts. These soils, more than 60 inches deep, were formed from mixed sedimentary rock on old alluviums (Richardson et al., 1979). Average annual precipitation is 15 inches with extremes from 12 to over 30 inches (Ffolliott, 1988).

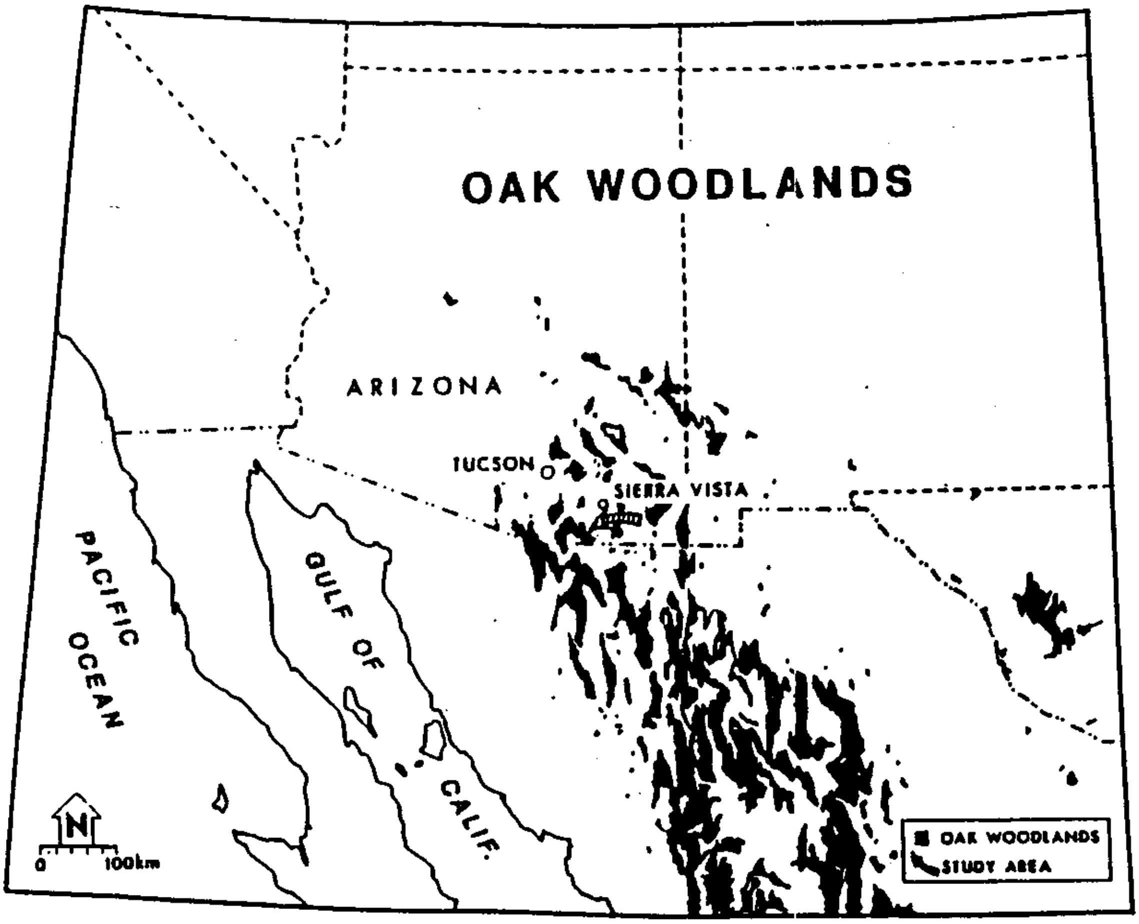

Figure 1. Location of Study Area in Madrean Evergreen Woodlands.

The Oak Woodlands

The oak woodlands, the focus of this study, are concentrated in the Sierra Madre Occidental of Mexico, reaching northward into southern Arizona, southwestern New Mexico and Texas. The oak woodlands, also referred to as encinal or Madrean evergreen woodlands, occur at elevations of between 4,000 and 7,500 feet above sea level and in aggregate cover over 31,500 square miles. Depth and type of soil determine the structural development of these woodlands (Ffolliott, 1988).

Quercus is the dominant single genus of trees in the Huachuca mountains, permitting the application of the term encinal to much of the woodland. Among the oak species, Mexican blue oak (*Quercus oblongifolia*) occurs at the lowest elevation. As elevation increases, it is soon joined by Emory oak then white oak (*Quercus arizonica*). These three often occur together, but Mexican blue oak is seldom found above 5,200 feet (Wallmo, 1955).

The oak woodland is best developed in the canyons and on lower northerly slopes. It forms an open savanna in many places along the foot of the mountains at the heads of the bajadas. On the west side of the mountains oak woodland occupies a belt on the bajada 1-3 miles wide. The trees become more dense farther up the canyons and on the lower northerly slopes, with Emory, Arizona, and silverleaf (*Quercus hypoleucoides*) oaks still dominating. Higher up, netleaf oak (*Quercus reticulata*) and Gambel oak are common. Alligator juniper is the most common and uniformly distributed associate throughout the oak woodlands (Wallmo, 1955).

Emory oak and Arizona white oak are two of the most important species in the oak woodlands. These species are drought-deciduous, an adaptation to water stress, and are not truly evergreen (Phillips, 1912). Emory oak varies in form, size, and character more than any other oak in its range. It is a medium sized tree commonly attaining a height of 30 feet, and rarely exceeding 40 feet. Its limbs are set at an acute angle to the trunk, and it is distinguished from Arizona white oak by that oaks perpendicular limbs. The crown tends to be rounded (Miller and Lamb, 1985).

Emory oak tends to occur a little lower on the mountain slopes than does Arizona white oak, at elevations of about 4,000 to 6,900 feet. Emory oak associates with Arizona white oak, Mexican blue oak and gray oaks (*Quercus grisea*), and a wide variety of shrubs common in the area (Miller and Lamb, 1985). Emory oak has little value for lumber, but is used for fuel and posts, and is valuable for wildlife food and cover.

Field Methods

Increment cores were collected from 115 trees on five sites exhibiting a variety of stand and topographical situations. Sample trees free from morphological flaws (e.g knots, bending, scars or showing signs of dying) were selected randomly on each site. Individual tree characteristics measured were diameter outside bark at breast height (dbh), diameter outside bark at root collar (drc), proportion of the stem occupied by the crown, and crown vigor. Crown vigor was indicated by nominal values of 1, 2 and 3. A value of 1 was given for trees with healthy crowns (if they showed no signs of dying-out or mistletoe), a nominal value of 2 was given to crowns showing signs of mistletoe or dying-out in less than a quarter of the crown. If more than a quarter but less than half the crown was affected, a nominal value of 3 was given. Trees with more than half their crowns affected by mistletoe or dying-out were not included in the sample.

An increment borer was used to extract cores at breast height from each sample tree. The cores then were inserted in numbered paper straws. Each sample tree formed the center of a 0.2-acre plot on which measurements of stand density in terms of basal area per acre, slope percent, and aspect were taken.

Six sample trees ranging from 4 to 9 inches in dbh were felled and two-inch thick disk cross-sections sawed-off at three different tree heights (at ground level, 4.5 and 8.5 feet). The increment cores and disk sections were transported to the Tree Ring Laboratory, University of Arizona, Tucson, for analysis.

Laboratory Methods

In the laboratory, each increment core was soaked in distilled water overnight and its green volume determined by the water immersion. The cores then were oven-dried for 24 hours at 105°C and weighed on a precision balance to the nearest 0.001 gram. Specific gravity of each core was determined by dividing oven-dry weight by green volume (USDA Forest Service, 1956). After removal of bark, disk specific gravity values were determined as described above.

Analytical Procedures

Mean and the standard error of the 115 estimates of increment core specific gravity were determined. Whole tree specific gravity was estimated from the sample of six trees by summing weighted values of disk specific gravity collected at each tree height. Specific gravity of disk section obtained at stump height was taken to represent specific gravity of bolt (sections of tree stem less than 8 feet) between stump height and breast height, while specific gravity of disk section at breast height represented that for the bolt between 4.5 feet and 8.5 feet. Specific gravity of disk section obtained at 8.5 feet represented that for the bolt between 8.5 feet and the rest of the tree height up to an upper diameter limit of 2 inches. Volume of each bolt (in cubic feet) was computed for each bolt log using Smalian's formula (Avery and Bukhart, 1983). Whole tree specific gravity was computed by weighting the specific gravity of the bolts by their respective volumes and combining for a tree specific gravity value. Simple regression analysis was used to determine whether average tree specific gravity could be predicted from increment core specific gravity.

A one-way analysis of variance was used to determine whether there were any differences in specific gravity of the disk sections obtained at the three different heights. Duncan's multiple range test was used to identify which disk sections were different from others (Zar, 1984).

Sample trees were categorized into three dbh classes. These dbh class were defined arbitrarily as <u>small</u> (dbh < 7 inches), <u>medium</u> (dbh > 7 inches and dbh < 10 inches) and <u>large</u> (dbh > 10 inches). A one-way analysis of variance was performed to find out whether specific gravity was different. Duncan's multiple range test was performed to identify which diameter groups were different from others.

Sample trees were classified into three crown size categories. These categories were arbitrarily defined as class 1 (crown covering ≥ 0.7 of tree height), class 2 (crown covering $0.5 - < 0.7$ of tree height) and class 3 (crown covering < 0.5 of the tree height). Differences in core specific gravity among these classes were tested using a one-way analysis of variance.

A one-way analysis of variance was performed to find out whether there were differences in core specific gravity among three basal area classes. Classes were defined arbitrarily as class 1 basal area (ba) ≤ 50 ft^2/acre, class 2 ba $> 50 \leq 75$ ft^2/acre and class 3 ba > 75 ft^2/acre.

Differences in increment core specific gravity of trees in three crown vigor classes was examined by a one-way analysis of variance. Trees assigned a nominal crown vigor value were put in class 1, while those given crown vigor values of 2, and 3 were put in class 2 and class 3, respectively.

Slope, aspect and a knowledge of latitude of study area were used to come up with a potential solar radiation index which indicated the amount of solar radiation each plot was receiving (Frank and Lee, 1966). This index was used as one of the measurable stand variables.

Both linear and multiple regression analysis was used to describe relationships between increment core specific gravity and individual tree and stand variables. Transformations of tree and stand variables done were inverse, square, inverse square and logarithmic transformations. Stepwise multiple regression of individual tree and stand variables and their transformations was performed (SAS Institute Inc., 1989). All tests in the study were evaluated at the 5% level of significance.

Selected physical properties of Emory oak were estimated through solutions of empirical equations based on knowledge of specific gravity (Markwardt and Wilson 1935, USDA Forest Service 1956). These equations are presented in the appendix.

RESULTS AND DISCUSSION

Specific Gravity

Average specific gravity and the 95 percent confidence interval of Emory oak obtained from increment cores was 0.567 ± 0.011. This value is less than the value of 0.634 ± 0.010 reported for Gambel oak in northern Arizona (Barger and Ffolliott 1964), but higher than the value of 0.453 ± 0.010 for alligator juniper in northern Arizona (Barger and Ffolliott, 1965). Coefficients of variation for Emory oak, Gambel oak, and alligator juniper are 9.55%, 5.41% and 7.41%, respectively. Emory oak and Gambel oak would be considered as heavy woods while alligator juniper would be considered as moderately light to moderately heavy (Panshin et al, 1964).

The regression equation for predicting average tree specific gravity from increment core specific gravity was, $Y = 0.521 + 0.376X \pm 0.012$, where Y = tree specific gravity and X = increment core specific gravity. The coefficient of determination for this equation was 0.660 (Figure 2).

Specific gravity of disk sections obtained at the three different tree heights were different statistically (Table 1). Results of Duncan's multiple range test revealed that specific gravity of disk sections at stump height was greater than that of disks obtained at 8.5 feet (Table 2). However specific gravity of disk sections at breast height was not different

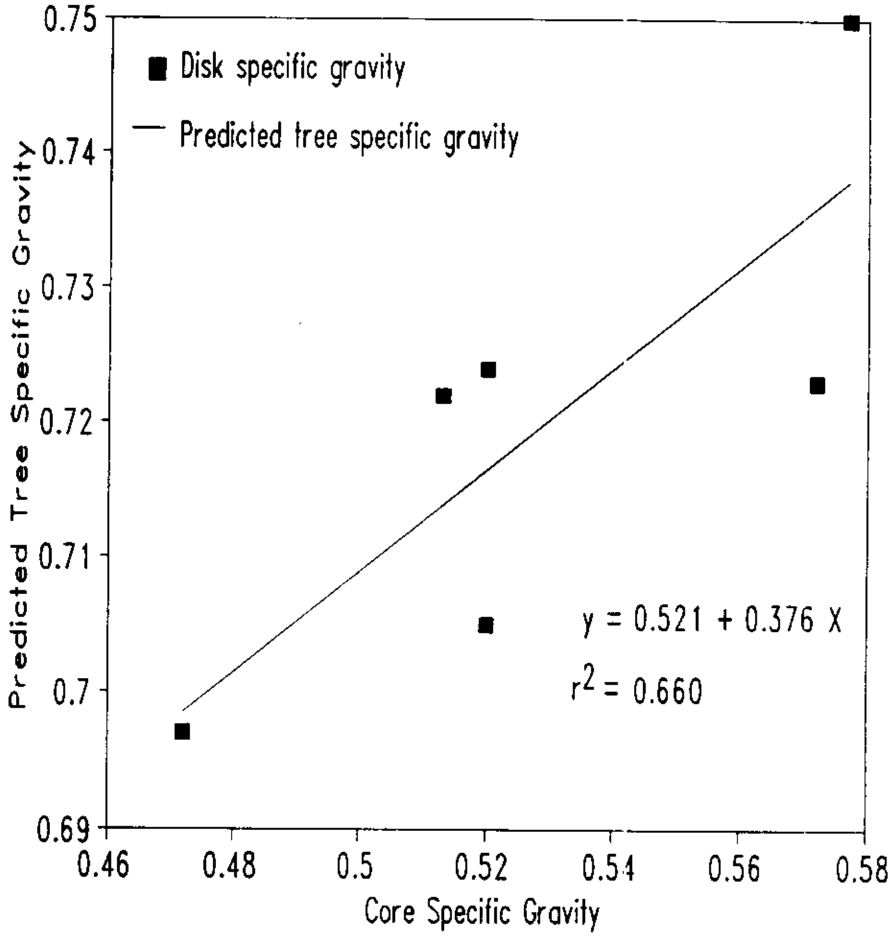

Figure 2. Relationship Between Increment Core Specific Gravity at Breast Height and Tree Specific Gravity (Estimated from Disk Sections) for Emory Oak

Table 1. One-Way Analysis of Variance for Specific Gravity of Disk Sections Obtained at Three Different Heights on Trees.

Source	d.f	SS	MS	F
Model	2	0.00742	0.00371	6.77*
Error	15	0.00822	0.00547	
Corrected total	17	0.01564		

*Significant at $P < 0.05$.

Table 2. Duncan's Multiple Range Test for Disk Specific Gravity at Three Different Heights on Tree.

Duncan Grouping[1]		Mean	N	Disk source
	A	0.748	6	Stump height
	A			
B	A	0.721	6	Breast height
B				
B		0.699	6	8.5 feet

[1] Means with the same letter are not significantly different at the 95% level of confidence.

from that of disk sections from either stump height or 8.5 feet (Figure 3).

Results of a one-way analysis of variance revealed that increment core specific gravity among the three dbh classes was different (Table 3). The mean core specific gravities and 95 percent confidence interval about true mean for the small, medium and large dbh classes were 0.536 ± 0.0180, 0.563 ± 0.0134 and 0.537 ± 0.0198 respectively. Duncan's multiple range test revealed differences between small and large dbh classes but the medium dbh class was not different from either the small or the large classes (Table 4). No differences in increment core specific gravity were found among, crown size classes, basal area classes and crown vigor classes.

Regression equations accounting for significant variability in increment core specific gravity had dbh, drc and their transformations as independent variables. Combining independent variables in multiple regression did not significantly improve the correlations. Coefficients of determination for the linear regression equations indicated low predictive capabilities (Table 5). Barger and Ffolliott (1971), working with ponderosa pine (*Pinus ponderosa*) found weak correlations between commonly measured tree and stand characteristics, which were of little value in identifying causes of variation in specific gravity.

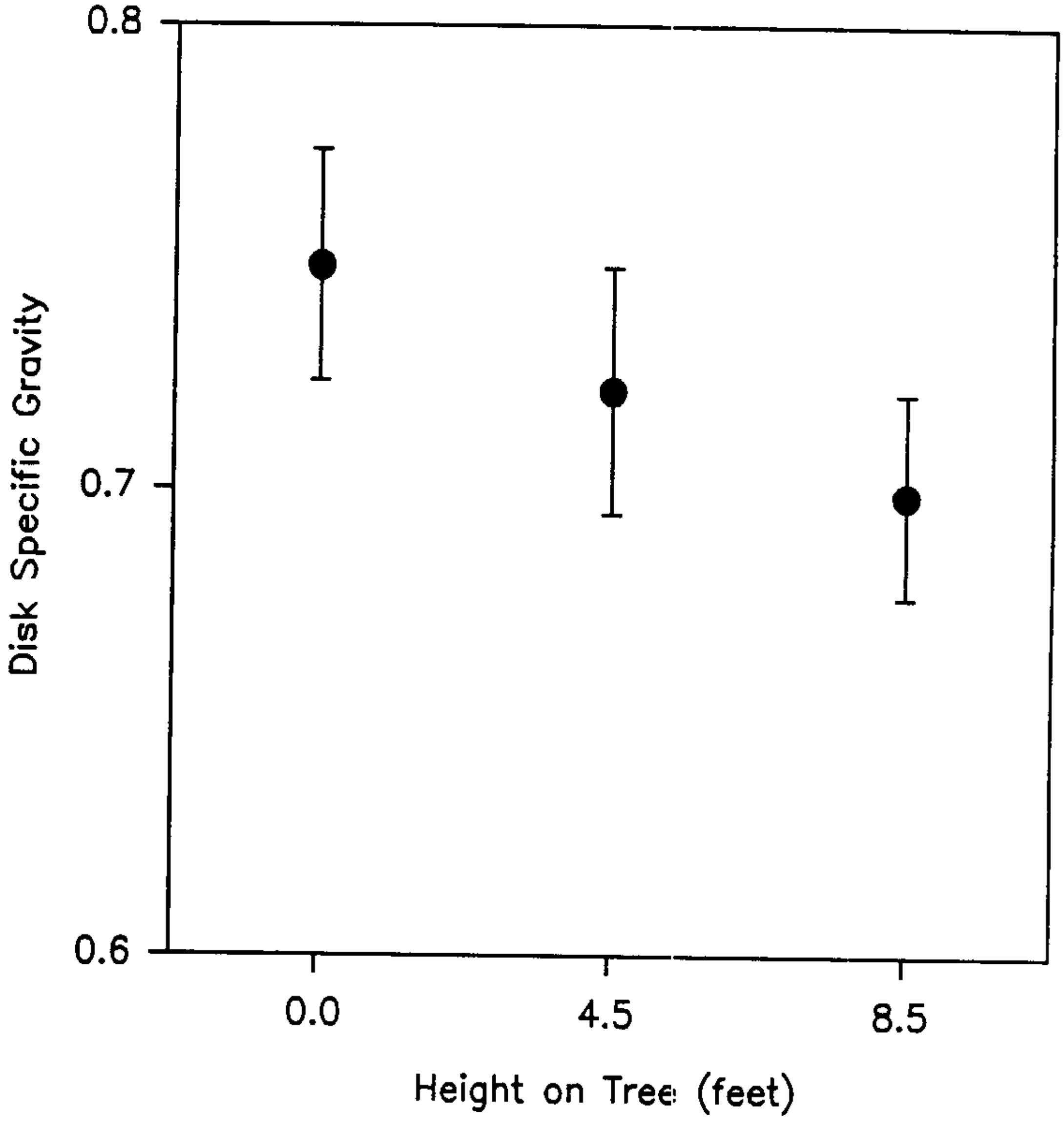

Figure 3. Mean and 95% Confidence Interval of Disk Specific Gravity at Different Tree Heights.

Table 3. One-Way Analysis of Variance for Increment Core Specific Gravity on Three Diameter Classes

Source	d.f	SS	MS	F
Model	2	0.0280	0.140	6.76*
Error	113	0.234	0.00210	
Corrected total	115	0.2621		

*Significant at $P < 0.05$.

Table 4. Duncan's Multiple Range Test for Core Specific Gravity on Three Diameter Classes.

Duncan Grouping[1]		Mean	N	Diameter Class
	A	0.586	43	Small
	A			
B	A	0.563	52	Medium
B				
B		0.537	20	Large

[1] Means with the same letter are not significantly different at the 95% level of confidence.

Table 5. Regression Equations, Coefficients of Determination and Standard Error of Estimate Derived from Significant Variables

Regression Equation	Coefficient of Determination[1]	Standard Error of Estimate
$Y = 0.648 - 0.0076X_1$	0.130	0.00207
$Y = 0.644 - 0.00976X_2$	0.156	0.00238
$Y = 0.524 + 4.06X_3$	0.171	0.938
$Y = 0.526 + 2.10X_4$	0.182	0.182

where;

Y = increment core specific gravity

X_1 = diameter at root collar (drc)

X_2 = diameter at breast height (dbh)

$X_3 = 1/\text{drc}^2$

$X_4 = 1/\text{dbh}^2$

---

[1] Significant at 5% level

Estimated Physical Properties

Selected physical properties of Emory oak were estimated from specific gravity of increment cores (Table 6). Estimated physical properties of Emory oak were lower than those for Gambel oak determined earlier (Barger and Ffolliott 1972), but they were higher than those for alligator juniper, also determined earlier by Barger and Ffolliott (1965). These differences are reflected largely by the differences in specific gravity among the three tree species. These findings indicate that Emory oak has lower wood strength, stiffness, shock resistance and hardness than Gambel oak, and yield a lower fiber and charcoal recovery than Gambel oak. However, when compared to alligator juniper, Emory oak has greater wood strength, stiffness, shock resistance and hardness. Emory oak also will yield more fiber and charcoal than alligator juniper.

Table 6. Estimated Physical Properties of Emory Oak, Gambel oak and Alligator Juniper[1]

Property	Unit of measure	Emory Oak	Gambel Oak[2]	Alligator Juniper[2]
Static bending:				
Fiber stress at proportional limit	Lb./in.^{2}	5,018	5,330	3,800
Modulus of rapture	Lb./in.^{2}	8,659	10,060	6,560
Modulus of elasticity	M Lb./in.^{2}	1,338	1,510	1,070
Work to maximum load	in.- Lb./in.^{3}	13	16	9
Total work	in.- Lb./in.^{3}	33	42	21
Impact bending:				
Fiber stress at proportional limit	Lb./in.^{2}	11,661	13,540	8,830
Modulus of elasticity	M Lb./in.^{2}	1,667	1,880	1,330
Height drop (50-lb hammer) causing failure	in.	42	52	29
Compression parallel to grain:				
Fiber stress at proportional limit	Lb./in.^{2}	2,977	3,350	2,380
Maximum crushing strength	Lb./in.^{2}	3,816	4,300	3,060
Compression perpendicular to grain:				
Fiber stress at proportional limit	Lb./in.^{2}	837	1,090	510
Hardness:				
End	Lb.	1,043	1,365	633
Side	Lb.	954	1,249	579

---

[1] Based on equations developed by Markwardt (1930) and the USDA Forest Service (1956).

[2] From Barger and Ffolliott (1972).

CONCLUSIONS

Conclusions drawn from this study are:

1. Specific gravity of Emory oak as estimated from increment cores was 0.567 ± 0.011. Increment core specific gravity was different among three diameter classes (small, medium and large). It was highest in the small class and lowest in the large class.

2. Average tree specific gravity was correlated with increment core specific gravity, providing a basis to predict specific gravity of Emory oak trees without destructive sampling.

3. Specific gravity of disk sections obtained at stump height was higher than that of sections obtained at 8.5 feet. However, specific gravity of disk sections obtained at breast height was not different from that of disks removed from either stump height or 8.5 feet.

4. Only dbh and drc were related significantly to increment core specific gravity, of the individual tree and stand variables tested. These relationships have limited value in prediction, however.

5. Estimated physical properties of Emory oak were lower than those for Gambel oak, essentially because of the lower specific gravity of Emory oak. In contrast, estimated physical properties of Emory oak were higher than those of Alligator juniper as a result of the latter's higher specific gravity.

Results from this study provide a basis on which future research on variations in specific gravity and physical properties of species in the oak woodlands can be carried. Future work on specific gravity of Emory oak could include the comparison of specific gravities of samples obtained from other areas in the San Rafael Valley and other sites (such Santa Catalina, Pinaleno and Santa Rita Mountains). Such studies might be more useful if sites were defined more specifically in terms of factors influencing tree growth (such as soil characteristics and temperature).

It would be worthwhile to obtain additional disk cross-section samples to define the relationship between core specific gravity and whole tree specific gravities more thoroughly. These disk cross-sections could be collected during fuelwood harvests. Specific gravity obtained from the study represents values of unextracted wood. It would be interesting in future to see how specific gravity is affected by the removal of extractives from wood.

Appendix. Specific Gravity - Strength Relations Among Different Species[1]

Property	Unit	Moisture Condition Green
Static bending:		
Fiber stess at proportional limit	Lb./in.^{2}	$10{,}200G^{1.25}$
Modulus of rapture	Lb./in.^{2}	$17{,}600G^{1.25}$
Work to maximum load	in.-Lb./in.^{2}	$35.6G^{1.75}$
Total Work	in.-Lb./in.^{2}	$103G^2$
Modulus of elasticity	M Lb./in.^{2}	2360G
Impact Bending:		
Fiber stress at proportional limit	Lb./in.^{2}	$23{,}700G^{1.25}$
Modulus of elasticity	M Lb./in.^{2}	2,940G
Height of drop	in.	$114G^{1.75}$
Compression parallel to grain:		
Fiber stress at proportional limit	Lb./in.^{2}	5,250G
Maximum crushing strength	Lb./in.^{2}	6,730G
Modulus of elasticity	M Lb./in.^{2}	2,910G
Compression perpendicular to grain:		
Fiber stress at proportional limit	Lb./in.^{2}	$3{,}000G^{2.25}$
Hardness:		
End	Lb.	$3{,}740G^{2.25}$
Side	Lb.	$3{,}420G^{2.25}$

[1] From USDA Forest Service (1956).

G = specific gravity based on oven-dry weight and green volume.

LITERATURE CITED

Avery, T.E. and H.E. Burkhart. 1983. Forest measurements. McGraw-Hill, Inc., New York, 331pp.

Bahre, C.J and C.F. Hutchinson. 1985. The historic impact of fuelwood cutting on the semidesert woodlands of southeastern Arizona. Journal of Forest History, 29:175-186.

Bamber, R.K., and J. Burley. 1983. The wood properties of radiata pine. Commonwealth Agricultural Bureau, England, 84pp.

Barger, R.L. and P.F. Ffolliott. 1964. Specific gravity of Arizona Gambel oak. USDA Forest Service Research Note RM-19, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 2pp.

Barger, R.L. and P.F. Ffolliott. 1965. Specific gravity of alligator juniper in Arizona. USDA Forest Service Research Note RM-40, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 2pp.

Barger, R.L. and P.F. Ffolliott. 1971. Effect of extractives on specific gravity of southwestern ponderosa pine. USDA Forest Service Research Note RM-205, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 4pp.

Barger, R. L. and P.F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Service Research Paper RM-83, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 80pp.

Borelli, S. 1990. Natural regeneration of oak woodlands in southeastern Arizona: A survey. Master's thesis. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, 54pp.

Boulding, K.E. 1977. Wood in the energy economy. <u>**In**</u> Forestry for America's future: Beyond the bicentennial, Proceedings of the Society of American Foresters, Oct 3-7, 1976, New Orleans National Convention, Society of American Foresters, Washington, D.C., pp. 1-7.

Callison, J. 1989. Site quality indices for the Emory oak woodlands of southeastern Arizona. PhD. Dissertation. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, 47pp.

Christopher, J.F. and H.E. Wahlgren. 1964. Estimating specific gravity of South Arkansas pine. USDA Forest Service Research Paper SO-14, Southern Forest and Experimental Station, New Orleans, Louisiana, 10pp.

Chudnoff, M. 1980. Tropical timbers of the world. USDA Forest Service Forest Products Laboratory, Madison, Wisconsin, 826pp.

Elliott, G.K. 1970. Wood density in conifers. Commonwealth Forestry Bureau Technical Committee, 44pp.

Ffolliott, P.F. 1988. Characteristics of the woodland. <u>In</u> Ffolliott, P.F. and J.D. Hasbrouck (eds.) 1988. Oak woodland management - proceedings of the workshop. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, pp. 1-6.

Ffolliott, P.F., and R. Leferve. 1988. Future research needs in the oak woodlands. <u>In</u> Ffolliott, P.F. and J.D. Hasbrouck (eds.). Oak woodland management - Proceedings of the workshop. School of Renewable Natural Resources, Univ. Arizona, Tucson, pp. 45-46.

Ffolliott, P.F., W.O. Rasmussen, T.K. Warfield, and D.S. Borland. 1979. Supply, demand, and economics of fuelwood markets in selected population centers of Arizona. Arizona Land Marks, 9:1-74.

Frank, E.C. and R. Lee. 1966. Potential solar beam irradiation on slopes. USDA Forest Service Research Paper RM-18. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 166pp.

Gilmore, A.R., S.G. Boyce, and R.A. Ryker. 1966. The relationship of loblolly pine to environmental factors in southern Illinois. Forest Science, 12(4):399-405.

Goggans, J.F. 1961. The interplay of environment and heredity as factors controlling wood properties in conifers. School of Forestry, North Calorina State College Technical Report No.11, 56pp.

Goldstein, I.S. 1980. New technology for new uses of wood. Tappi 63(2):105-108.

Hamilton, J.R. 1961. Variation of wood properties in southern red oak. Forest Products Journal 11(6):267-271.

Hamilton J.R., P.J. Litwin, and F.H. Tryon. 1978. A note on the influence of soil parent material on northern red oak specific gravity. Wood Fiber 10:2-5.

Harris, J.M. 1965. A survey of wood density, tracheid length and latewood characteristics of radiata pine grown in New Zealand. New Zealand Forest Service Technical Report 47, 31pp.

Lawton, R.O. 1984. Ecological constraints on wood density in a tropical montane rain forest. American Journal of Botany 71:261-267.

Lewark, S. 1979. Wood characteristics in Norway spruce breeding programs. International Union of Forestry Research Organizations meeting, Bucharest, Romania, 24pp.

Maeglin, R.R. 1966. Predicting specific gravity of plantation-grown red pine. USDA Forest Service Research Note FPL-0149, USDA Forest Products Laboratory, Madison, Wisconsin, 14pp.

Markwardt, L.J. 1930. Comparative strength properties of woods grown in the United States. USDA Forest Service Forest Products Laboratory Technical Bulletin 158, Forest Products Laboratory, Madison, Wisconsin, 38pp.

Markwardt, L.J., and T.R.C. Wilson. 1935. Strength and related properties of woods grown in the United States. USDA Forest Service Forest Products Laboratory Technical Bulletin 479, Forest Products Laboratory, Madison, Wisconsin, 99pp.

McMurtray, M. 1978. Inventory of utilizable oak species in the Santa Catalina Mountains. School of Renewable Natural Resources, University of Arizona, Tucson, 5pp.

Miller, H.A. and S.H. Lamb. 1985. Oaks of North America. Naturegraph Publishers; Happy Camp, California, 327pp.

Myer, J.E. 1930. The structure and strength of four North American woods as influenced by range, habitat and position in the tree. New York State College of Forestry Technical Bulletin No.13, 39pp.

Panshin, A.J., C. De Zeeuw and H.P. Brown. 1964. Textbook of Wood Technology. Volume 1 - Structure, identification, uses, and properties of the commercial woods of the United States. McGraw-Hill Book Company, New York, 643pp.

Patterson, J.G. 1980. Potential energy equivalents of vegetation types in Arizona. Master's Thesis. School of Renewable Resources, University of Arizona, Tucson, Arizona, 136pp.

Paul, B.H. 1959. Second growth oak. Southern Lumberman Journal 63(1):15.

Pearson, R.G. and R.C. Gilmore. 1980. Effect of fast growth rate on the mechanical properties of loblolly pine. Forest Products Journal 30(5):47-54.

Phillips, F.J. 1912. Emory oak in southeastern Arizona. USDA Forest Service Circular 201, Washington, D.C., 15pp.

Richardson, M.L., S.D. Clemmons and J.C. Walker. 1979. Soil survey of Santa Cruz and parts of Cochise and Pima counties, Arizona. USDA Soil Conservation Service and Forest Service, Tucson, Arizona, 122pp.

SAS Institute Inc. 1989. SAS/STAT User's guide: statistics, version 6. SAS Institute Inc. Cary, North Carolina, 1,686pp.

Savina, A.V. 1956. The Physiological justification for thinning Forests. Translated from Russian by Israel Program for Science Translation for National Science Foundation and USDA, 91pp.

Taras, M.A. and H.E. Wahlgren. 1963. A comparison of increment core sampling methods for estimating tree specific gravity. USDA Forest Service Research Paper SE-7, Southeastern Forest Experiment Station, Asheville, North Carolina, 16pp.

Tolisano, J.A. 1984. Contributions of woody biomass to energy requirements in Arizona. Master's thesis. School of Renewable Resources, University of Arizona, Tucson, Arizona, 62pp.

Tongvichit, B. 1987. A standard volume table for Emory oak in Southeastern Arizona. Master's professional paper. School of Renewable Resources, University of Arizona, Tucson, Arizona, 23pp.

Touchan, R. 1986. Growth and yield of Emory oak woodlands in southeastern Arizona. Master's thesis. School of Renewable Resources, University of Arizona, Tucson, Arizona, 36pp.

USDA Forest Service. 1956. Methods of determining the specific gravity of wood. USDA Forest Service Forest Products Laboratory Technical Note B-14, Forest Products Laboratory, Madison, Wisconsin, 6pp.

USDA Forest Service. 1965. Southern wood density survey. 1965 Status Report. USDA Forest Service Research Paper FPL-26, Forest Products Laboratory, Madison, Wisconsin, 38pp.

van Buijtenen, J.P. 1982. Fiber for the future. Tappi 65(8): 10-12.

Wahlgren, H.E., and D.L. Fassnacht. 1959. Estimating tree specific gravity from a single increment core. USDA Forest Service Forest Products Laboratory Report FPL-2146, USDA Forest Products Laboratory, Madison, Wisconsin, 24pp.

Wahlgren, H.E., A.C. Hart and R.R. Maeglin. 1966. Estimating specific gravity of Maine conifers. USDA Forest Service Research Paper FPL 61, USDA Forest Products Laboratory, Madison, Wisconsin, 25pp.

Wallmo, O.C. 1955. Vegetation of the Huachuca Mountains, Arizona. The American Midland Naturalist 54(2):466-480.

Warren, B.R. and R.V. Mirams. 1963. A survey of basic density and fiber length variation in *Pinus radiata*. New Zealand Forest Service Technical Report 7, 22pp.

Wilde, S.A. and B.H. Paul. 1959. Growth, specific gravity, and chemical composition of quaking aspen on different soil types. USDA Forest Service Report FPL-2144, USDA Forest Products Laboratory, Madison, Wisconsin, 10pp.

Zahner, R. 1968. Site quality and wood quality in upland hardwoods: theoretical considerations of wood density. Forest Soils Conference, Raleigh, North Carolina, 43pp.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall Inc., Englewood Cliffs, New Jersey, 718pp.

Zobel, B.J., F. Henson and C. Webb. 1960. Estimation of certain wood properties of loblolly and slash pine trees from breast height sampling. Forest Science 6: 155-162.

Zobel, B.J. and J.P. van Buijtenen. 1989. Wood variation: its causes and control. Springer-verlag, Berlin, Germany, 363pp.

Zobel, B.J., M. Mathias, R.C. Kellison, and J.H. Roberds. 1968. Moisture content of southern pine trees. Technical Report 37, School of Forestry Resources, North Carolina State University, Raleigh, North Carolina, 44pp.