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SITE INDEX, HEIGHT, AND YIELD PREDICTION EQUATIONS FOR BLUE OAK AND COAST LIVE OAK IN MONTEREY AND SAN LUIS OBISPO COUNTIES, CALIFORNIA

by

Norman H. Pillsbury

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Michael J. De Lasaux

June 5, 1985

NATURAL RESOURCES MANAGEMENT DEPARTMENT
CALIFORNIA POLYTECHNIC STATE UNIVERSITY
SAN LUIS OBISPO, CALIFORNIA

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ABSTRACT

SITE INDEX, HEIGHT, AND YIELD PREDICTION EQUATIONS FOR BLUE OAK AND COAST LIVE OAK IN MONTEREY AND SAN LUIS OBISPO COUNTIES, CALIFORNIA

Norman H. Pillsbury

and

Michael J. De Lasaux

Site index, height, variable density yield, and stand volume yield prediction equations were developed for blue oak (*Quercus douglasii* Hook & Arn.) and coast live oak (*Quercus agrifolia* Nee) from data obtained from 25 plots of each species, respectively, located in Monterey and San Luis Obispo counties, California.

Height-age data was obtained from sample tree stem analysis. The individual parameter prediction equation approach was used to develop the site index and height prediction equations.

The variable density and stand volume yield prediction equations were developed from stand information obtained at each of the sample plots. Individual yield equations of each type were developed for all trees, all trees 10 cm. and larger, all trees 20.0 cm. and larger and all trees 27.5 cm. and larger for both species.

Basic stand characteristics for the 25 stands of each species are also summarized. Stand, stock and frequency tables for basal area, volume and number of stems were developed from the sample data.

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CHAPTER I

INTRODUCTION

The hardwoods of the western United States are an important natural resource, although often overlooked. Oaks comprise about 80 per cent of California's total hardwood resource (Bolsinger, 1979). It is estimated that oaks grow on 15 to 20 million acres in California. This acreage represents 15 to 20 percent of the entire state (Callaham, 1979). Their extensive acreage means there is tremendous volume available for producing fiber for fuel and wood products. In addition, California's oaks provide valuable wildlife habitat, forage, watershed protection, and landscape enhancement.

Past utilization of California hardwoods has often been an example of mismanagement. The Agricultural Adjustment Administration (now the Agricultural Stabilization and Conservation Service, A.S.C.S.) has instituted programs to remove thousands of acres of oak woodland to enhance grazing in the Sierra foothills (Rossi, 1979). Oak from the woodlands of California's central coast have been used for charcoal and tannin, and the woodlands themselves have been converted to cropland or rangeland. The recent demands for a renewable source of energy, increasing urbanization, rangeland and agricultural practices are continuing to pressure the resource.

Since the oil embargo of 1973 there has been a dramatic increase in fuel wood consumption in the United States. The increasing price of petroleum fuels, improvements in wood burning stove efficiency, and wood being a renewable source of energy have all contributed to the increased use of fuelwood (Standiford et al., 1983). Nationwide the U.S. Forest Service firewood harvest increased by 400% from 1973 to 1982, from a harvest of 200,000 cords to almost 5 million cords (Forest Service, 1983). Many homes, which at one time relied upon gas for heating and cooking, have converted to heating systems which utilize wood. A recent survey shows that wood is now used for 9 to 11% of the space heating in homes nationwide (Skog and Watterson, 1983). The same survey estimated that 28% of all California homes burn wood for fuel with an average annual consumption of three quarters of a cord. Another indication of the increase in firewood consumption is the 900% increase in woodstove sales in California from 1973 to 1979 (California woodheat handbook, 1980). In Monterey, San Luis Obispo, and Santa Barbara counties it was estimated that 4,300 cords of oak were sold as fuelwood in 1979, and that between 1977 and 1980 the volume of fuelwood sold increased by 175% (Pillsbury and Williamson, 1980). In 1982, 20,000 cords of firewood were transported from Southern Oregon to the San Francisco Bay area.

The increased demand for fuelwood presents a challenge to the resource manager. Sound management of California's oak resource requires a base of information about existing volume, present and potential growth, and potential yield. The management of forest resources requires many analytical "tools" to assess productive capacity. Management for the production of wood fiber requires methods for determining the volume of individual trees and the productive capacity of the land in terms of growth and expected yields. The basic tools for forest management are: volume equations or tables for determining tree volume; site index prediction curves or equations for assessing the productive potential of a given site; and yield tables or equations that are based on growth data for predicting present and future volume yield.

Growth and yield information are needed by the resource manager to quantify past and/or potential forest production and response to silvicultural treatments. Decisions regarding harvesting practices, such as, cutting levels, cutting intervals (rotation), and rotation age estimation, require growth and yield prediction "tools". Silvicultural research and planning, and on a broader scale, ecological research and environmental management require quantitative models for growth and yield prediction (Alder, 1980).

Until recently, a need for the basic forestry "tools" for western hardwood species was not previously recognized; for the most part, conscious management was not associated with western hardwoods. As a result growth, yield, and site quality characteristics of most western hardwoods have never been studied. Past studies of site, growth, and yield of western hardwoods have primarily involved red alder (Alnus rubra Bong.), tanoak (Lithocarpus densiflorus (Hook. and Arn.) Rehd.), and California black oak (Quercus kelloggii Newb.). Site index curves (Bishop and Johnson, 1958) and a simultaneous growth and yield model (Nguyen, 1979) exist for red alder. Site index curves have been prepared for tanoak (Porter and Wiant, 1965) and California black oak (Powers, 1972).

This is the first study to develop site index, height growth, and yield prediction equations for blue oak and coast live oak. The report provides the resource manager with the information needed to properly assess the productive potential of blue oak and coast live oak stands. The approach used in developing this information assumes that wood fiber production is the primary management objective.

The objectives of this study were: (1) to establish and sample 25 plots each of coast live oak and blue oak in Monterey and San Luis Obispo counties, (2) analyze the growth of the stems of one to four dominant trees from each plot, (3) to express the results in the form of site index and height growth prediction equations, (4) to develop a preliminary yield prediction equation for each species, and (5) to quantify basic stand characteristics.

CHAPTER II

LITERATURE REVIEW

Site Quality

Management of a forest resource for wood fiber requires knowledge of productive potential. Without this knowledge total fiber production potential may not be realized or, at the other extreme, harvest could exceed growth, and lead to over harvesting, and in some cases depletion of the resource. The productive capacity of a forested area is most often defined in terms of site quality. Site quality is influenced by a composite of environmental factors that are edaphic, topographic, climatic, genetic, and biological in nature.

There are several approaches to the estimation of site quality (Table 1). They may be classed as either direct or indirect estimating systems. The direct estimation of site quality is based upon physical measurements of the trees or stand itself. The indirect approach generally uses environmental factors, such as edaphic characteristics, that influence site productivity. It is generally applied where direct methods cannot be used because requisite stand characteristics, such as even-age structure, or adequate stand age, do not exist. A brief description of each of the methods is given here. The reader is directed to Carmean (1975) for a more indepth review of the literature.

Table 1. Methods for estimating site quality (Carmean, 1975)

I. Direct Estimation of Site Quality

A. Growth monitoring. Productivity is estimated from stand volume growth based on periodic measurements.

B. Growth intercept. Based on a selected, relatively short period of height growth after tree has attained breast-height.

C. Site index curves. Uses the height obtained by the dominant stand at a specified reference age.

1. Harmonized technique - family of site index curves that are proportional to the average guiding curve based on total height and total age measurements of trees from many plots representing the range of ages and site qualities.

2. Polymorphic techniques - site index curves that are non-proportional and more accurately represent the diversity of sites and height growth patterns. Usually based upon stem analysis.

II. Indirect Estimation of Site Quality

A. Mensurational Methods. Alternative methods relating site quality to various measured stand features. Used for stands and trees not suited for directly measuring site index.

B. Plant indicators. Occurrence, and abundance of certain lesser plants and shrubs provide indication of site quality.

C. Physiographic site classification. Based on integrated complex of climate, relief, geologic materials, soil profile, ground water, and communities of plants, animals and man.

D. Synecological coordinates. Based on the ranking of environmental factors considered important for the occurrence and growth of forest trees.

E. Soil-site evaluation. Based upon correlation between site index estimates and edaphic, topographic and climatic features.

In-depth Review of the Site Index System

The most widely used method of assessing site quality is the site index system. For this reason, special review is presented here.

The height of the dominant stand at some specified reference age has been recognized as the best single indicator of site potential and is termed "site-index". "The height of free-grown trees of a given species and of a given age is more closely related to the capacity of a given site to produce wood of that species than any other one measure" (Spurr and Barnes, 1980). Height also is influenced by stand density less than any other measurable tree characteristic (Spurr and Barnes, 1980). Extremes of stocking, however, either severe understocking or overstocking, will influence height growth (Daniel et al., 1979). Juvenile height growth, as a basis for site classification, can be misleading as it is often independent of site and often highly variable. Elimination of this bias can be accomplished by treating breast-height as age zero and successive height-age points are relative to breast-height age (Stage, 1963; Curtis, 1974; Dahms, 1963; Heger, 1968; Barrett, 1978; and Cochran, 1979).

Site-index curves are generally used in two ways. They are primarily used for classification purposes where the site index for a given stand is determined so that growth potential may be classified. Site-index curves are also commonly used to make future height predictions. There are several limitations to the use of site index which are not commonly recognized: (1) since height is only one of the components of volume, site index is not synonomous with volume productivity (Curtis, 1964); (2) ecological relationships which are often the most important factors in determining site productivity are not well illustrated by site index information as it is usually presented (Goodlett, 1960); (3) the estimation of site index involves the projection of presently measured height forward or backward in time to a standard reference age, by means of site-index equations or site-index curves. The error associated with this approach is generally unknown, and it depends upon the accuracy with which the site-index relationships can represent the growth of individual stands (Curtis, 1964).

Historical development. The first generation of site-index curves developed in the United States by Bruce (1926) and others in the 1920's resulted in anamorphic curves which are proportional to one another. The techniques employed were based on Von Baurs (1881) methods. This technique involved the measurement of heights and ages on a series of plots in a number of stands that represent a range of site productivity levels.

The anamorphic method with its resultant harmonized curves is a relatively simple approach and has been the basis for many site productivity estimation systems. There are errors associated with the method which when eliminated could increase the precision and usefulness of the site-index techniques (Curtis, 1964). The sources of error are: (1) the large variability of the height-age data, which represents the entire range of sites. As a result of the variability the type of curve that describes the relationship is not well defined

(Curtis, 1964). (2) The assumption that the relationship of height to age is constant and proportional over the range of sites, stand conditions, and ages (Curtis, 1964). Height growth patterns of dominant trees within the stand are influenced by micro-site influences and tree-soil relationships and vary through out the life of the stand. (3) The assumption that site quality is independent of stand age. Younger stands are often associated with higher site quality and older stands are associated with lower site quality. On high quality sites trees reach merchantability and are harvested at a younger age. Accessibility may also influence the age of the stand. More accessible stands would tend to be harvested more frequently. Where such biases have occurred in past site index studies the guiding curves are generally warped upward at younger age and downward at older ages (Spurr and Barnes, 1980).

These intrinsic errors could be eliminated by repeated measurements of permanent plots on a range of sites through out the life of the stand. However, because of the problems associated with permanent plots, such as inadequate documentation, and the long time span necessary for repeated measuring, this option is often not a feasible approach for eliminating the biases.

Stem Analysis. New techniques that present the polymorphic nature of tree growth and rely on stem analysis methods have evolved over the last 25 years. However, as early as 1931 Bull reported polymorphic growth curves (non-proportional), derived from internode measurements. With evidence of polymorphic growth patterns it was realized that improved methods were necessary for development of site-index curves. Stem analysis methods became widely used in the late 1950's and early 1960's. Since then most site-index curve construction for both hardwoods and conifers has been accomplished using stem analysis techniques. Field and computational procedures have been outlined by Dahms (1963, 1975), Curtis (1964), Stage (1963), Johnson and Worthington (1963), Heger (1968), Barrett (1978) and Erdman *et al*. (1982).

Site index preparation methodology. The methodology for development of site index estimating systems has been steadily evolving over the years. There is no recognized "cookbook" approach to site index system development. The field techniques which have been developed are fairly standard. Several approaches to the analysis of the basic height/age data, that is obtained through stem analysis, can be found in the literature. The dissimilarity in methods is the result of conceptual differences and intent of application (Curtis *et al*., 1974) and different approaches used to remove certain biases. Recent work with western conifers by several authors, Dahms (1974), Barrett (1978), Cochran (1979) and Dolph (1983) has been based upon similar procedures.

The number of trees cut in each plot for the studies referenced earlier has ranged from one to six; normally more than one tree represents each plot. Stage (1963) suggested sampling a fixed number of trees per acre to eliminate a bias caused by the decrease in the number of dominant trees per acre with increasing age. Site index determinations based on a constant number of the tallest trees per acre insure that comparable populations are sampled at all ages. Sampling a constant number of the tallest trees introduces some bias because stands which have been subject to mortality and top damaging agents for a longer time will retain only a fraction of the original population of tallest trees. Compensation for this additional bias may be achieved by eliminating a small number of the very largest trees from samples of young stands (Stage, 1963).

The basic data obtained from stem analysis provides paired observations of height and age which are then plotted to give individual tree height/age curves. Because the height at the sectioning point does not represent the actual height reached for a given year, adjustment is required to give a better estimate of height (Carmean, 1972; Lenhardt, 1972).

Approaches to the use of the height/age data for each plot has varied. Some researchers (Johnson _et al_., 1963; Heger, 1968; Beck, 1971; McQuilkin, 1974) used the height/age points for each tree for further computation while others have used the average height at various ages of all the trees in a plot. In the latter the basic observation becomes an average height/age curve which represents height growth on one homogenous site (Bailey and Clutter, 1974). This technique introduces bias because older age classes are represented by successively fewer plots located on areas of poorer site quality (Carmean, 1972). This bias might be eliminated by stratifying the data into 10-ft site index classes (Carmean, 1974) or by mathematically adjusting the curve of mean heights for all of the sample trees (Curtis, 1964). Dahms (1963, 1975), in correcting for a bias caused by shifts in the relative heights of the dominant trees in a stand, used the tree that was tallest in each plot for each decade, based on the average breast-height stand age, as a height/age pair. The average breast-height stand age is defined as the average age at breast height of the sample dominant trees at a plot. Thus, the height/age curve for each plot was a composite of the tallest dominant tree at any time throughout the life of the stand. The technique of using the tallest dominant tree throughout the life of the stand has also been employed by Barrett (1978) for ponderosa pine in the northwestern United States and by Cochran (1979) for white fir and grand fir in Oregon and Washington.

There are several approaches to the data analysis. Carmean (1972) stratified the height/age data into 10-feet site index classes based on tree height at the index age. Separate equations expressing height growth patterns for each site index class were then fit through regression so that the curve for each site index class is independent of the others.

Johnson and Worthington (1963) fit a simple linear regression of site index on height at each decadal age (10, 20, 30,...). The slope values for each regression were smoothed and the resultant equation was used to predict the slope parameter in the site index prediction equation. They also forced all their regressions through the origin by eliminating the intercept parameter. This method has the disadvantage that the site-index curves are forced to be proportional (Dahms, 1975).

Curtis et al. (1974) simultaneously fitted functions that expressed the intercept and slope values in such a way that the sum of squares of the deviations from the site-index curves were a minimum (Dahms, 1975).

Dahms (1975), Barrett (1978), Cochran (1979) and Dolph (1983) first developed models to express both the slope parameter and average height as functions of age in the linear model, SI = a + b(HT). Then the intercept was calculated from the slope and the average height value. This approach resulted in putting the even ten-year regressions in a smoothed relationship of one to another, and provided a basis for placing individual year regressions between the ten-year regressions by interpolation (Dahms, 1975). This same methodology can also be used to develop compatible height-growth curves by simply making height the dependent variable and site index the independent variable. Comparison of this approach with the simultaneous solution approach of Curtis et al. (1975) found that the two methods resulted in nearly identical site-index estimating curves.

Stage (1963) took a different approach to the preparation of polymorphic site-index curves. By modifying the definition of site index he rated sites according to the height increment attained by a dominant tree of a standard height. Stage (1963) also took a unique approach to the problem of height growth variation that occurs during the early stages of stand development. He counted the number of annual rings within a 1.5 inch radius of the pith at breast height and prepared a set of polymorphic site-index curves for plots where 10, 20, or 25 rings occur within the 1.5 inch radius. Thus by preparing separate site-index curves for the different levels of ring density he accounts for early suppression.

Site index modeling. Prior to the use of stem analysis methods for site-index curve construction curves were based on equations with the general form

$$\text{Height} = f(\text{Age, Site index}). \qquad [1]$$

The advent of stem analysis techniques enables the researcher to fit regressions of the form used in Eq. (1), or alternatively fit the model

$$\text{Site Index} = f(\text{Height, Age}). \qquad [2]$$

Many studies using stem analysis methods continued to use Eq. (1) for preparation of site index curves. Curtis _et al_. (1974) suggests that since site index is the quantity to be estimated, it should be treated as the dependent variable and Eq. (2) should be used for preparing site-index curves and Eq. (1) should be used for preparation of height-growth curves.

Several biological growth functions have been proposed for modeling tree height-age data, and a variety have been used in preparing site-index curves for many species of trees (Carmean, 1972).

The exponetial form of Von Bertalanffy's monomolecular growth function (Eq. 3) is commonly used to model height growth.

$$H = b_1(1 - e^{b_2 age})^{b_3} \quad [3]$$

where H = tree height at any age

b_1 = coefficient expressing asymptotic tree height (i.e., estimated ultimate tree height)

b_2 = coefficient determining rate of tree height growth

b_3 = coefficient determining initial pattern of height growth

e = base of natural logarithm

Base age. Preparation of site-index curves normally requires that a base age be pre-selected. Because total production over the rotation is most generally sought and is closely related to height at rotation age, index age should approximate expected rotation age (Curtis *et al*., 1974). Varying the base age results in differing sets of site-index estimation curves (Strand, 1964; Heger, 1973) and height-growth curves (Heger, 1973). Bailey and Clutter (1974) have prepared base age invariant polymorphic site-index curves based on the assumption that a linear relationship exists between the logarithm of height and age to a negative power. Devan and Burkhart (1982) developed base age invariant polymorphic site-index curves that were based on a segmented polynomial differential model and derived by fitting height increment as a function of height and age.

Selection of Site Index System Development Method

Several approaches to the development of site-index prediction systems have been discussed. The decision was made to use the parameter prediction methods developed by Dahms (1975) and used by several others (Barrett, 1978; Cochran, 1979; and Dolph, 1983).

The choice of which method to use in the present study was based on several criteria. The method should be based upon sound statistical procedures and be accepted as a valid method for developing a site index estimating system. The acceptance of the method is evidenced by its use in at least three studies since Dahms (1975) original work. The present study is part of a larger study to develop height growth curves. Therefore, it was important that the two types of curves be compatible. The methods are also well documented with easy to follow procedures in papers by Barrett (1978) and Cochran (1979).

Height Growth

The estimation of future volume of a tree or stand with standard volume equations requires estimates of future diameter at breast height and future height. Traditionally, height growth predictions have been based on site index prediction curves which had been constructed using anamorphic methods based on the model (1) above.

The relationship was then inverted and site index was estimated from observed values of height and age. "The general pattern of analysis and thinking established in the past carried over into early stem analysis work" (Curtis et al , 1974). However, because an actual estimate of site index in the form of measured heights of the sample trees at the chosen base age is available from stem analysis model (2), above, where site index is the dependent variable is possible.

The different dependent variables in the above functions result in different prediction systems and in application will provide different estimates of height and site index (Curtis et al, 1974). Curtis et al (1974) have shown that traditional site index prediction systems based upon the model (1), above, do not actually provide estimates of site index but instead provide estimates of height of a stand on land of a given site quality. Hilt and Dale (1982) recently used model (1) with height, age, dbh and site index estimates for upland oak to develop a general model to predict total tree height.

Dahms (1974), Barrett (1978) and Cochran (1979) have developed compatible site index and height growth prediction equations based on the two models above.

Yield

At some point during the managment of a forest or woodland for fiber production the resource manager will require estimates of volume yield. Yield prediction has evolved to the point where intensive management practices require complex yield estimating systems that are capable of providing yield estimates with varying levels of inputs and timing and intensity of treatments.

Yield prediction models can be categorized by the complexity of the mathematical approach involved (Clutter et al, 1983):

A. Yield models in tabular form
B. Yield models as equations and systems of equations
   1. Direct prediction of volume per unit-area
   2. Volume per unit-area obtained by summation
      (a) Yield equations for classes of trees
      (b) Yield equations for individual trees

The advent of the computer has caused most recent yield prediction systems to be based on yield prediction equations. Yield models presented in tabular form are seldom used today (Clutter et al, 1983). Yield prediction systems based on equations range from the basic form which provide an estimate of yield per unit area as a function of age, basal area and site index to the complex single-tree-distance-dependent growth models which involve equations that model several parameters of growth for each individual tree in a stand as a function of its own characteristics, the characteristics of neighboring trees, and the distance to neighboring trees.

Yield prediction methods can be further subdivided depending upon whether the estimate of interest is future yield or current yield. There are two categories of current yield prediction systems. The first type are explicit prediction systems which provide estimates of volume per unit area as a function of stand age, stand density, and site productivity. These types are based on what are called variable density yield prediction equations (MacKinney et al, 1937; Schumacher, 1939). The second type, implicit prediction systems, are more complex involving the solution of equations which provide basic information on stand structure. Yield estimates implied by the predicted structure are then calculated from additional computations based on the stand structure information (Clutter et al, 1983).

CHAPTER III

SILVICULTURAL AND ECOLOGICAL CHARACTERISTICS OF BLUE OAK AND COAST LIVE OAK

Blue oak and Coast live oak were selected for the study because of their divergent growth habits, silvicultural characteristics and their large statewide distribution. The contrasting characteristics of the two species are outlined in Table 2.

Table 2. Relative differences between blue oak and coast live Oak

Characteristic	Blue Oak	Coast Live Oak
Geographic range	inland	coastal
Precipitation	lower rainfall	higher rainfall
Soils	shallow; xeric	deeper; mesic
Leaf habit	deciduous	evergreen
Sprouting ability	variable, but often poor	prolific

Blue oak distribution in Monterey and San Luis Obispo counties is fairly restricted to dry inland sites. Pure blue oak stands generally occur at elevations ranging from 30 to 90 meters (100 to 300 feet) mixing with digger pine at elevations between 150 and 915 meters (500 to 3,000 feet) to form the blue oak-digger pine type (Neal, 1980). Coast live oak is generally associated with coastal sites with elevation ranging from sea level to 915 meters (3,000 feet) (Finch and McCleery, 1980).

The Mediterranean type climate, characterized by hot dry summers and cool wet winters typifies the conditions of both species, however, coast live oak stands are more commonly found on sites which receive considerably more rainfall. Blue oak can occupy sites which receive as little as 254 mm (10 inches) of precipitation annually (Neal, 1980).

Both species are commonly found on well-drained soils. Finch and McCleery (1980) found that coast live oak stand density seems to relate to soil texture. Coastal stands that are fairly dense and with closed canopies are primarily associated with a loamy soil texture. Inland, where coast live oak trees are larger and stands are more open, sandy soils prevail. At higher elevations, adjacent to the coast, coast live oak is associated with shaly clay-loam soils.

Coast live oak and blue oak each have the capacity to sprout. However coast live oak is generally more prolific with the ability to crown sprout after severe damage by fire and sprout basally after cutting. Blue oak basal sprouting ability appears to vary with geographic location but is often poor or in some areas non-existent. Where sprouting does occur a bush-like or stunted tree form may result.

CHAPTER IV

METHODOLOGY

Field Sampling

Twenty-five, one-tenth hectare (0.2 acre) circular plots were located throughout Monterey and San Luis Obispo counties for each species (Figure 1). The criteria used for plot selection were:

1. The stand was pure or nearly pure with respect to species composition,

2. The stand was selected as even-aged if the trees appeared to be fairly uniform in size for both diameter and height. Actual stand age was difficult to determine in the field from increment cores because: 1) The borer will rarely pass through or near the pith since it is often off center where compression and tension wood has developed. This is particularly true with coast live oak. 2) The hardness of the wood itself makes boring difficult.

   An even-age stand is one in which the trees were initiated and developed as a stand. The actual ages of individual trees may vary plus or minus 15 years of the average stand age. Use of diameter distribution and tree heights to classify stand structure should be used with caution as trees having similar phenotypes may be many years apart. This is particularly true of blue oak which has a poor relationship between diameter and age (McClaran, 1983),

3. There were no signs of recent cutting,

4. The plot was located within the stand such that there was a surrounding buffer strip that was as wide as the dominant trees were tall.

PROJECT AREA

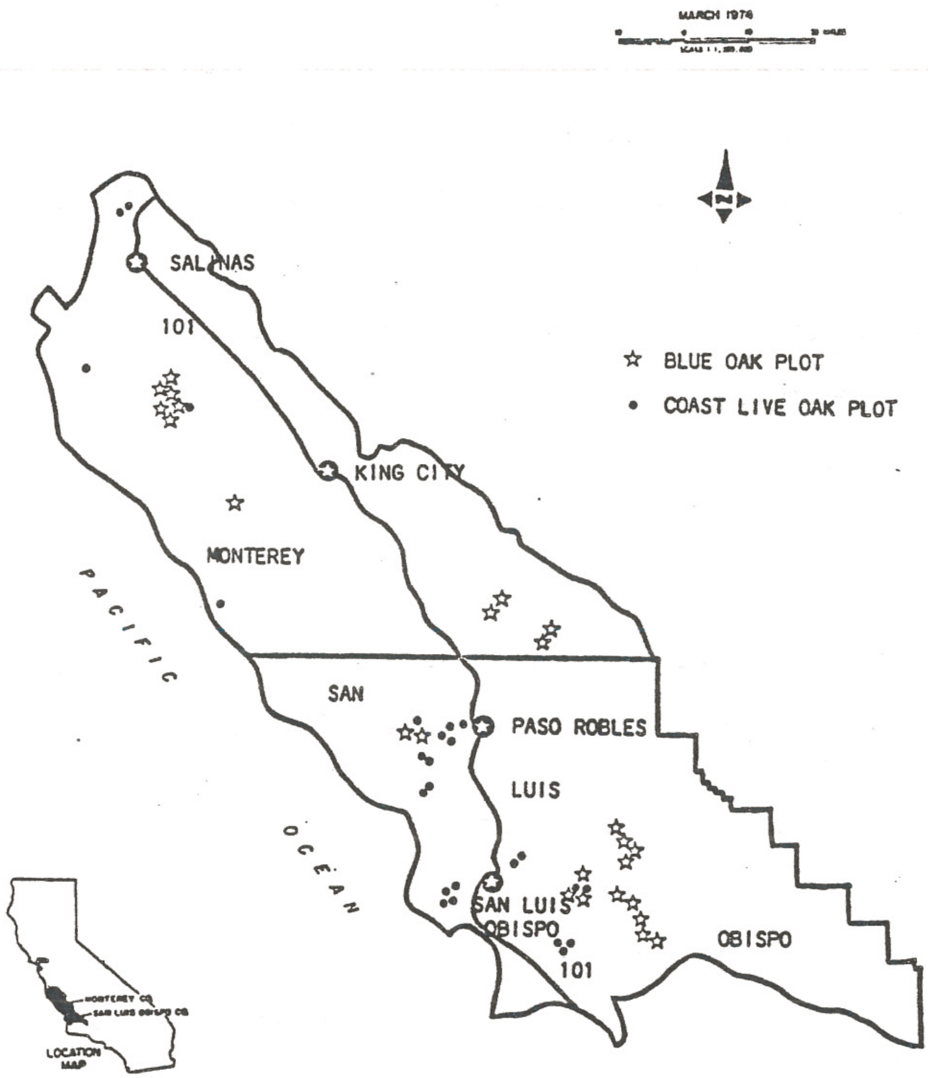


Figure 1. Blue oak and coast live oak sample site location in Monterey and San Luis Obispo counties, California

Stand Structure

Data collected for all trees within each sample plot included species and diameter at breast-height (dbh). Tree dbh was used to determine basal area and tree volume. Local volume equations developed using Pillsbury and Stephens (1978) and Pillsbury and Kirkley (1984) data were used to determine individual tree volume. The volume equations are listed in Appendix A. Stand, stock and basal area frequency tables that represent the average for the twenty-five sample plots for each species were developed using these information.

Site Index

Normally 2 trees were selected for stem analysis (occasionally only 1 or as many as 4) based on these criteria:

1. The tallest trees in the stand.
2. The tree showed no signs of past injury.
3. The tree showed no signs of past suppression.
4. The tree developed as part of the present stand (not a residual).

Trees chosen for stem analysis were felled and sectioned with disks taken at approximately 0.3 meter (1 foot), DBH (1.3 meters (4.5 feet)), 3.0 meters (10 feet), and successive intervals of 1.5 meters (5 feet). Intervals were adjusted if the sectioning point occurred at a fork or place of abnormal swelling. Disks were taken from the stem that was the tallest and the most upright. Table 3 describes the information obtained in the field from each plot and how it was measured.

Table 3. Tree and stand data obtained in the field.

Variable	Units	Measurement Description
CUT TREE:		
Total length	m	Measured with cloth tape as cumulative distance from base to the tip along sinuosities of main stem to nearest .01 m.
Total height	m	Measured with cloth tape from base to tip (straight line distance) of felled tree to nearest .01 m.
STAND DATA :		
Species	code	All woody species greater than 1.3 meters tall.
Diameter	cm	Measured with caliper to nearest 0.1 cm.

Tree Age

Tree ages at successive heights were determined by counting annual growth rings for each disk. Each species presented unique difficulties with respect to ring counting. Enhancement techniques such as those suggested by Maeglin (1979) for aging increment cores were tested. We found that obtaining a smooth surface and wetting the disk with water provided the best results. Blue oak had well-defined growth rings, however, due to slow radial growth, a smooth surface cut with a sharp knife and magnification from a dissecting scope (35X power) was often needed. Coast live oak required sanding of each disk to enhance ring definition. Often, after sanding, a 10X power hand lens was needed to count rings where radial growth was slowed considerably. Magnification beyond 10X power was usually too much and did not improve results. Soaking each coast live oak disk in water provided additional contrast needed for ring counting. The information measured from each disk is listed in Table 4.

Table 4. Data obtained from each disk.

Variable	Units	Measurement Description
Disk age	years	Determined by counting annual growth rings in two places
Diameter inside bark	mm	Calculated by taking geometric mean of long and short axes (nearest 1.0 mm)
Average bark thickness	mm	Average of four measurements of single bark thickness (nearest 1.0 mm)
10 year radial growth	mm	Measured along average radius on disk taken from breast height (nearest 1.0 mm)

The age of each disk was determined by counting the annual growth rings along the long and the short axes on the top surface. Each axis was counted until both age values were within two years. Diameter inside bark was determined by measuring the long and the short diameters and obtaining the geometric average. The 10 year radial growth increments were measured along a ray that was equal in length to the average radius. Radial growth was measured along a ray because, although they are often curved, they are generally perpendicular to the growth rings and give a reasonable estimate of radial growth.

CHAPTER V

STAND STRUCTURE AND COMPOSITION

Blue oak and coast live oak stands are being more intensively studied, used and managed today than in the past. Some knowledge of existing composition and structure will help land managers, foresters and others to develop a sound management plan for volume or basal area removal and stocking prescriptions.

Twenty-five plots were sampled in each forest type for the purpose of gathering data for site index and height growth prediction equation development. Because height growth may be influenced by extremes of stand density the sample stands were generally moderately to fully stocked, with crown closure generally greater than 50% in the blue oak stands and greater than 80% in the coast live oak stands. As a result of the density requirements in selecting sample plots, they may not represent the actual average stand condition. The stand structure and composition information reflects the average for stands which are moderately to fully stocked.

Stand tables (number of stems per acre for the average sample stand) were developed for each species. Both species are capable of basal sprouting, especially coast live oak, and as a result forking is common and stems often occur in clumps. In the case of forked stems if a single fork was below breast-height (1.3 meters (4.5 feet)) two stems were counted. Where the fork was above breast-height one stem was counted. Coast live oak often had 4-5 or even 6 stems arising from a common stump.

The blue oak sample stands averaged 926 live trees per hectare (375 trees/acre) which includes 885 blue oak stems per hectare (358 trees/acre) or 95% of the total live trees, and 41 trees per hectare (16 trees/acre) of other species. An average of 48 dead blue oak stems per hectare (19 stems/acre) were present. The coast live oak sample stands averaged 699 live trees per hectare (283 trees/acre) of which 645 (261 per acre) were coast live oak or 92% of the total live trees, and 54 stems per hectare (22 per acre) were other species. An average of 54 dead coast live oak stems per hectare (22 per acre) were present. A summary of sample stand information for both species is shown in Table 5. This comparison shows large differences between the species in terms of basic stand characteristics.

The blue oak and coast live oak sample stand averages are compared with earlier studies by White (1966) at the Hastings Reserve, McClaren (1983) in Tulare county, Pillsbury (1978) in Monterey and San Luis Obispo counties, and to a study by De Lasaux et al (1980) in Santa Barbara county in Table 6. Basal area provides the best basis for comparison of the studies for each species. The average basal area per hectare for blue oak for the four studies is approximately 19 square meters (83 square feet per acre) and for coast live oak the average basal area for three studies is approximately 35 square meters

Table 5. Statistical summary of stand characteristics for blue oak and coast live oak sample stands with moderate to fully stocked conditions used for site index measurements in Monterey and San Luis Obispo counties, California.

Variable Measured	Units	Blue Oak			Coast Live Oak		
		$\bar{x}$	s	range	$\bar{x}$	s	range
No. of live stems	#/ha (#/ac)	926 (375)	486 (197)	309 - 1,976 (125 - 800)	700 (283)	504 (204)	210 - 2,520 (85 - 1020)
Basal area	m^2/ha (ft^2/ac)	16 (71)	5 (22)	6 - 27 (26 - 118)	36 (155)	10 (44)	16 - 55 (70 - 240)
Ave. Stand diameter	cm (in)	15.7 (6.2)	3.7 (1.5)	9.8 - 24.0 (3.9 - 9.4)	27.3 (10.8)	6.3 (2.5)	13.2 - 35.5 (5.2 - 14.0)
Age	years	97	16	67 - 130	81	24	43 - 131
Volume	m^3/ha (ft^3/ac)	110 (1,575)	40 (572)	36 - 181 (514 - 2,586)	311 (4,449)	98 (1,400)	108 - 493 (1,543 - 7,045)
Volume growth	$m^3/ha/yr$ ($ft^3/ac/yr$)	1.14 (16.2)	0.37 (5.3)	0.44 - 1.74 (6.3 - 24.9)	3.83 (55.0)	1.73 (24.7)	1.48 - 7.58 (21.1 - 109)
Dead stems	#/ha (#/ac)	48 (19)	90 (36)	0 - 44 (0 - 180)	54 (22)	103 (42)	0 - 469 (0 - 190)

per hectare (151 square feet per acre). Comparison of volume per acre shows fairly large differences. This may be due to the use of different volume equations for the various studies.

Table 6. Comparison of number of stems, basal area and volume per hectare for 4 blue oak and 2 coast live oak studies.

	Number of stems #/ha (#/ac)	Volume m^3/ha (ft^3/ac)	Basal area m^2/ha (ft^2/ac)
BLUE OAK			
White[1]	511 (207)	N/A	20 (87)
Mclaren[2]	803 (325)	N/A	19 (83)
Pillsbury[3]	956 (387)	134 (1,915)	21 (91)
From Table 5	926 (375)	110 (1,575)	16 (71)
COAST LIVE OAK			
Pillsbury[4]	405 (164)	249 (3,558)	34 (148)
De Lasaux[5]	590 (239)	150 (2,144)	34 (148)
From Table 5	700 (283)	311 (4,449)	36 (155)

[1]White (1966). 49 plots in the Hastings Reserve and surrounding area, Monterey county.
[2]McClaren (1983). 15 plots in Tulare county.
[3]Pillsbury (1978). 10 plots in Monterey and San Luis Obispo counties.
[4]Pillsbury (1978). 5 plots in Monterey, San Luis Obispo and San Benito counties.
[5]De Lasaux (1980). 79 plots located on Dry Creek Ranch in Santa Barbara county.

In addition to averages of stand diameter, stand basal area and stand volume; distributions of diameter, basal area and volume by diameter class will provide information to aid in estimating volume reduction based on thinning strategies.

Sample stand averages for volume and basal area are shown by 20 year age classes in Table 7.

Table 7. Blue and coast live oak stand averages by age class for volume and basal area in Monterey and San Luis Obispo counties.

Age class	Number of plots	Average Volume m^3/ha	Average Volume (ft^3/ac)	Average Basal Area m^2/ha	Average Basal Area (ft^2/ac)
BLUE OAK					
61 - 80	1	58	(829)	11	(48)
81 - 100	14	89	(1,272)	16	(70)
101 - 120	8	129	(1,843)	17	(74)
121 - 140	2	109	(1,558)	16	(70)
COAST LIVE OAK					
40 - 60	7	307	(4,387)	38	(165)
61 - 80	8	359	(5,130)	38	(165)
81 - 100	4	320	(4,573)	35	(152)
101 - 120	4	243	(3,472)	25	(109)
121 - 140	2	375	(5,359)	40	(174)

Tables 23 through 32 in Appendix B show the number of stems per unit area in metric and English units (stand table), volume per unit area in metric and English units (stock table), as well as cumulative frequency tables for number of stems per unit area, basal area per unit area, and volume per unit area by diameter class for blue oak and coast live oak. Stand and stock table sub-totals are given for sapling size trees (diameter classes of 10 cm (4 inches) and less), fuelwood size trees (diameter classes greater than 10 cm and up to 25 cm (10 inches)) and sawlog size trees (diameter classes greater than 25 cm and up to 125 cm (50 inches)).

The distribution of plots by site index for Monterey and San Luis Obispo counties is given in Table 8. For purposes of presentation both species are given on a common scale in meters. The overlap of the two species at the seven to ten meter site-index classes represents the better sites for blue oak and the poorer coast live oak sites. From this it may be concluded that a site is very good for blue oak and poor for coast live oak where the two species occupy the same site.

Table 8. Site index (base age 50 years) distribution of sample plots in Monterey and San Luis Obispo counties.

Site Index Class (meters)	Blue oak (n = 25)	Coast live oak (n = 25)
4.1 - 5.5	5	
5.6 - 7.0	8	
7.1 - 8.5	8	4
8.6 - 10.0	4	3
10.1 - 11.5		6
11.6 - 13.0		4
13.1 - 14.5		2
14.6 - 16.0		2
16.1 - 17.5		2
17.6 - 19.0		2

A simple correlation (r) matrix for each species is shown in the Appendix C for all variables.

CHAPTER VI

SITE INDEX PREDICTION EQUATION DEVELOPMENT

The techniques used in the preparation of the site-index equations parallel those developed by Dahms (1975) for lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and used by Barrett (1978) and Cochran (1979), for ponderosa pine (*Pinus ponderosa* Laws.) and white fir (*Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.) and grand fir (*Abies grandis* (Dougl. ex D.Don.) Lindl.) in the west, respectively. This approach uses the tallest stand element at each decade of stand growth as the height observation for site index estimation. The tallest stand element is that tree which is tallest at any given age. Research has shown that shifts occur among the dominant trees so that the tallest stand element at one point in time may not be tallest throughout the life of the stand. For example, the tallest tree at age 50 may not be tallest at age 80. Use of the tallest stand element at each decade eliminates a bias that exists when the average dominant height is used to develop site-index equations. The bias can result in younger stands receiving higher site index ratings than older stands (Dahms, 1963).

Average stand age was calculated from average breast-height age of the cut trees. Average breast-height stand age is defined as the average stand age with breast-height being considered age zero.

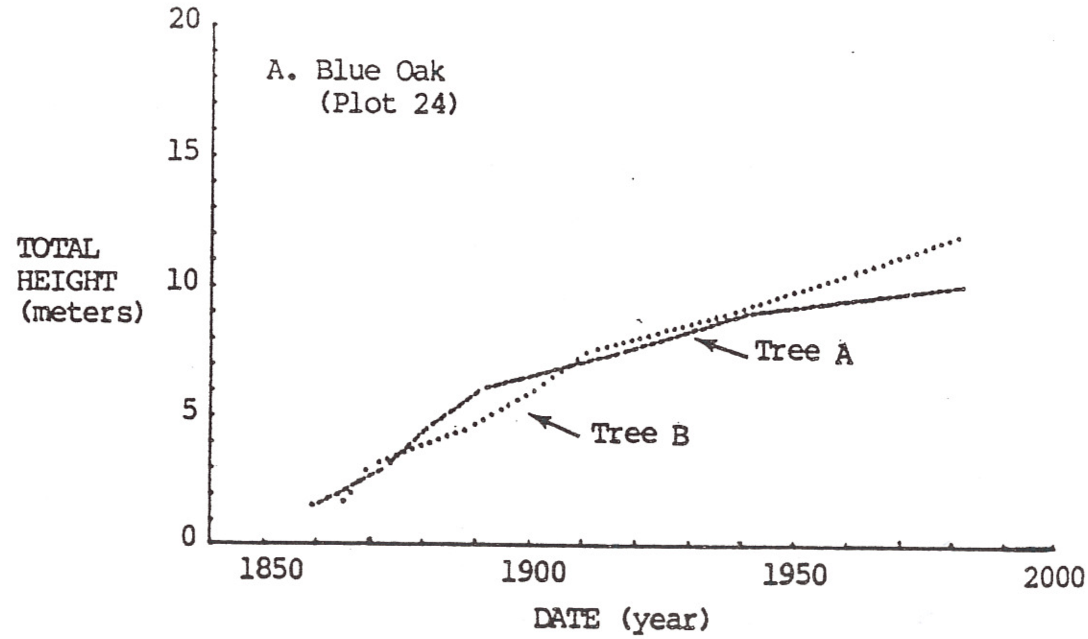
Breast-height is used as the basis for stand age for two reasons: (1) it reduces potential for bias from suppression of early height growth resulting from competition or damage, and (2) tree age is customarily determined by boring at breast-height. In the present study blue oak was found to average about 13 years to reach breast-height, although one-third of the trees took from 3 to 10 years and another one-third took 15 to 30 years. Coast live oak, which is a prolific sprouter, averaged 6 years to attain breast-height although many reached breast-height in one to two years.

The procedures used in developing the site index prediction equations are discussed below.

Height Data Analysis and Base Age Selection

Height Versus Age. Tree height/age data obtained from stem analysis was plotted for each stand. An example of a blue oak and coast live oak plot is shown in Figure 2. The height/age curves were inspected for indications of early height growth suppression or uneven-age structure. Stands were considered even-age when breast-height ages of cut trees were within 15 years of their mean. This resulted in dropping three trees from the data set because they were remnants of an earlier stand.

Dominant height shifts over the life of the stand were observed in 40% of the blue oak and 48% of the coast live oak stands. Barrett (1978) reported dominant height shifts of 90% for ponderosa pine.



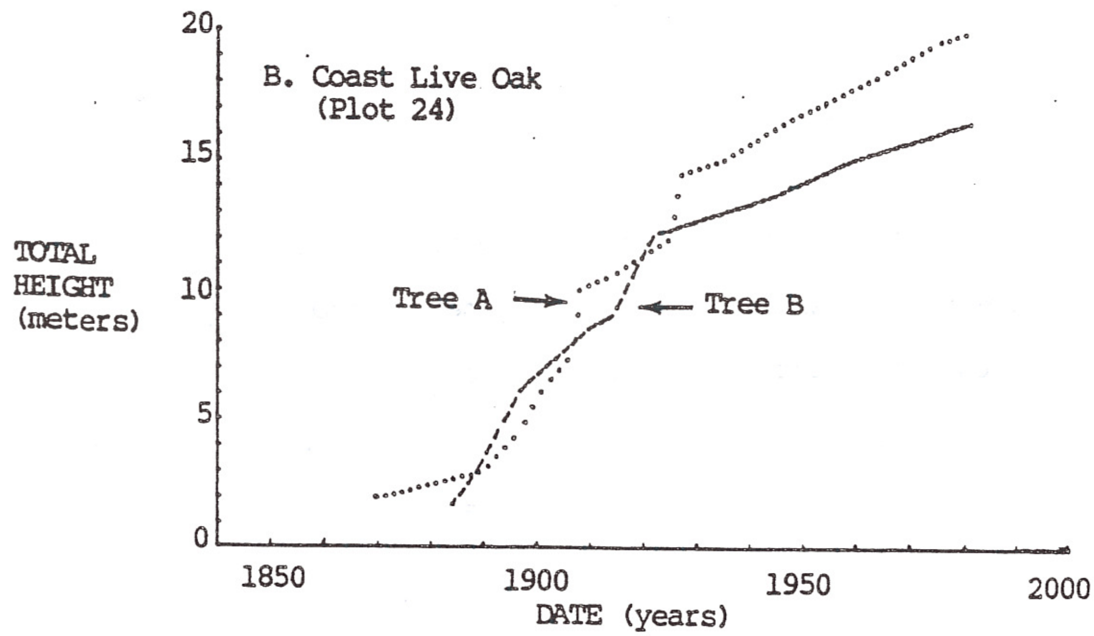


Figure 2. Graph of total height versus age at breast-height for a blue oak (A) and coast live oak (B) sample plot.

The individual tree height/age curves were adjusted so tree height more accurately reflects the actual height attained at the end of the growing season. This is needed because the measured height at the point of sectioning normally occurs at some intermediate point along the annual leader resulting in an underestimation of actual height at the determined age (Carmean, 1972). He assumed that on the average, section points occur at the middle of the annual leader and that annual height growth within the section is equal for each year. This rationale was used to develop the tree height adjustment equation (Eq. 4) which was used to adjust tree heights.

$$\text{adjusted tree height} = \text{unadjusted tree height} + (\text{segment length}/\text{age difference})/2 \qquad [4]$$

Adjusted tree heights for sample trees were plotted for each stand and the tallest tree at each decade was determined. Figure 3 shows the results of this procedure. Note that for coast live oak (Figure 3 (B)), at breast-height stand age 40, tree A was the tallest stand element, at breast-height stand age 50 tree B was tallest, and at the time of cutting tree A was again the tallest stand element. Similar shifting occurred among the two dominants within the blue oak stand. The adjusted 10 year height data (Appendix D) was the basis for further calculations.

Main Stem Length Versus Total Height. The decurrent growth habit of both coast live oak and blue oak presents an anomaly where total height, as measured in a straight line distance from the ground

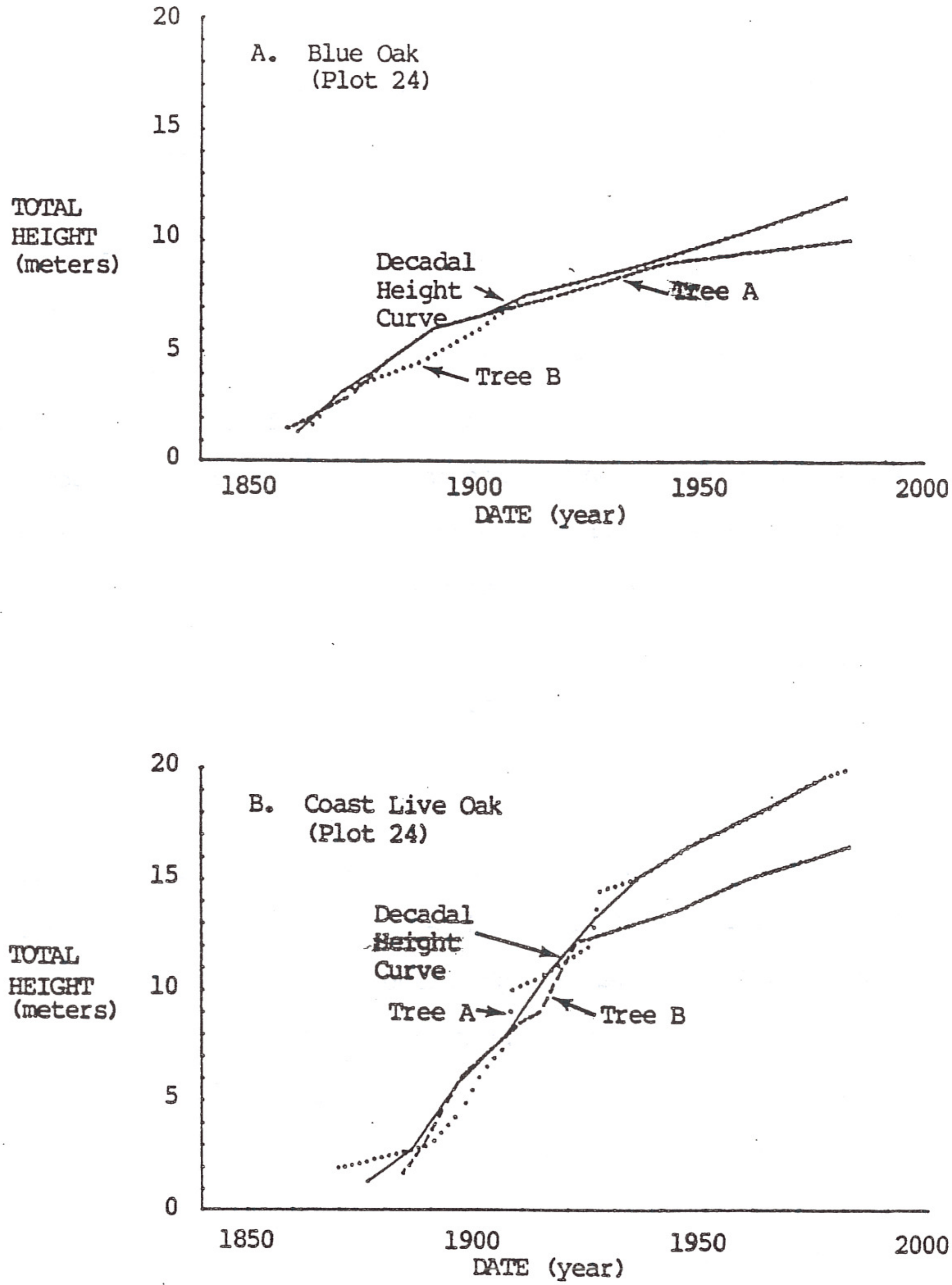


Figure 3. Graph of adjusted height versus age at breast-height with the decadal height/age curve for a blue oak (A) and coast live oak (B) sample plot. The decadal height/age curve is plotted with height/age points that represent the tallest stand element for each 10 year period.

to the tip, will differ from the total main stem length, as measured along the sinuosities of the main stem from the ground to the tip.

Measurement along the main stem provides a greater total length than a simple measurement of total height. Main stem length is needed since it will give a better measure of site productivity. However, in application total height is easier to measure. Equation (5), metric units, and Equation (6), English units, were developed to adjust total height measurements to correspond to the cumulative length along the main stem. Regressions of main stem length versus total height for each species resulted in similar regression coefficients and the data sets were combined. The fit of the equation is shown in Figure 4.

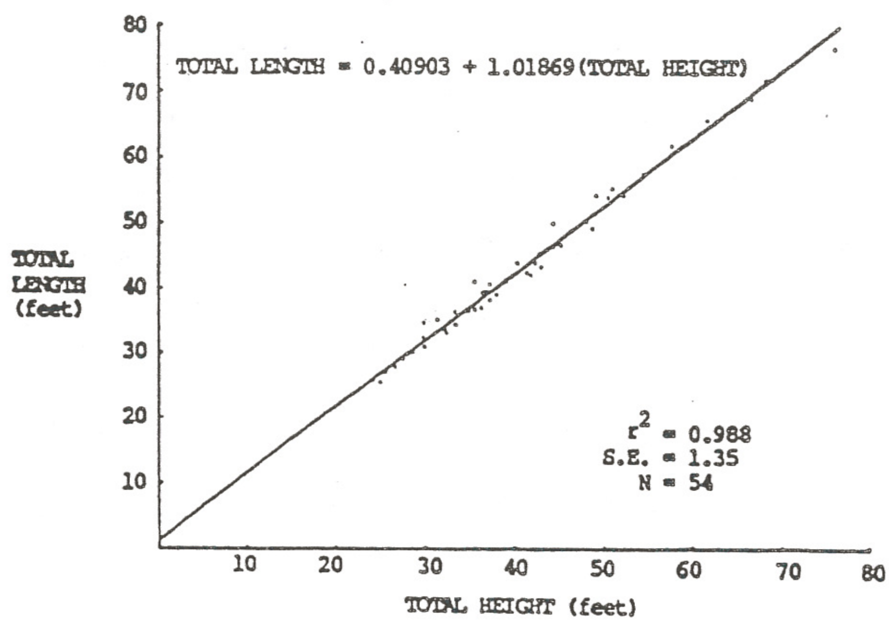


Figure 4. Total length versus total height using combined blue oak and coast live oak data sets.

$$\text{Main Stem Total Length (m)} = 0.40903 + 1.01869 \text{ (Total Height (m))} \qquad [5]$$

$r^2 = 0.988$, S.E.= 0.41 meters, n = 54

$$\text{Main Stem Total Length (ft)} = 1.34196 + 1.01869 \text{ (Total Height (ft))} \qquad [6]$$

$r^2 = 0.988$, S.E.= 1.35 feet, n = 54

Base Age Selection. Both blue oak and coast live oak were evaluated for site index at base age 50. Blue oak was also tested at base age 100 and coast live oak at base age 80 (the limit of the data) as possible alternatives.

When total production over the rotation is of primary interest the base age should approximate the expected rotation age (Curtis *et al.*, 1974). Since technical rotation age, based on culmination of mean annual increment, could not be estimated with the available data, selection of base age was based on other criteria.

The following considerations were made in selecting a base age of 50 years for both species. The most important consideration is the restriction imposed by the available data. Sample size decreased with increasing age for both species. Of the 25 blue oak plots only 15 were at least 100 years while all 25 plots were at least 50 years old. The situation was similar for the coast live oak plots where only 9 plots were at least 100 years old while all 25 plots were at least 50 years old. A base age of 80 years was also considered for coast live oak. However, only 18 plots were at least 80 years old.

Developing site-index curves for blue oak for base age 50 may, at first, not seem practical since few stands in California are less than

60 years old. The youngest blue oak stand sampled in this study was 67 years old. Further, using 100 years as the base age would have provided a better index of site productivity for current stands (ages mostly greater than 70 years). However, it is unlikely that a base age of 100 for blue oak would ever be used where management for fiber production is the objective since growth is relatively slow and a technical rotation would most likely occur before age 100. The selection of base age 50 for blue oak assumes the user would manage a new stand for fiber. This would occur where blue oak is capable of sprouting and surviving (only a few locations in California) or if artificial regeneration methods assure survival.

Although coast live oak is a more rapidly growing species than blue oak, a base age of 50 years was also selected for site index evaluation. A base age of 50 years can be realistically used following harvest as well as predicting site index for many existing stands. However a base age of 80 years could be used to provide a better estimate of production for older stands.

Another consideration in choosing a base age of 50 years for both species was that it allowed for comparision of the two species.

Site Index Equations

The methods used in developing the site index prediction equations are a variant of the parameter prediction method outlined by Clutter *et al.* (1983). The procedure involves the development of equations to model the individual intercept (a), slope (b), and height (HT) parameters in the basic site index model (Eq. 7).

$$SI - 1.3 \text{ meters} = a + b\ (HT - 1.3 \text{ meters}) \quad [7]$$

where, SI = site index (total height of tallest stand element at base age 50)

HT = tallest tree height at successive 10 year intervals

a and b = regression coefficients

− 1.3 meters = to correct for breast-height measurements

The procedure involves five major steps which are show in Figure 5, summarized below and discussed in greater detail on the following pages.

1. Eq. 7 is fit to the height data for successive decades (decadal ages, e.g. 10, 20, 30,..., AGE_n).
2. The slope coefficients (b) from step 1 are then modeled by regressing them against the decadal ages to obtain the slope prediction (b) equation.
3. Develop an average height prediction ($\hat{HT}$) equation to model the HT parameter in Eq. 7 by regressing average decadal height for all plots against decadal age.
4. The intercept coefficient (a) in Eq. 7 is then derived by substituting the slope (b) and average height ($\hat{HT}$) prediction models into Eq. 7 and rearranging.
5. The site index prediction equation is then obtained by substituting the intercept (a), slope (b) and average height ($\hat{HT}$) prediction models into Eq. 7.

Step 1: Site Index Regression. Linear regression models were fit to the decadal height data for each successive decade (10, 20, 30, ..., AGE_n) using the basic site index equation (Eqn. 7). Tables 9 and 10 are summaries of the regression equations for each species. The regression line for each equation, illustrated in

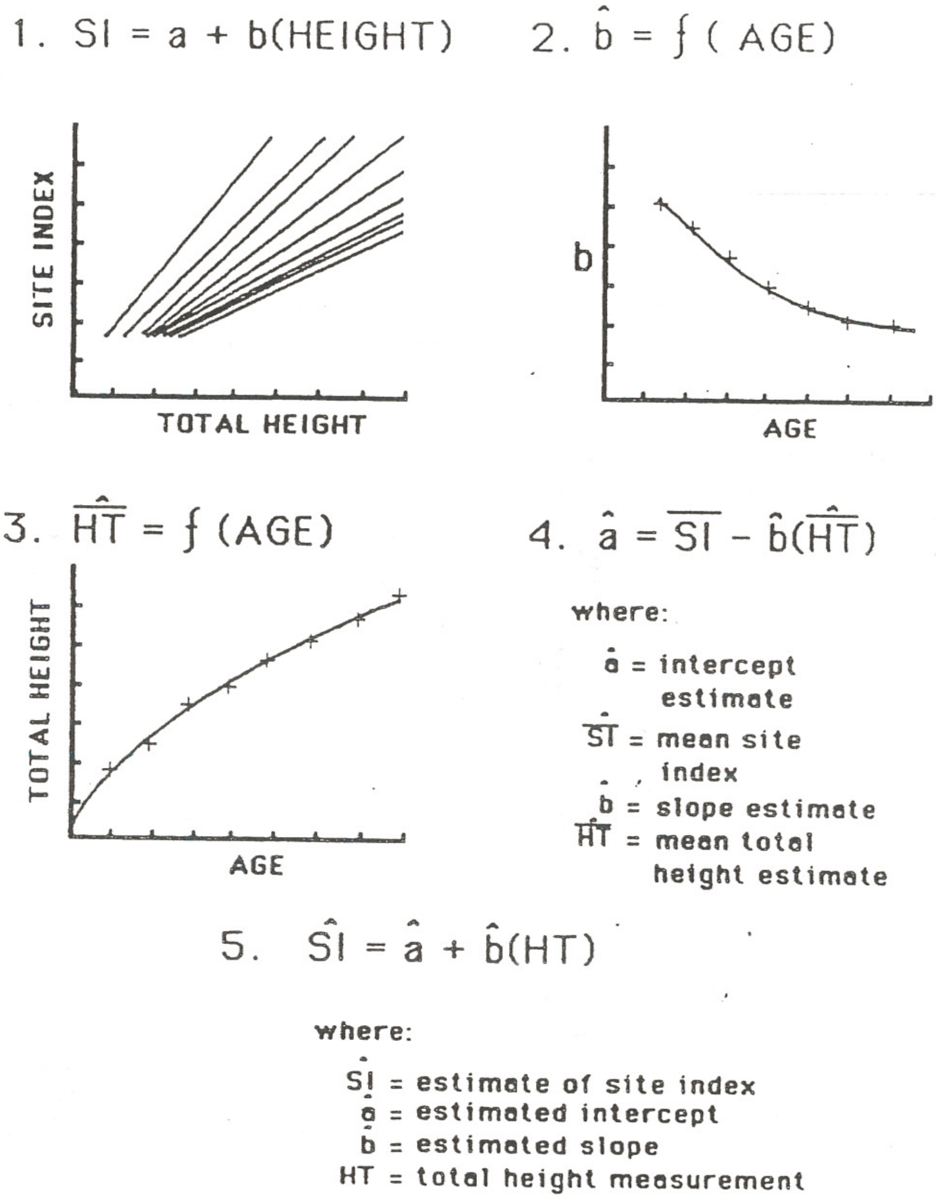


Figure 5. Illustration of the 5 major steps used in developing site-index prediction curves. Step 1 involves linear regression of site index versus total height at successive decades. The slope of the regression lines obtained in Step 1 are modeled in Step 2. Step 3 involves development of average decadal height prediction model. The models developed in Steps 2 and 3 are substituted into site index model (SI = a + b (HT)) which is then rearranged to obtain the intercept (a) in Step 4. In Step 5 the slope prediction, average decadal height, and intercept estimation models are substitued into the final site index model.

Figure 6, shows the relationship between height of the tallest stand element and the height attained at the base age (site index), at 10 year intervals.

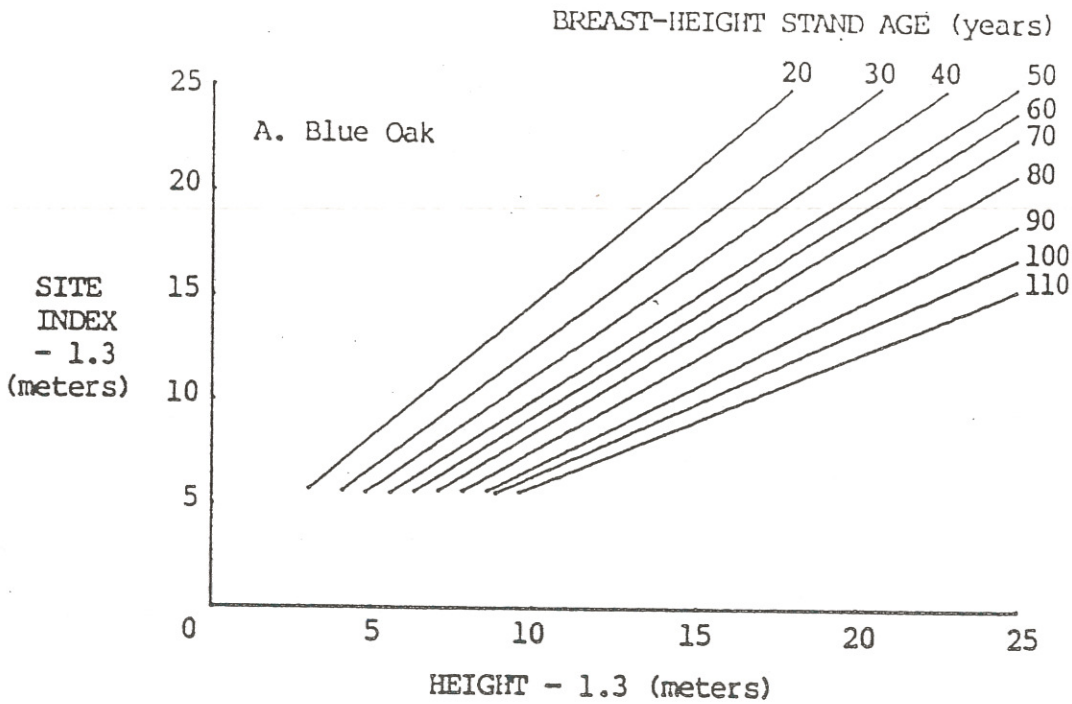
Table 9. Blue oak site index regression summaries.

Breast-height age (years)	Site Index (m)		a		b	Total height (m)	r^2	Standard error of estimate (%)	n
20	SI-1.3	=	1.82723	+	1.28214	(HT-1.3)	0.76	14.1	25
30	"	=	0.93991	+	1.15806	"	0.91	8.4	25
40	"	=	0.40593	+	1.07423	"	0.98	4.3	25
50	"	=	0.00000	+	1.00000	"	1.00	0.0	25
60	"	=	-0.51920	+	0.97407	"	0.99	2.8	25
70	"	=	-0.97742	+	0.94208	"	0.97	5.3	25
80	"	=	-1.23778	+	0.88256	"	0.92	8.1	24
90	"	=	-0.99021	+	0.77734	"	0.85	11.4	24
100	"	=	-0.57729	+	0.69543	"	0.80	13.4	15
110	"	=	-0.43319	+	0.63070	"	0.75	16.4	10

Table 10. Coast live oak site index regression summaries.

Breast-height age (years)	Site Index (m)		a		b	Total height (m)	r^2	Standard error of estimate (%)	n
20	SI-1.3	=	1.83421	+	1.52794	(HT-1.3)	0.60	16.1	25
30	"	=	0.79958	+	1.26173	"	0.76	12.4	25
40	"	=	-0.48611	+	1.19586	"	0.91	7.7	25
50	"	=	0.00000	+	1.00000	"	1.00	0.0	25
60	"	=	0.60869	+	0.84037	"	0.97	4.4	23
70	"	=	1.29721	+	0.70853	"	0.95	6.3	21
80	"	=	1.16914	+	0.65597	"	0.94	6.8	18
90	"	=	0.95857	+	0.63866	"	0.97	4.6	9
100	"	=	0.67470	+	0.60715	"	0.96	5.1	9

The slope (b) for each breast-height age regression line represents the rate of height growth for different levels of site



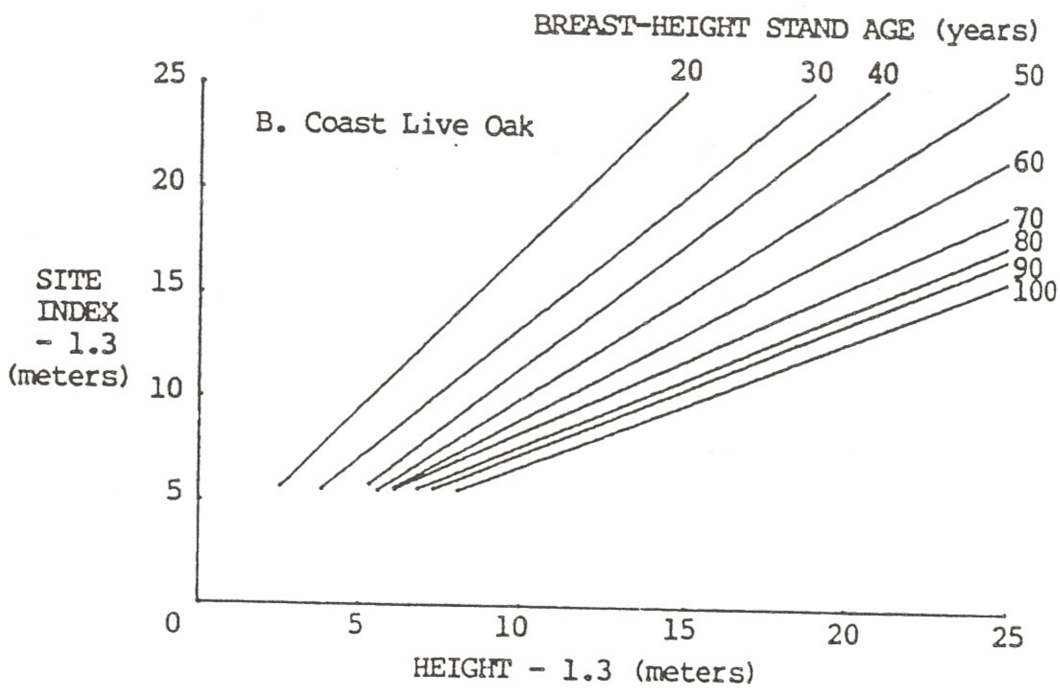


Figure 6. Linear regression lines from individual regressions of site index (height at age 50) versus height at breast-height stand ages 10, 20, 30, ..., 110 years for blue oak (A) and at breast-height stand ages 10, 20, 30, ..., 100 years for coast live oak (B).

quality. The slope of each regression line characteristically decreases with increasing age because the height attained by the tallest stand element on a good site is greater relative to that of a poor site as stand age increases.

Step 2: Slope Coefficient Calculation. Using non-linear regression (Ralston, 1982), the decadal estimates of slope (b), from step 1, were smoothed and conditioned to pass through 1 at the base age. Conditioning the smoothed curve is necessary so that site index (height at age 50) equals the mean height at age 50 obtained from the plot data. The algebraic process for conditioning an equation to pass through a desired point at a given time is explained below. In the example, $\hat{b}$ is conditioned to equal 1 when breast-height decadal age is equal to 50, using the von Bertalanffy growth model. The von Bertalanffy model was one of three models used in developing the site index prediction equations. The algebraic proccess for conditioning the other two models is given in Appendix E.

The general model is:

$$\hat{b} = a + b_1(1- e^{b_2 AGE})^{b_3} \qquad [8]$$

Where, $\hat{b}$ = slope estimate (rate of height growth for different site conditions)

AGE = breast-height decadal age ($10, 20, 30, \ldots AGE_n$)

e = base e logarithm

a, b_1, b_2, b_3 are coefficients to be estimated through non-linear regression

With the constraint, $\hat{b} = 1$ when AGE = 50, Equation (8) becomes:

$$1 = a + b_1(1- e^{b_2 50})^{b_3} \qquad [9]$$

Equation (9) is then subtracted from Equation (8) to eliminate the intercept coefficient (a), yielding Equation (10):

$$\hat{b} - 1 = b_1(1- e^{b_2 AGE})^{b_3} - b_1(1- e^{b_2 50})^{b_3} \qquad [10]$$

The "1" is then moved to the other side to obtain Equation (11), the conditioned form of the general model (Eq. 8), which has three coefficients (b_1, b_2 and b_3) to be estimated using non-linear regression:

$$\hat{b} = 1 + b_1(1- e^{b_2 AGE})^{b_3} - b_1(1-e^{b_2 50})^{b_3} \qquad [11]$$

After fitting Equation (11), the first and the last terms are combined to obtain the intercept (a) in Equation (8).

Figure 7 shows the effect of conditioning Equation (8). The conditioned slope ($\hat{b}$) prediction equations for each species are listed below and their fit is illustrated in Figure 8.

Blue oak

$$\hat{b} = 1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621} \qquad [12]$$

$r^2 = 0.995$, SE = 0.037

NOTE: The goodness-of-fit estimates, while reported, are not statistically applicable to non-linear regression.

Coast live oak

$$\hat{b} = 1.607197 - 1.117641(1 - e^{-0.037426AGE})^{3.650238} \quad [13]$$

$$r^2 = 0.995, \ SE = 0.046$$

The slope estimates ($\hat{b}$) at various breast-height ages to be substituted into Equation (6) are given in Tables 11 and 13 (metric units) and Tables 12 and 14 (English units) for both species.

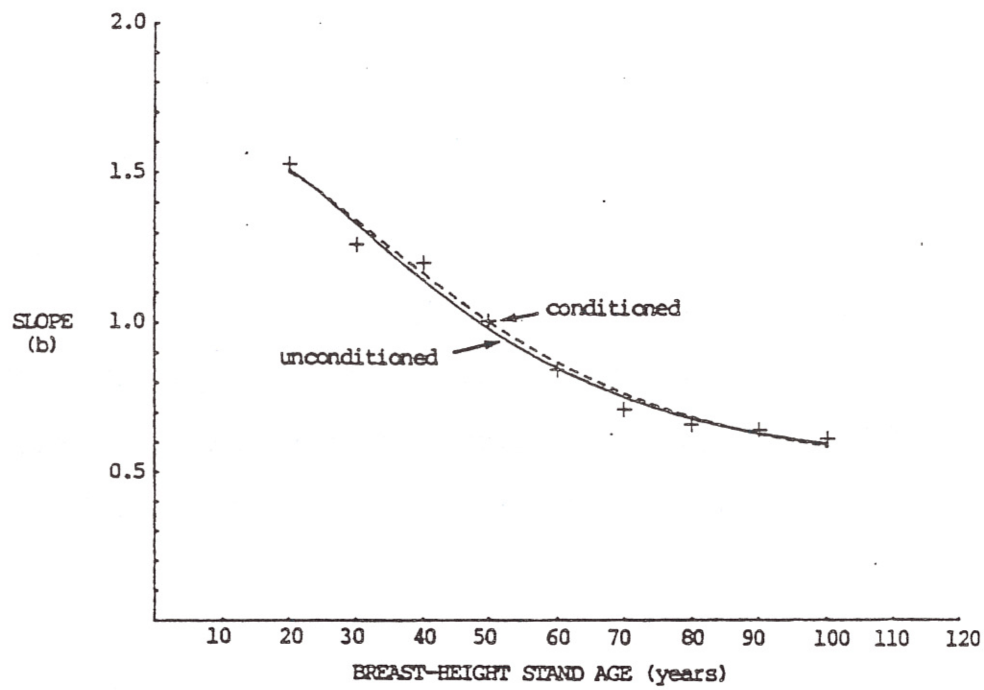


Figure 7. Simultaneous plot of conditioned and unconditioned slope prediction (b) curves showing the effect of conditioning the curve to pass through b = 1 at the base age.

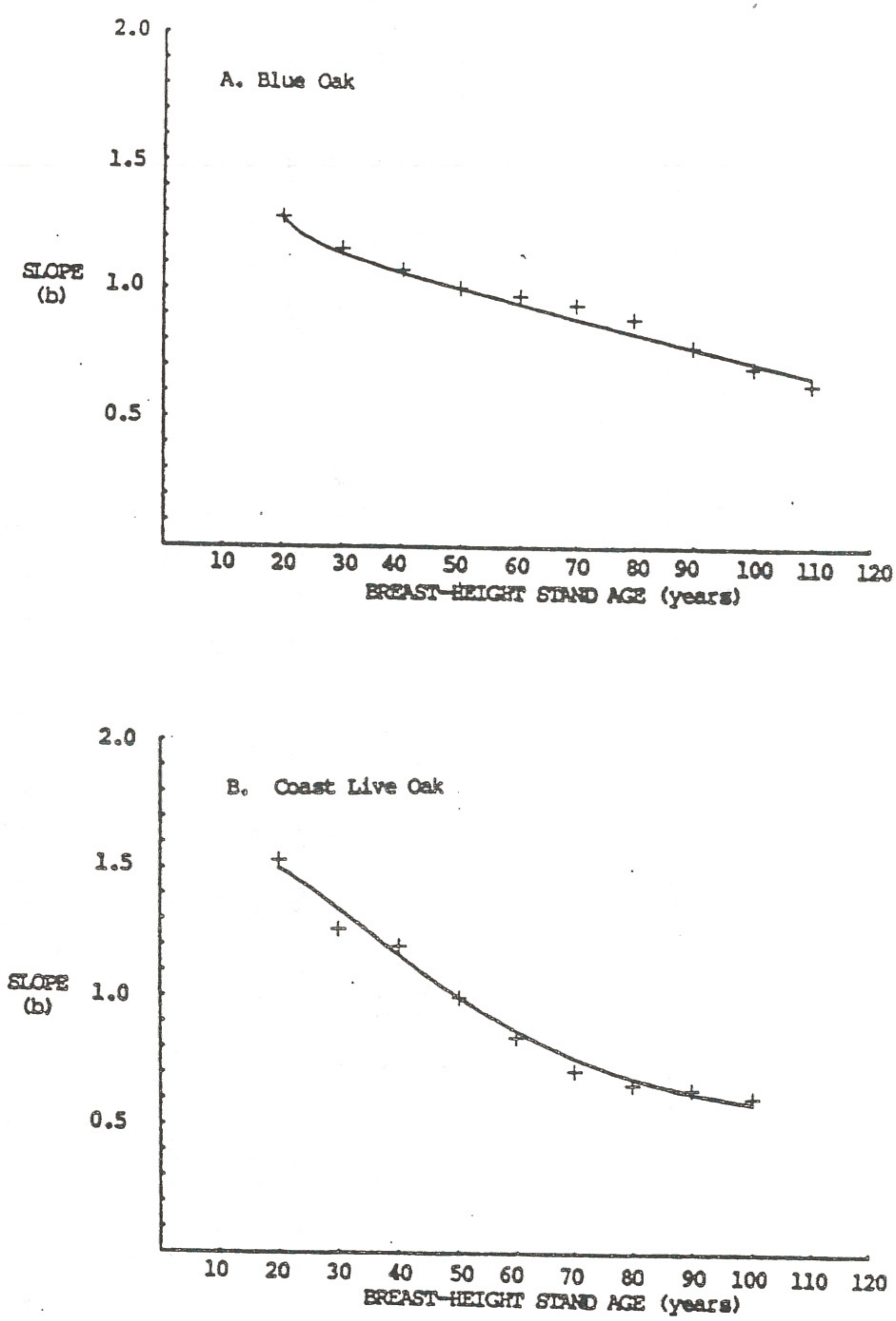


Figure 8. Slope prediction ($\hat{b}$) curve for blue oak (A), based on Equation (12), and coast live oak (B), based on Equation (13).

Table 11. a and b coefficients by years for the family of regressions for estimating site index (SI - 1.30 meters) for blue oak (base age 50) [1/] in Monterey and San Luis Obispo counties.

Breast-height age	Years between decades: 0		1		2		3		4		5		6		7		8		9	
Years	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
20	1.916	1.283	1.868	1.256	1.806	1.234	1.736	1.216	1.661	1.201	1.585	1.187	1.507	1.176	1.429	1.165	1.351	1.155	1.274	1.145
30	1.198	1.136	1.123	1.128	1.050	1.120	0.978	1.112	0.908	1.105	0.839	1.097	0.772	1.090	0.706	1.083	0.643	1.076	0.580	1.069
40	0.520	1.063	0.461	1.056	0.403	1.050	0.347	1.043	0.293	1.037	0.241	1.031	0.189	1.024	0.140	1.018	0.092	1.012	0.045	1.006
50	0.000	1.000	-0.044	0.994	-0.086	0.988	-0.127	0.982	-0.166	0.976	-0.204	0.970	-0.241	0.964	-0.276	0.958	-0.310	0.953	-0.343	0.947
60	-0.374	0.941	-0.404	0.935	-0.433	0.929	-0.461	0.924	-0.487	0.918	-0.512	0.912	-0.536	0.907	-0.558	0.901	-0.580	0.895	-0.600	0.889
70	-0.619	0.884	-0.637	0.878	-0.654	0.872	-0.670	0.867	-0.685	0.861	-0.698	0.856	-0.711	0.850	-0.722	0.844	-0.732	0.839	-0.741	0.833
80	-0.750	0.827	-0.757	0.822	-0.763	0.816	-0.768	0.811	-0.772	0.805	-0.775	0.800	-0.777	0.794	-0.779	0.788	-0.779	0.783	-0.778	0.777
90	-0.776	0.772	-0.774	0.766	-0.770	0.761	-0.765	0.755	-0.760	0.749	-0.754	0.744	-0.746	0.738	-0.738	0.733	-0.729	0.727	-0.719	0.722
100	-0.708	0.716	-0.697	0.711	-0.684	0.705	-0.671	0.700	-0.657	0.694	-0.641	0.689	-0.626	0.683	-0.609	0.678	-0.591	0.672	-0.573	0.667
110	-0.554	0.661																		

[1/] To estimate site index, measure total height of the tallest tree per 0.1 hectare plot. Determine average breast-height stand age from at least two of the tallest trees per plot. Select the appropriate a and b values above. Substitute values into the equation (SI - 1.30) = a + b((c + d(Measured height)) - 1.30). Where c and d are coefficients to adjust measured height (c = 0.40903, d = 1.01869). For example, for a plot with an average breast-height stand age of 75 years and with the tallest tree having a measured height of 9 meters, solve the equation, SI - 1.30 = -0.698 + 0.856((0.40903+ 1.01869(9)) - 1.30), for a site index of 7.7 meters.

Table 12. a and b coefficients by years for the family of regressions for estimating site index (SI - 4.5 feet) for blue oak (base age 50) 1/ in Monterey and San Luis Obispo counties.

Breast-height age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
Years	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
20	6.286	1.283	6.128	1.256	5.925	1.234	5.695	1.216	5.451	1.201	5.199	1.187	4.943	1.176	4.687	1.165	4.432	1.155	4.179	1.145
30	3.930	1.136	3.685	1.128	3.445	1.120	3.209	1.112	2.979	1.105	2.753	1.097	2.533	1.090	2.318	1.083	2.108	1.076	1.904	1.069
40	1.705	1.063	1.511	1.056	1.323	1.050	1.140	1.043	0.962	1.037	0.789	1.031	0.622	1.024	0.459	1.018	0.301	1.012	0.148	1.006
50	0.000	1.000	-0.143	0.994	-0.282	0.988	-0.416	0.982	-0.545	0.976	-0.670	0.970	-0.790	0.964	-0.906	0.958	-1.017	0.953	-1.125	0.947
60	-1.228	0.941	-1.326	0.935	-1.421	0.929	-1.511	0.924	-1.597	0.918	-1.680	0.912	-1.758	0.907	-1.832	0.901	-1.903	0.895	-1.969	0.889
70	-2.032	0.884	-2.091	0.878	-2.146	0.872	-2.198	0.867	-2.246	0.861	-2.290	0.856	-2.331	0.850	-2.369	0.844	-2.402	0.839	-2.433	0.833
80	-2.460	0.827	-2.483	0.822	-2.503	0.816	-2.520	0.811	-2.533	0.805	-2.544	0.800	-2.551	0.794	-2.554	0.788	-2.555	0.783	-2.552	0.777
90	-2.547	0.772	-2.538	0.766	-2.526	0.761	-2.511	0.755	-2.493	0.749	-2.472	0.744	-2.449	0.738	-2.422	0.733	-2.392	0.727	-2.359	0.722
100	-2.324	0.716	-2.286	0.711	-2.245	0.705	-2.201	0.700	-2.154	0.694	-2.105	0.689	-2.052	0.683	-1.998	0.678	-1.940	0.672	-1.880	0.667
110	-1.817	0.661																		

1/ To estimate site index, measure total height of the tallest tree per 1/5 acre plot. Determine average breast-height stand age from at least two of the tallest trees per plot. Select the appropriate a and b values above. Substitute values into the equation (SI - 4.5) = a + b((c + d(Measured height)) - 4.5). Where c and d are coefficients to adjust measured height (c = 1.34196, d = 1.01869). For example, for a plot with an average breast-height stand age of 75 years and with the tallest tree having a measured height of 25 feet, solve the equation, SI - 4.5 = -2.290 + 0.856((1.34196 + 1.01869(25)) - 4.5), for a site index of 21.3 feet.

Table 13. a and b coefficients by years for the family of regressions for estimating site index (SI - 1.30 meters) for coast live oak (base age 50) [1/] in Monterey and San Luis Obispo counties.

Breast-height age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
Years	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
20	1.908	1.499	1.690	1.486	1.487	1.472	1.299	1.457	1.126	1.442	0.966	1.426	0.819	1.410	0.685	1.393	0.563	1.376	0.453	1.359
30	0.355	1.342	0.267	1.324	0.190	1.306	0.122	1.288	0.063	1.271	0.014	1.253	-0.028	1.235	-0.062	1.217	-0.088	1.199	-0.108	1.181
40	-0.122	1.164	-0.129	1.147	-0.132	1.129	-0.129	1.112	-0.121	1.096	-0.110	1.079	-0.094	1.063	-0.075	1.047	-0.053	1.031	-0.028	1.015
50	0.000	1.000	0.030	0.985	0.062	0.970	0.095	0.956	0.130	0.942	0.166	0.928	0.204	0.915	0.242	0.902	0.280	0.889	0.319	0.877
60	0.359	0.864	0.398	0.852	0.438	0.841	0.477	0.830	0.516	0.819	0.555	0.808	0.593	0.798	0.630	0.788	0.667	0.778	0.703	0.768
70	0.738	0.759	0.773	0.750	0.806	0.741	0.839	0.733	0.870	0.725	0.900	0.717	0.929	0.709	0.957	0.702	0.984	0.694	1.010	0.687
80	1.034	0.681	1.057	0.674	1.079	0.668	1.100	0.662	1.119	0.656	1.138	0.650	1.154	0.644	1.170	0.639	1.185	0.634	1.198	0.629
90	1.210	0.624	1.221	0.619	1.230	0.615	1.239	0.610	1.246	0.606	1.252	0.602	1.257	0.598	1.261	0.594	1.264	0.590	1.265	0.587
100	1.266	0.583																		

[1/] To estimate site index, measure total height of the tallest tree per 0.1 hectare plot. Determine average breast-height stand age from at least two of the tallest trees per plot. Select the appropriate a and b values above. Substitute values into the equation (SI - 1.30) = a + b((c + d(Measured height)) - 1.30). Where c and d are coefficients to adjust measured height (c = 0.40903, d = 1.01869). For example, for a plot with an average breast-height stand age of 70 years and with the tallest tree having a measured height of 12 meters, solve the equation, SI - 1.30 = 0.738 + 0.759((0.40903+ 1.01869(12)) - 1.30), for a site index of 10.7 meters.

Table 14. a and b coefficients by years for the family of regressions for estimating site index (SI - 4.5 feet) for coast live oak (base age 50) 1/ in Monterey and San Luis Obispo counties.

Breast-height age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
Years	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
20	6.259	1.499	5.545	1.486	4.880	1.472	4.263	1.457	3.693	1.442	3.168	1.426	2.687	1.410	2.247	1.393	1.848	1.376	1.488	1.359
30	1.164	1.342	0.877	1.324	0.622	1.306	0.400	1.288	0.208	1.271	0.045	1.253	-0.092	1.235	-0.203	1.217	-0.290	1.199	-0.355	1.181
40	-0.399	1.164	-0.424	1.147	-0.432	1.129	-0.422	1.112	-0.398	1.096	-0.360	1.079	-0.309	1.063	-0.246	1.047	-0.173	1.031	-0.091	1.015
50	-0.000	1.000	0.098	0.985	0.202	0.970	0.312	0.956	0.427	0.942	0.546	0.928	0.668	0.915	0.793	0.902	0.920	0.889	1.048	0.877
60	1.177	0.864	1.307	0.852	1.436	0.841	1.565	0.830	1.693	0.819	1.820	0.808	1.945	0.798	2.068	0.788	2.189	0.778	2.307	0.768
70	2.423	0.759	2.536	0.750	2.645	0.741	2.751	0.733	2.854	0.725	2.954	0.717	3.049	0.709	3.141	0.702	3.229	0.694	3.313	0.687
80	3.393	0.681	3.469	0.674	3.541	0.668	3.609	0.662	3.672	0.656	3.732	0.650	3.788	0.644	3.839	0.639	3.886	0.634	3.930	0.629
90	3.969	0.624	4.005	0.619	4.036	0.615	4.064	0.610	4.087	0.606	4.108	0.602	4.124	0.598	4.137	0.594	4.146	0.590	4.151	0.587
100	4.153	0.583																		

1/ To estimate site index, measure total height of the tallest tree per 1/5 acre plot. Determine average breast-height stand age from at least two of the tallest trees per plot. Select the appropriate a and b values above. Substitute values into the equation (SI - 4.5) = a + b((c + d(Measured height)) - 4.5). Where c and d are coefficients to adjust measured height (c = 1.34196, d = 1.01869). For example, for a plot with an average breast-height stand age of 70 years and with the tallest tree having a measured height of 40 feet, solve the equation, SI - 4.5 = 2.423 + 0.759((1.34196 + 1.01869(40)) - 4.5), for a site index of 35.5 feet.

Step 3: Average Decadal Height Versus Age. Average decadal heights for the 25 plots were then determined for each species (Table 15). At ages beyond 80 years the sample size became progressively smaller for both species and the mean site index was slightly different. This bias was corrected by adjusting the decadal heights to the mean overall site index by substituting the actual intercept (a) and slope (b) values from the regressions calculated in step 1 for that age and the average site index for all the plots in Equation (14).

$$HT - 1.3 \text{ meters} = a + b\,(\overline{SI} - 1.3 \text{ meters}). \qquad [14]$$

where, $HT - 1.3$ meters = Corrected estimate of height,

$\overline{SI} - 1.3$ meters = mean site index for all plots, and

a and b = site index regression coefficients, from Step 1, for each decade

Table 15. Average decadal height (HT - 1.3 meters) data for blue oak and coast live oak.

Age	Blue oak (m)	Coast live oak (m)
10	2.15	3.98
20	3.57	6.19
30	4.72	8.32
40	5.58	9.86
50	6.41	11.30
60	7.11	12.55
70	7.84	13.73
80	8.66	15.40
90	9.51	16.15
100	10.09	17.44
110	10.67	

The average decadal heights were then smoothed and conditioned to pass through mean site index (mean height at base age) of 6.41 meters for blue oak and 11.30 meters for coast live oak. Conditioning this model is necessary for the same reason as stated earlier in step 2. The model was also constrained so that height would equal 0 meters (1.3 meters) at breast-height age 0. This latter constraint was met by eliminating the intercept coefficient from Equation (8).

Thus the model becomes:

$$\hat{HT} - 1.3 \text{ meters} = b_1(1 - e^{b_2 AGE})^{b_3} \quad [15]$$

where, $\hat{HT} - 1.3$ meters = estimate of average decadal height

AGE = breast-height decadal age $(10, 20, 30, \ldots AGE_n)$

e = base e logarithm

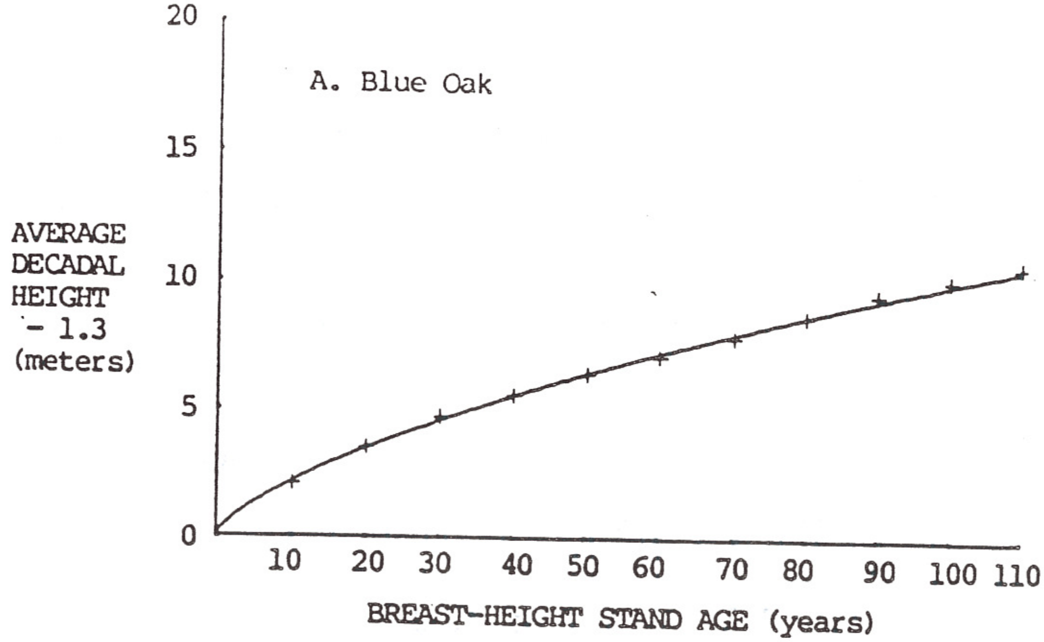
a, b_1, b_2, b_3 are coefficients to be estimated

Because the model is slightly different, the algebraic process for conditioning the smoothed curve to pass through mean site index at the base age is different. This process is outlined in Appendix E. The equations used to estimate the height component in Equation (6), for both species, in both metric and English units, are given below. Figure 9 illustrates the fit of the conditioned height prediction equation for each species.

Blue oak

Metric: $$\hat{HT} - 1.3 \text{ meters} = 30.892152\ (1 - e^{-0.002109 AGE})^{0.683229} \quad [16]$$
$r^2 = 0.9939$, SE = 0.1389 meters

English: $$\hat{HT} - 4.5 \text{ feet} = 101.351892\ (1 - e^{-0.002109 AGE})^{0.683229} \quad [17]$$
$r^2 = 0.9939$, SE = 0.4557 feet



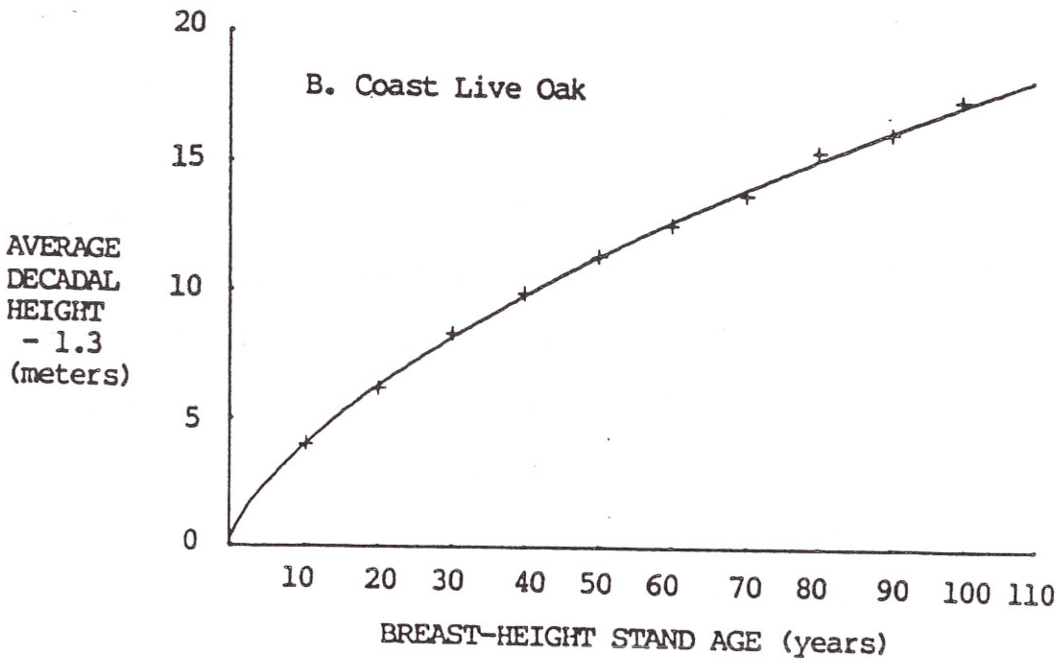


Figure 9. Average decadal height prediction ($\hat{HT}$) curve for blue oak (A), based on Equation (16), and coast live oak (B), based on Equation (18).

Coast live oak

Metric: $\hat{HT} - 1.3 \text{ meters} = 43.129421\ (1 - e^{-0.002969AGE})^{0.676188}$ [18]

$r^2 = 0.9938$, SE = 0.1789 meters

English: $\hat{HT} - 4.5 \text{ feet} = 141.500295\ (1 - e^{-0.002969AGE})^{0.676188}$ [19]

$r^2 = 0.9938$, SE = 0.5869 feet

Step 4: Intercept Coefficient Calculation. The slope prediction ($\hat{b}$) equations and the average height prediction ($\hat{HT}$) equations developed in steps 2 and 3 were used to determine the intercept coefficient (a) in Equation (6) by substitution to obtain Equation (20):

$$SI - 1.3 \text{ meters} = a + \hat{b}\ (\hat{HT} - 1.3 \text{ meters}), \quad [20]$$

and rearranging, yielding Equation (21) as follows:

$$\hat{a} = (\overline{SI} - 1.3 \text{ meters}) - \hat{b}\ (\hat{HT} - 1.3 \text{ meters}). \quad [21]$$

where, $\overline{SI}$ = mean height at breast-height age 50,

$\hat{b} = a + b_1\ (1 - e^{b_2 AGE})^{b_3}$,

$\hat{HT} = b_1\ (1 - e^{b_2 AGE})^{b_3}$, and

$-\ 1.3$ = corrects for breast height measurement

The equations used to predict the intercept (a) in Equation (6) are given below. The estimates of $\hat{a}$ for various ages are those shown in Tables 11 and 13 (metric units) and Tables 12 and 14 (English units).

Blue oak

$$\text{Metric: } \hat{a} = 6.41 - \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$

$$\left(30.892152\ (1 - e^{-0.002109AGE})^{0.683229}\right) \qquad [22]$$

$$\text{English: } \hat{a} = 21.03 - \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$

$$\left(101.351892\ (1 - e^{-0.002109AGE})^{0.683229}\right) \qquad [23]$$

Coast live oak

$$\text{Metric: } \hat{a} = 11.30 - \left(1.607197 - 1.117641(1 - e^{-0.037426AGE})^{3.650238}\right)$$

$$\left(43.129421\ (1 - e^{-0.002969AGE})^{0.676188}\right) \qquad [24]$$

$$\text{English: } \hat{a} = 37.07 - \left(1.607197 - 1.117641(1 - e^{-0.037426AGE})^{3.650238}\right)$$

$$\left(141.500295\ (1 - e^{-0.002969AGE})^{0.676188}\right) \qquad [25]$$

Step 5: Site Index Model

Substituting the prediction models, $\hat{b}$ (Eq. 8), $\hat{HT}$ (Eq. 14), and $\hat{a}$ (Eq. 21), and the total height correction equation (Eq. 5) into Equation (6), the basic model SI - 1.3 meters = a + b (HT - 1.3 meters), gives the final equation (Eq. 26) used to estimate site index as a function of age and height. The site-index prediction equations in both metric (Eqs. 27 and 29) and English units (Eqs. 28 and 30) for each species are given below. The site-index prediction curves in metric and English units are shown in Figures 10 and 11.

FINAL FORM

$$\hat{SI} - 1.3 \text{ meters} = \hat{a} + \hat{b}\ (HT - 1.3 \text{ meters}) \qquad [26]$$

where, SI - 1.3 meters = Site index estimate with 1.3 meters allowance for breast-height measurement,

$$\hat{a} = (\overline{SI} - 1.3) - (b_1 - b_2AGE + \frac{b_3}{AGE + b_4}$$

$$(b_1{}'(1- e^{b_2{}'AGE})^{b_3{}'} \text{ for blue oak, or,}$$

$$\hat{a} = (\overline{SI} - 1.3) - (b_1 + b_2(1- e^{b_3AGE})^{b_4})$$

$$(b_1{}'(1- e^{b_2{}'AGE})^{b_3{}'} \text{ for coast live oak,}$$

$$\hat{b} = b_1 - b_2AGE + \frac{b_3}{AGE + b_4} \text{ for blue oak,}$$

$$\hat{b} = b_1 + b_2(1- e^{b_3AGE})^{b_4}), \text{ for coast live oak, and}$$

HT - 1.3 meters = Measured total length after correction for total height bias using Equation (5) (Tot. Length = 1.34196 + 1.01869 (TOT. HT)) minus 1.3 meters to account for breast-height measurement.

NOTE: b_1,b_2,b_3 and b_4 are coefficients from Equations 12 or 13, and b_1', b_2' and b_3' are coefficients from Equations 16 and 18 (metric units for each species) or Equations 17 and 19 (English units for each species).

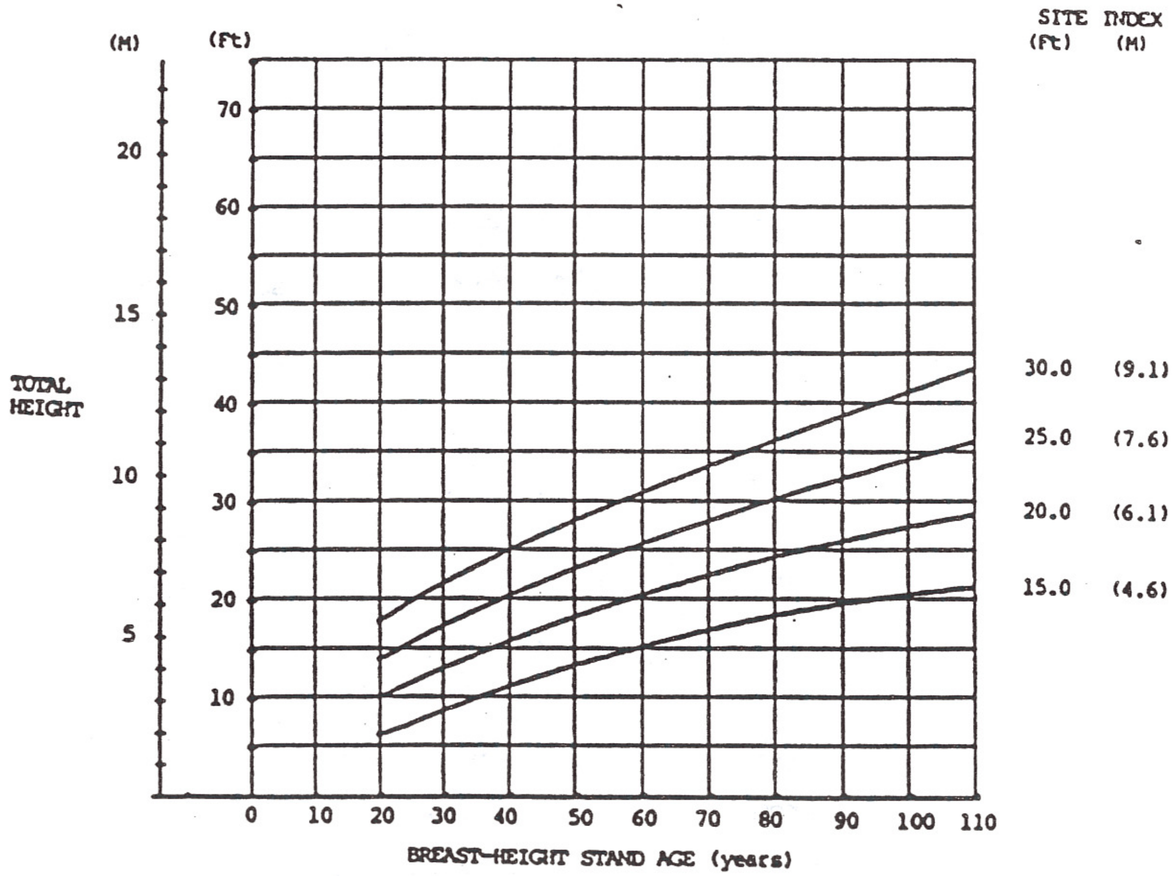


Figure 10. Blue oak site-index prediction curves based on Equation (27). Note that the corrections for breast-height measurements (- 1.3 meters) and total length (Eq. 5) have already been made. Simply use measured total height and average breast-height stand age to obtain estimated site index.

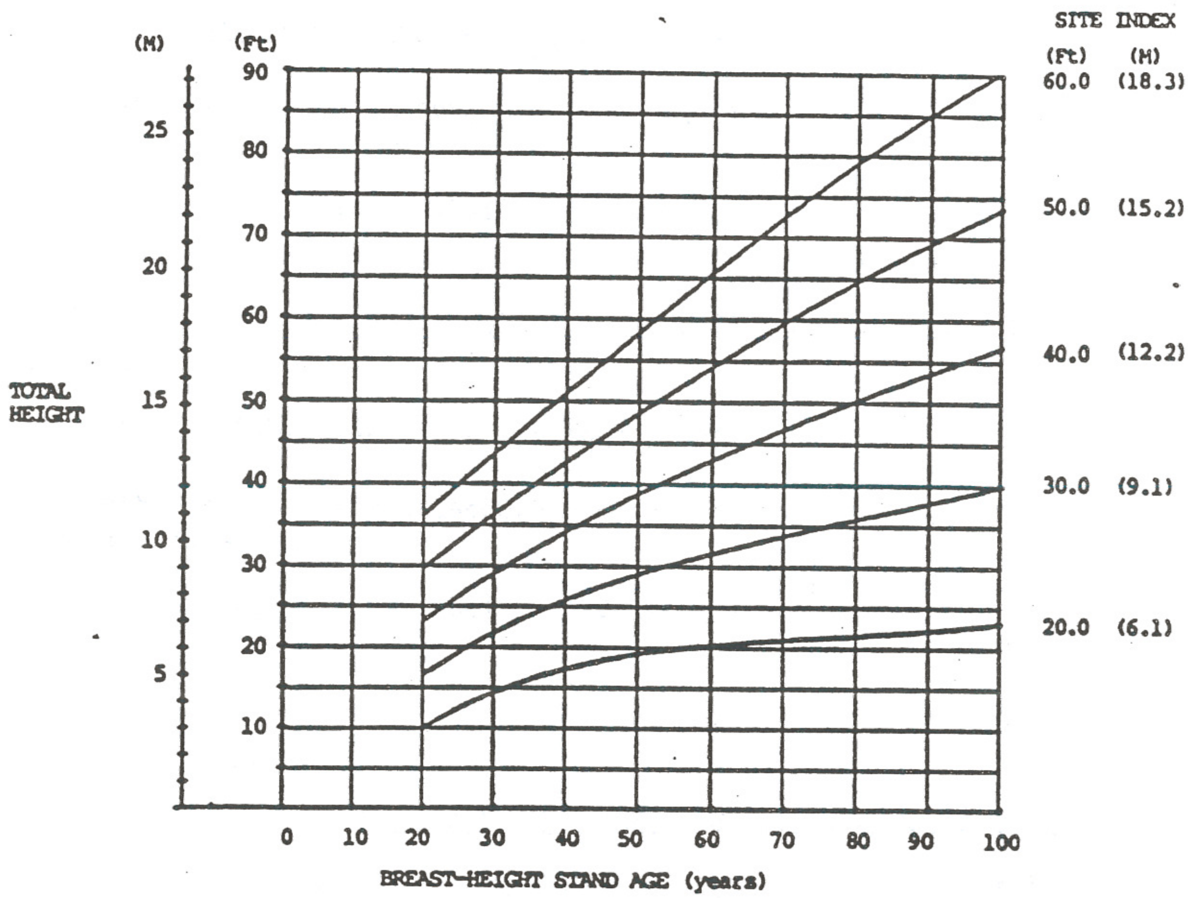


Figure 11. Coast live oak site-index prediction curves based on Equation (27). Note that the corrections for breast-height measurements (- 1.3 meters) and total length (Eq. 5) have already been made. Simply use measured total height and average breast-height stand age to obtain estimated site index.

Final Blue Oak Site Index Prediction Equation

$$\text{Metric: } SI - 1.3 = 6.41 - \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$
$$\left(30.892152\left(1 - e^{-0.002109AGE}\right)^{0.683229}\right) +$$
$$\left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$
$$\left(\left(0.40903 + 1.01869\,(HT)\right) - 1.3\right) \qquad [27]$$

$$\text{English: } SI - 4.5 = 21.03 - \left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$
$$\left(101.351892\left(1 - e^{-0.002109AGE}\right)^{0.683229}\right) +$$
$$\left(1.249698 - 0.005423AGE + \frac{0.757848}{AGE - 14.671621}\right)$$
$$\left(\left(1.34196 + 1.01869\,(HT)\right) - 4.5\right) \qquad [28]$$

Final Coast Live Oak Site Index Prediction Equation

$$\text{Metric: } SI - 1.3 = 11.30 - \left(1.607197 - 1.117641\left(1 - e^{-0.037426AGE}\right)^{3.650238}\right)$$
$$\left(43.129421\left(1 - e^{-0.002969AGE}\right)^{0.676188}\right) +$$
$$\left(1.607197 - 1.117641\left(1 - e^{-0.037426AGE}\right)^{3.650238}\right)$$
$$\left(\left(0.40903 + 1.01869\,(HT)\right) - 1.3\right) \qquad [29]$$

$$\text{English: } SI - 4.5 = 37.07 - \left(1.607197 - 1.117641\left(1 - e^{-0.037426AGE}\right)^{3.650238}\right)$$
$$\left(141.500295\left(1 - e^{-0.002969AGE}\right)^{0.676188}\right) +$$
$$\left(1.607197 - 1.117641\left(1 - e^{-0.037426AGE}\right)^{3.650238}\right)$$
$$\left(\left(1.34196 + 1.01869\,(HT)\right) - 4.5\right) \qquad [30]$$

Site-Index System Goodness of Fit

The precision of the blue oak and coast live oak site-index prediction systems can be initially judged by examining the coefficient of determination (r^2) and the standard error of the estimate for each of the individual site index regressions (Tables 9 and 10). Examination of these goodness of fit estimates for each species indicates that the relationship between site index and height at early ages (20 to 40 years) and older ages (80 to 100 years) for coast live oak is somewhat better than the blue oak.

It is also possible to test the precision of the prediction system to estimate site index with the actual height/age data from stem analysis through linear regression analysis. The independent variable is predicted site index, using the site-index prediction equations, with the decadal heights from the stem analysis data as the height observation, and the actual site index, height at age 50 years, is the dependent variable.

The SE and the r^2 estimates for each age are only approximate because the $\hat{a}$ and $\hat{b}$ values for each age are themselves estimated values of a and b (Table 16).

The estimates of site index become more precise as breast-height stand age approaches index age. Site index estimation was not as precise at earlier ages as older ages, particularly for coast live oak stands. Figures 12 (A) and 12 (B) show the progression with age of site index estimates at each of the 25 sample plot locations based on the decadal height/age data.

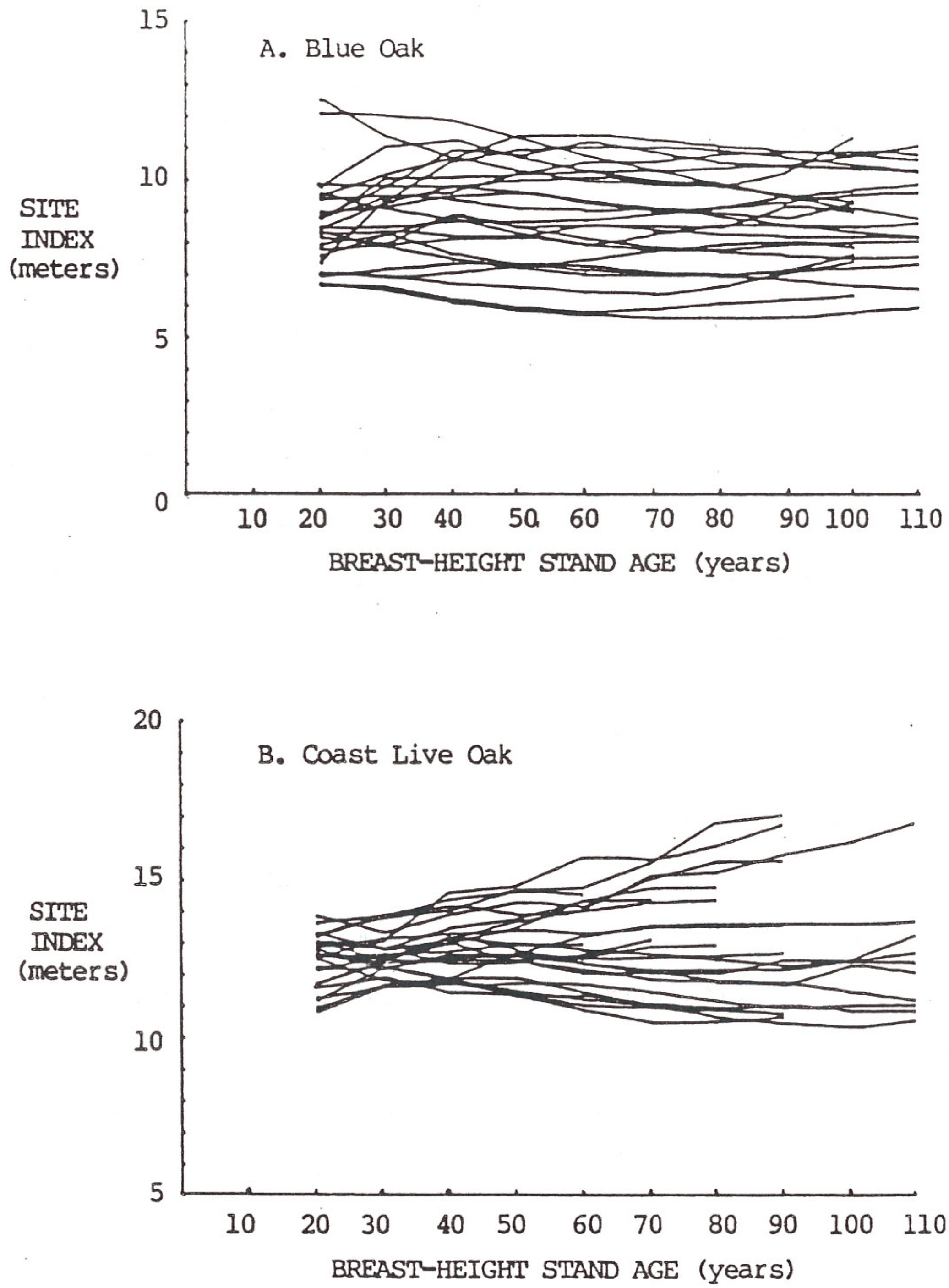


Figure 12. Plot of estimates of site index by location and age for blue oak (A) and coast live oak (B). The lines connect successive estimates of site index at the 25 sample plots, based on height of the tallest stand element at 10 year intervals (Data is given in Appendix D).

Table 16. Statistics for goodness-of-fit of site index curves generated by the site index prediction equations

Breast-height age (years)	Blue oak: Standard Error of Estimate (feet)	Blue oak: r^2	Blue oak: N	Coast live oak: Standard Error of Estimate (feet)	Coast live oak: r^2	Coast live oak: N
20	1.02	0.75	25	1.91	0.60	25
30	0.64	0.91	25	1.57	0.76	25
40	0.31	0.97	25	0.91	0.91	25
50	0.00	1.00	25	0.00	1.00	25
60	0.26	0.99	25	0.51	0.97	23
70	0.44	0.97	25	0.75	0.95	21
80	0.57	0.92	24	0.76	0.94	18
90	0.74	0.85	24	0.71	0.97	9
100	0.93	0.80	15	0.65	0.96	9
110	1.02	0.75	10			

There is considerable variability in the site index estimates at early ages. At breast-height age 20, 88% of the blue oak and 44% of the coast live oak site index estimates were within 1.5 meters of the actual site index. With increasing age the lines connecting successive estimates of site index more closly approximate the system of horizontal lines that is "expected from an ideal site index estimating system" (Curtis *et al.*, 1974). At breast-height age 100 years all site index estimates were within 1.5 meters (5 feet) of actual site index for both species.

Application of Site Index Prediction System

Estimates of site index for a blue oak or coast live oak stand can be obtained by following the steps given below.

1. Determine the average breast high stand age from a sample of at least two of the tallest trees in a 0.1 ha (one-fifth acre) plot located within the stand. Measure the total height of several dominant trees to determine the tallest tree (tallest stand element). Sample tree selection should be made with the following considerations:

Stand Criteria

a) The stand should be pure or nearly pure (90%).
b) The stand should be even-age. The actual ages of individual trees may vary plus or minus 15 years of the average stand age. For the best results, stand age determination may require falling or boring several trees (at least two).
c) There should be no signs of recent cutting.
d) The sample plot should be located within the stand such that there is a surrounding buffer strip that is at least as wide as the dominant trees are tall.

Sample Tree Selection Criteria

a) Sample trees should be the tallest in the stand.
b) No signs of past injury should be visible.
c) No signs of suppression should be evident from breast-height disk or increment core.
d) The tree should have developed as part of the present stand (not a residual)

Having obtained the basic information necessary to estimate site index, average breast high stand age and height of the tallest stand element, there are three options available for predicting site index:

1) Use site index graph (Figure 10 for blue oak or Figure 11 for coast live oak).

2) Use the site index intercept (a) and slope (b) coefficient table (Table 11 in metric units or Table 13 in English units) for blue oak or coast live oak (Table 12 in metric units or Table 14 in English units).

   EXAMPLE: To estimate the site index of a coast live oak stand that is 43 years old at breast height and the tallest stand element is 9.5 meters tall select the appropriate intercept (a) and slope (b) coefficients from Table 12. Substitute the values into the equation, $(SI - 1.3) = a + b\ ((0.40903 + 1.01869(12.09)) - 1.3)$.

   $$SI - 1.3 = -0.129 + 1.112\ ((\ 0.40903 + 1.01869(9.5)) - 1.3)$$

   $SI - 1.3 = 9.79$ meters, therefore predicted site index is 11.09 meters $(9.79 + 1.3 = 11.09)$.

3) If a computer is available the appropriate site index equation (Eq. 17 for blue oak or Eq. 18 for coast live oak) may be used. An example of the full site index prediction equation is shown below with the same plot data from the example in option 2 above.

Coast Live Oak Site Index Prediction Equation

$$SI - 1.3 = 11.3 - (1.607197 - 1.117641(1- e^{-0.037436(43)})^{3.650238})$$

$$(43.129421(1- e^{-0.002969(43)})^{0.676188} +$$

$$(1.607197 - 1.117641(1- e^{-0.037436(43)})^{3.650238})$$

$$((0.40903 + 1.01869\ (9.5)) - 1.3)$$

$SI - 1.3 = 9.79$, therefore the predicted $SI = (9.79 + 1.3) =$ 11.09 meters.

CHAPTER VII

HEIGHT PREDICTION EQUATION DEVELOPMENT

Height prediction equations or curves provide estimates of the pattern of height development of dominant trees or stands which actually attain a specified height (site index) at the specified index age (Curtis *et al.*, 1974).

The basic model used for height prediction (Eq. 31) is the reverse of site index model (Eq. 3) where height is now the variable to be predicted and thus becomes the dependent variable. The steps used to develop the height prediction equations are the same as those used to develop the site-index prediction equations in the preceding chapter with the only difference being that HT is now the dependent variable and SI is the independent variable.

$$HT - 1.3 \text{ meters} = a + b\,(SI - 1.3 \text{ meters}) \qquad [31]$$

where,

HT = total height
SI = site index (height at base age)
a and b = regression coefficients, and
1.3 meters = corrects for breast-height measurement

Step 1: Height Regression

The height versus age data (Appendix D) previously used for construction of the site index equations is used in the height prediction equation development. Linear regressions in the form of

Equation (31) were fit to the height/age data for each decade. Summaries of the regressions are shown in Tables 17 and 18.

Table 17. Blue oak height prediction regression summaries.

Breast-height age (years)	Total height (m)		a		b	Site Index (m)	r^2	Standard error of estimate (%)	n
20	HT-1.3	=	-0.22241	+	0.59217	(SI-1.3)	0.76	17.2	25
30	"	=	-0.33925	+	0.78977	"	0.91	9.4	25
40	"	=	-0.24741	+	0.91053	"	0.98	4.5	25
50	"	=	0.00000	+	1.00000	"	1.00	0.0	25
60	"	=	0.59677	+	1.01667	"	0.99	2.6	25
70	"	=	1.26514	+	1.02594	"	0.97	4.5	25
80	"	=	1.94967	+	1.04693	"	0.92	6.5	24
90	"	=	2.50691	+	1.09234	"	0.85	9.1	24
100	"	=	2.75188	+	1.14510	"	0.80	11.0	15
110	"	=	3.06644	+	1.18620	"	0.75	13.2	10

Table 18. Coast live oak height prediction regression summaries.

Breast-height age (years)	Total height (m)		a		b	Site Index (m)	r_2	Standard error of estimate (%)	n
20	HT-1.3	=	1.75747	+	0.39270	(SI-1.3)	0.60	14.9	25
30	"	=	1.47896	+	0.60559	"	0.76	11.6	25
40	"	=	1.26120	+	0.76057	"	0.91	7.0	25
50	"	=	0.00000	+	1.00000	"	1.00	0.0	25
60	"	=	-0.35209	+	1.15659	"	0.97	4.6	23
70	"	=	-0.99761	+	1.33581	"	0.95	6.9	21
80	"	=	-0.87723	+	1.44010	"	0.94	7.4	18
90	"	=	-0.93891	+	1.51194	"	0.97	4.9	9
100	"	=	-0.38129	+	1.57712	"	0.96	5.3	9

Step 2: Slope Coefficient Calculation

The decadal estimates of slope (b) were then smoothed and conditioned to pass through 1 at the base age using techniques previously discussed. The blue oak slope (b) prediction equation was developed graphically and is not based on non-linear regression results. The slope (b) prediction equations for each species are listed below.

Blue oak

$$\hat{b} = -74.987061 - 76.139260\,(1- e^{-0.035065AGE})^{0.010520} \qquad [32]$$

Coast live oak

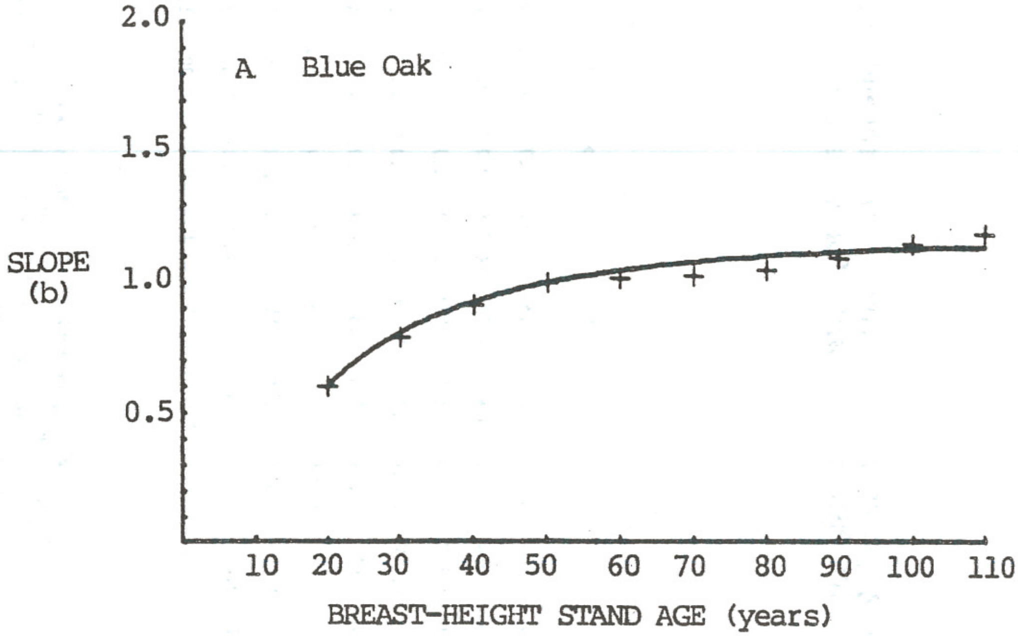
$$\hat{b} = 0.283428 + 1.454074\,(1- e^{-0.034702AGE})^{3.646735} \qquad [33]$$

$$R^2 = 99.33,\ SE = 0.04$$

Figure 13 shows the slope ($\hat{b}$) prediction curves for both species. The height prediction slope ($\hat{b}$) estimates for various ages for each species are shown in tables 19 and 21 (metric units) and 20 and 22 (English units).

Step 3: Average Decadal Height Versus Age

The equations (Eqs. 16-19) used in predicting decadal mean height in step 3 of site index equation development in Chapter VI were used for developing the height prediction equations.



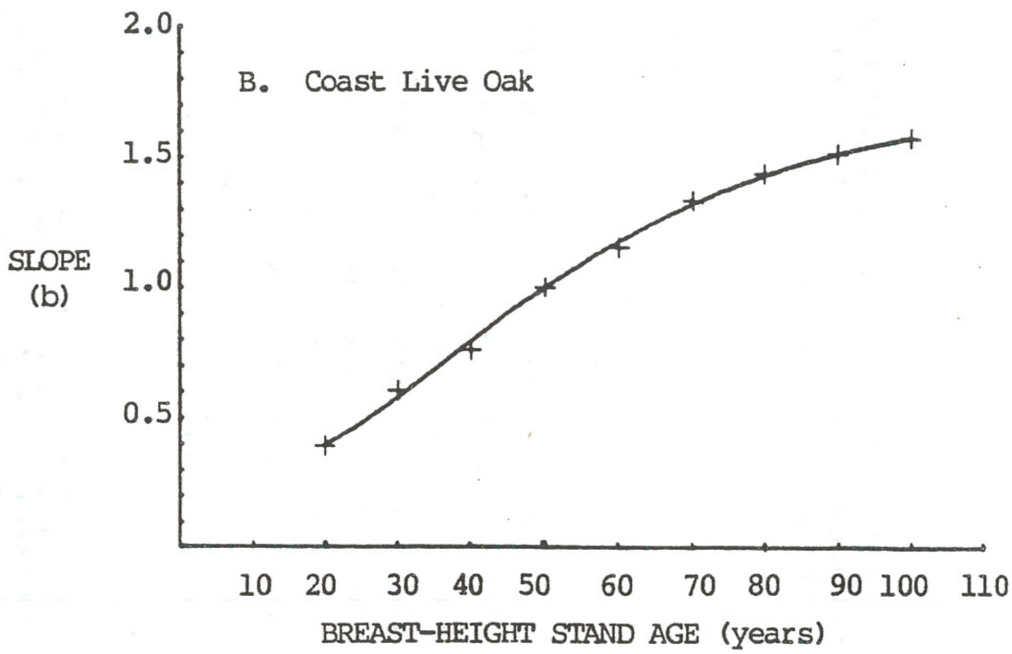


Figure 13. Slope prediction ($\hat{b}$) curve for blue oak (A), based on Equation (32), and coast live oak (B), based on Equation (33).

Table 19. Intercept (a) and slope (b) coefficient estimates by years for the family of regressions for estimating future height of the tallest stand element (metric units)[1/] for blue oak in Monterey and San Luis Obispo counties.

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
20	−0.379	0.605	−0.433	0.632	−0.478	0.657	−0.515	0.680	−0.544	0.702	−0.567	0.722	−0.583	0.742	−0.594	0.760	−0.600	0.777	−0.601	0.793
30	−0.598	0.809	−0.592	0.823	−0.581	0.837	−0.567	0.850	−0.550	0.863	−0.531	0.875	−0.508	0.886	−0.483	0.897	−0.456	0.907	−0.427	0.917
40	−0.396	0.926	−0.362	0.935	−0.328	0.944	−0.291	0.952	−0.253	0.960	−0.214	0.967	−0.174	0.974	−0.132	0.981	−0.089	0.988	−0.045	0.994
50	−0.000	1.000	0.046	1.006	0.093	1.011	0.140	1.017	0.188	1.022	0.237	1.026	0.287	1.031	0.337	1.036	0.388	1.040	0.439	1.044
60	0.491	1.048	0.543	1.052	0.596	1.056	0.649	1.059	0.702	1.062	0.756	1.066	0.810	1.069	0.865	1.072	0.919	1.075	0.974	1.078
70	1.029	1.080	1.084	1.083	1.140	1.085	1.195	1.088	1.251	1.090	1.307	1.092	1.363	1.094	1.419	1.096	1.475	1.098	1.531	1.100
80	1.587	1.102	1.644	1.104	1.700	1.106	1.756	1.107	1.813	1.109	1.869	1.110	1.925	1.112	1.981	1.113	2.038	1.115	2.094	1.116
90	2.150	1.117	2.206	1.119	2.263	1.120	2.319	1.121	2.375	1.122	2.430	1.123	2.486	1.124	2.542	1.125	2.598	1.126	2.653	1.127
100	2.709	1.128	2.764	1.129	2.819	1.129	2.875	1.130	2.930	1.131	2.985	1.132	3.039	1.132	3.094	1.133	3.149	1.134	3.203	1.134
110	3.257	1.135																		

[1/] Height at a future date of the tallest element of a young stand may be estimated on land of known site index by selecting "a" and "b" values for the appropriate breast-height age from the table. Substitute "a" and "b" values in the equation (HT − 1.3 meters) = a + b (((SI − 0.40903)/1.01869) − 1.3) for the particular breast-height age desired. For example, to estimate the height of the tallest trees in the stand at breast-height age 75 on land with a known site index of 6.1 meters, solve the equation, (HT − 1.3) = 1.307 + 1.092 (((6.1 − 0.40903)/1.01869) − 1.3), for a total height of 7.3 meters.

Table 20. Intercept (a) and slope (b) coefficient estimates by years for the family of regressions for estimating future height of the tallest stand element (English units)[1/] for blue oak in Monterey and San Luis Obispo counties.

Breast-high age	0		1		2		3		4		5		6		7		8		9	
	Years between decades																			
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
20	-1.245	0.605	-1.422	0.632	-1.569	0.657	-1.689	0.680	-1.785	0.702	-1.859	0.722	-1.914	0.742	-1.950	0.760	-1.969	0.777	-1.973	0.793
30	-1.963	0.809	-1.941	0.823	-1.906	0.837	-1.861	0.850	-1.805	0.863	-1.741	0.875	-1.667	0.886	-1.585	0.897	-1.496	0.907	-1.400	0.917
40	-1.298	0.926	-1.189	0.935	-1.075	0.944	-0.956	0.952	-0.831	0.960	-0.703	0.967	-0.569	0.974	-0.432	0.981	-0.292	0.988	-0.147	0.994
50	-0.000	1.000	0.150	1.006	0.304	1.011	0.460	1.017	0.618	1.022	0.779	1.026	0.941	1.031	1.106	1.036	1.273	1.040	1.441	1.044
60	1.611	1.048	1.783	1.052	1.955	1.056	2.129	1.059	2.305	1.062	2.481	1.066	2.658	1.069	2.837	1.072	3.016	1.075	3.196	1.078
70	3.376	1.080	3.557	1.083	3.739	1.085	3.921	1.088	4.104	1.090	4.287	1.092	4.471	1.094	4.655	1.096	4.839	1.098	5.023	1.100
80	5.208	1.102	5.392	1.104	5.577	1.106	5.762	1.107	5.947	1.109	6.131	1.110	6.316	1.112	6.501	1.113	6.686	1.115	6.870	1.116
90	7.055	1.117	7.239	1.119	7.423	1.120	7.607	1.121	7.790	1.122	7.974	1.123	8.157	1.124	8.340	1.125	8.523	1.126	8.705	1.127
100	8.887	1.128	9.069	1.129	9.250	1.129	9.431	1.130	9.612	1.131	9.792	1.132	9.972	1.132	10.151	1.133	10.330	1.134	10.509	1.134
110	10.687	1.135																		

1/ Height at a future date of the tallest element of a young stand may be estimated on land of known site index by selecting "a" and "b" values for the appropriate breast-height age from the table. Substitute "a" and "b" values in the equation (HT - 4.5 feet) = a + b (((SI - 1.34196)/1.01869) - 4.5) for the particular breast-height age desired. For example, to estimate the height of the tallest trees in the stand at breast-height age 75 on land with a known site index of 20 feet, solve the equation, (HT - 4.5) = 4.287 + 1.092 (((20 - 1.34196)/1.01869) - 4.5), for a total height of 23.9 feet.

Table 21. Intercept (a) and slope (b) coefficient estimates by years for the family of regressions for estimating future height of the tallest stand element (metric units)[1/] for coast live oak in Monterey and San Luis Obispo counties.

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
20	1.745	0.400	1.778	0.415	1.798	0.431	1.806	0.448	1.804	0.465	1.791	0.483	1.769	0.501	1.738	0.521	1.699	0.540	1.652	0.560
30	1.599	0.580	1.540	0.601	1.476	0.622	1.408	0.643	1.335	0.665	1.259	0.686	1.179	0.708	1.098	0.729	1.014	0.751	0.929	0.772
40	0.843	0.794	0.756	0.815	0.669	0.837	0.582	0.858	0.496	0.879	0.410	0.900	0.325	0.920	0.241	0.940	0.159	0.961	0.079	0.980
50	-0.000	1.000	-0.077	1.019	-0.151	1.038	-0.223	1.057	-0.293	1.075	-0.360	1.093	-0.425	1.111	-0.487	1.128	-0.546	1.145	-0.602	1.162
60	-0.655	1.178	-0.706	1.194	-0.753	1.210	-0.798	1.225	-0.839	1.240	-0.878	1.254	-0.914	1.269	-0.946	1.283	-0.976	1.296	-1.003	1.309
70	-1.027	1.322	-1.048	1.335	-1.067	1.347	-1.082	1.359	-1.095	1.370	-1.105	1.382	-1.113	1.393	-1.118	1.403	-1.120	1.414	-1.120	1.424
80	-1.118	1.434	-1.113	1.443	-1.106	1.452	-1.096	1.461	-1.085	1.470	-1.071	1.479	-1.055	1.487	-1.037	1.495	-1.017	1.503	-0.995	1.510
90	-0.971	1.517	-0.945	1.524	-0.918	1.531	-0.889	1.538	-0.858	1.544	-0.825	1.551	-0.791	1.557	-0.756	1.563	-0.719	1.568	-0.680	1.574
100	-0.641	1.579																		

[1/] Height at a future date of the tallest element of a young stand may be estimated on land of known site index by selecting "a" and "b" values for the appropriate breast-height age from the table. Substitute "a" and "b" values in the equation (HT - 1.3 meters) = a + b (((SI - 0.40903)/1.01869) - 1.3) for the particular breast-height age desired. For example, to estimate the height of the tallest trees in the stand at breast-height age 75 on land with a known site index of 12.2 meters, solve the equation, (HT - 1.3) = -1.105 + 1.382 (((12.2 - 0.40903)/1.01869) - 1.3), for a total height of 14.4 meters.

Table 22. Intercept (a) and slope (b) coefficient estimates by years for the family of regressions for estimating future height of the tallest stand element (English units)[1] for coast live oak in Monterey and San Luis Obispo counties.

Breast-high age	Years between decades																			
	0		1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
20	5.725	0.400	5.833	0.415	5.899	0.431	5.927	0.448	5.918	0.465	5.876	0.483	5.803	0.501	5.701	0.521	5.573	0.540	5.421	0.560
30	5.247	0.580	5.054	0.601	4.844	0.622	4.618	0.643	4.379	0.665	4.129	0.686	3.869	0.708	3.601	0.729	3.327	0.751	3.048	0.772
40	2.766	0.794	2.481	0.815	2.196	0.837	1.910	0.858	1.626	0.879	1.345	0.900	1.066	0.920	0.792	0.940	0.522	0.961	0.258	0.980
50	-0.000	1.000	-0.251	1.019	-0.496	1.038	-0.733	1.057	-0.961	1.075	-1.182	1.093	-1.393	1.111	-1.596	1.128	-1.790	1.145	-1.975	1.162
60	-2.150	1.178	-2.315	1.194	-2.471	1.210	-2.617	1.225	-2.754	1.240	-2.880	1.254	-2.997	1.269	-3.105	1.283	-3.203	1.296	-3.291	1.309
70	-3.370	1.322	-3.439	1.335	-3.500	1.347	-3.551	1.359	-3.593	1.370	-3.627	1.382	-3.652	1.393	-3.668	1.403	-3.676	1.414	-3.676	1.424
80	-3.667	1.434	-3.651	1.443	-3.628	1.452	-3.596	1.461	-3.558	1.470	-3.513	1.479	-3.460	1.487	-3.401	1.495	-3.335	1.503	-3.263	1.510
90	-3.185	1.517	-3.101	1.524	-3.011	1.531	-2.915	1.538	-2.814	1.544	-2.707	1.551	-2.596	1.557	-2.479	1.563	-2.358	1.568	-2.232	1.574
100	-2.102	1.579																		

[1] Height at a future date of the tallest element of a young stand may be estimated on land of known site index by selecting "a" and "b" values for the appropriate breast-height age from the table. Substitute "a" and "b" values in the equation (HT - 4.5 feet) = a + b (((SI - 1.34196)/1.01869) - 4.5) for the particular breast-height age desired. For example, to estimate the height of the tallest trees in the stand at breast-height age 75 on land with a known site index of 40 feet, solve the equation, (HT - 4.5) = -3.627 + 1.382 (((40 - 1.34196)/1.01869) - 4.5), for a total height of 47.0 feet.

Step 4: Intercept Coefficient Calculation

Obtaining the intercept required substituting mean site index $\overline{SI}$ and $\hat{b}$ into Eq. (31) and rearranging to obtain "a".

$$\hat{HT} - 1.3 = a + \hat{b}\ (\overline{SI} - 1.3) \qquad [34]$$

therefore,

$$\hat{a} = (\hat{HT} - 1.3) - \hat{b}\ (\overline{SI} - 1.3) \qquad [35]$$

where, $\hat{HT} = b_1\ (1 - e^{b_2 AGE})^{b_3}$,

$\hat{b} = -b_0 + b_1(1 - e^{b_2 AGE}) - 50)^{b_3}$, and

$\overline{SI}$ = Mean height at age 50

- 1.3 = corrects for breast-height measurement

The intercept (a) prediction equations for each species are listed below and "a" values are given in Tables 19 and 21 (metric units) and 20 and 22 (English units).

Blue Oak

Metric: $\hat{a} = (30.892152\ (1 - e^{-0.002109AGE})^{0.683229}) - (-74.987061 - 76.139260\ (1- e^{-0.035065AGE})^{0.010520}) (6.41)$ [36]

English: $\hat{a} = (101.351892\ (1 - e^{-0.002109AGE})^{0.683229}) - (-74.987061 - 76.139260\ (1- e^{-0.035065AGE})^{0.010520}) (21.03)$ [37]

Coast Live Oak

Metric: $\hat{a} = (43.129421\ (1 - e^{-0.002969AGE})^{0.676188}) - (0.283428 + 1.454074\ (1 - e^{-0.034702AGE})^{3.646735})\ (11.3)$ [38]

English: $\hat{a} = (141.500295\ (1 - e^{-0.002969AGE})^{0.676188}) - (0.283428 + 1.454074\ (1 - e^{-0.034702AGE})^{3.646735})\ (37.07)$ [39]

Step 5: Height Growth Model

Substituting $\hat{a}$, $\hat{b}$, and $\hat{H}t$ into the basic equation HT - 1.3 = a + b (SI - 1.3) gives the final equation (Eq. 40) used to estimate height as a function of site index and age. The height prediction equations (Eqs. 41 and 43 (metric units) and 42 and 44 (English units)) for each species are given below. The height prediction curves are shown in Figures 14 and 15.

FINAL FORM

$$\hat{HT} - 1.3 = \hat{a} + \hat{b}\ (SI - 1.3) \qquad [40]$$

where, $\hat{HT} - 1.3$ = Total height estimate with 1.3 meter allowance for breast-height measurement,

$$\hat{a} = (b_1(1 - e^{b_2 AGE})^{b_3}) - (b_{0'} + b_{1'}(1 - e^{b_{2'} AGE})^{b_{3'}})\ (\overline{SI} - 1.3)$$

$$\hat{b} = b_{0'} + b_{1'}(1 - e^{b_{2'} AGE})^{b_{3'}}$$

SI - 1.3 = Measured site index (NOTE: Eq. 2 should be applied to correct for bias caused by sinuous growth habit and obtain estimate of total height at the base age)

NOTE: b_1, b_2 and b_3 are coefficients from Equations (16) and (18) (metric units) or (17) and (19) (English units)

b_0', b_1', b_2' and b_3' are coefficients from Equations (32) and (33).

<u>Blue Oak Height Prediction Equation</u>

Metric: $$HT - 1.3 = (30.892152\ (1- e^{(-0.002109AGE)})^{0.683229}) -$$
$$(-74.987061 + 76.13926\ (1- e^{(-0.035065AGE)})^{0.010520})\ (6.41) +$$
$$(-74.987061 + 76.13926\ (1- e^{(-0.035065AGE)})^{0.010520})$$
$$(((SI - 0.40903)/\ 1.01869) - 1.3) \quad [41]$$

English: $$HT - 4.5 = (101.351892\ (1- e^{(-0.002109AGE)})^{0.683229}) -$$
$$(-74.987061 + 76.13926\ (1- e^{(-0.035065AGE)})^{0.010520})\ (21.03) +$$
$$(-74.987061 + 76.13926\ (1- e^{(-0.035065AGE)})^{0.010520})$$
$$(((SI - 1.34196)/\ 1.01869) - 4.5) \quad [42]$$

<u>Coast Live Oak Height Prediction Equation</u>

Metric: $$HT - 1.3 = (43.129421\ (1- e^{(-0.002969AGE)})^{0.676188}) -$$
$$(0.283428 + 1.454074\ (1- e^{(-0.034702AGE)})^{3.646735})\ (21.03) +$$
$$(0.283428 + 1.454074\ (1- e^{(-0.034702AGE)})^{3.646735})$$
$$(((SI - 0.40903)/\ 1.01869) - 1.3) \quad [43]$$

English: $$HT - 4.5 = (141.500295\ (1- e^{(-0.002969AGE)})^{0.676188}) -$$
$$(0.283428 + 1.454074\ (1- e^{(-0.034702AGE)})^{3.646735})\ (37.07) +$$
$$(0.283428 + 1.454074\ (1- e^{(-0.034702AGE)})^{3.646735})$$
$$(((SI - 1.34196)/\ 1.01869) - 4.5) \quad [44]$$

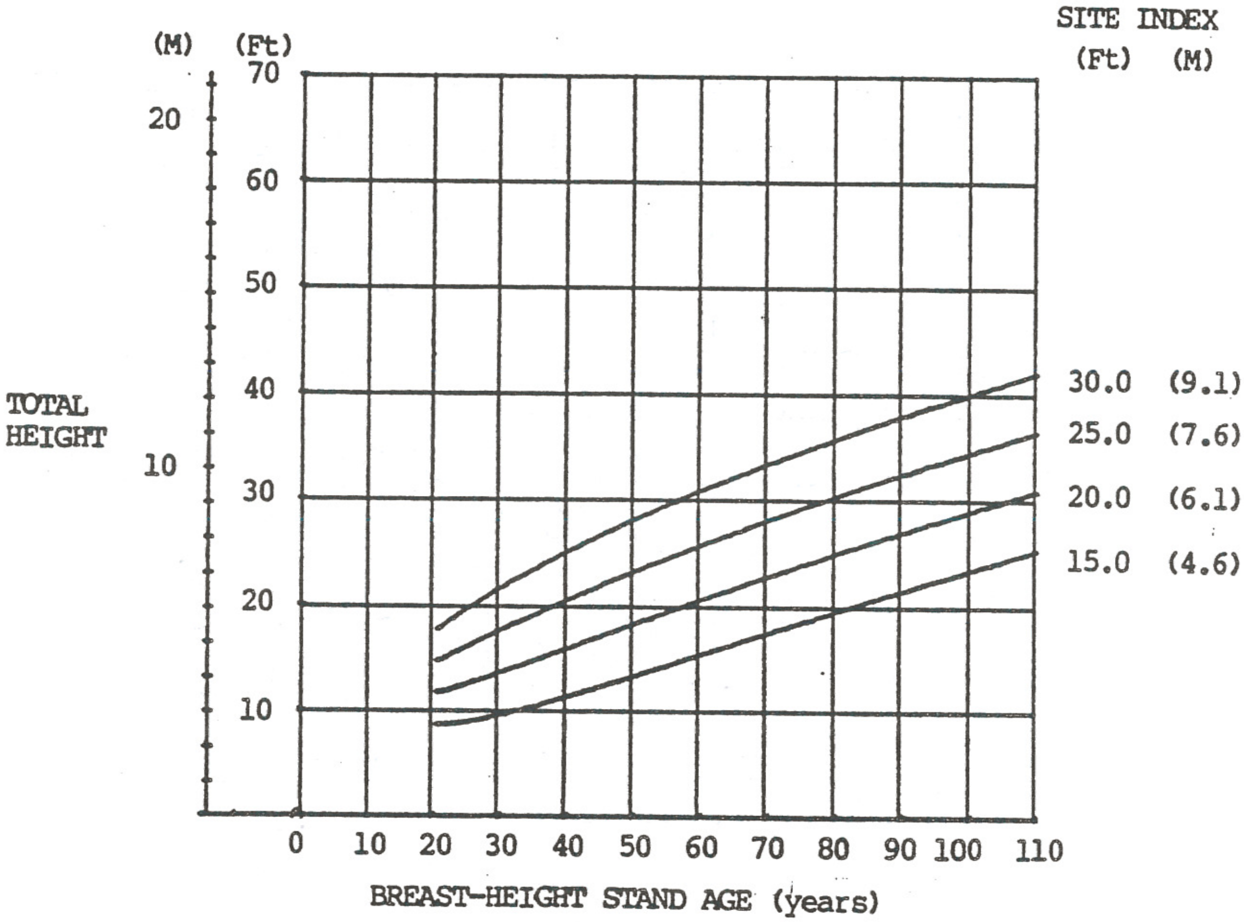


Figure 14. Blue oak height prediction curves based on Equation (41) or Equation (42). Note that the corrections for breast-height measurements (-1.3 meters) have been made. The total length correction to obtain total height (Eq. 5) as it applies to site index has been made as well (Total Height = ((Site Index - 0.40903)/1.01869)).

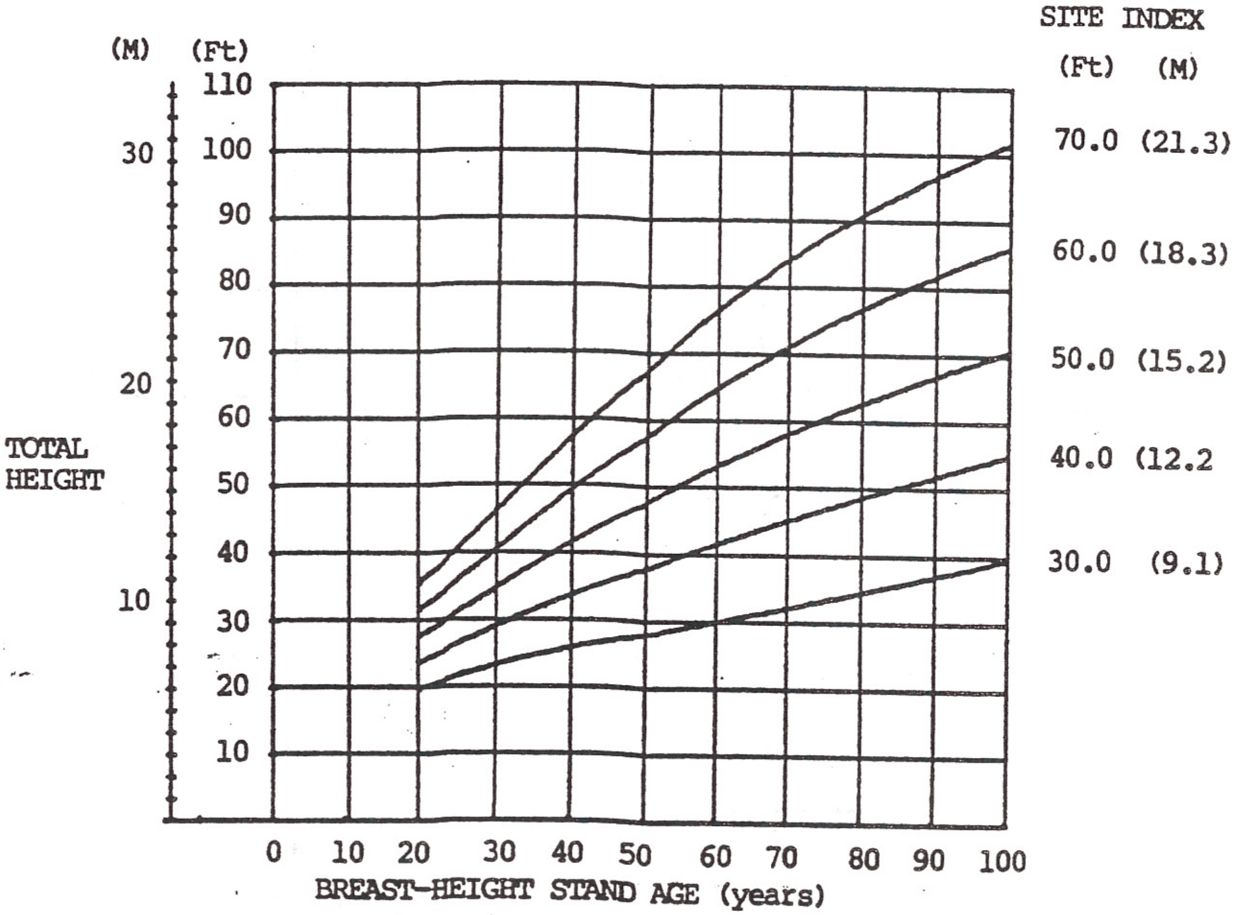


Figure 15. Coast live oak height prediction curves based on Equation (43) or Equation (44). Note that the corrections for breast-height measurements (-1.3 meters) have been made. The total length correction to obtain total height (Eq. 5) as it applies to site index has been made as well (Total Height = ((Site Index - 0.40903)/1.01869)).

In summary, it is important to distinguish between the site index and height prediction equations. They differ both conceptually and in application. The height-age data used to develop the two types of equations is the same and the regression equation form is similar; the difference being that the dependent and independent variables are interchanged. Different dependent variables will lead to different systems of curves, and in application different estimates of site index for a given height and age (Curtis et al., 1974). Application of the site index curves or equations will give an estimate of height at the specified base age of the tallest stand element whose present height and age are known. The height prediction curves will portray the height development pattern of the tallest stand element in stands of known site index.

Application of Height Prediction System

The prediction of height of the tallest stand element at a future date of a stand of known site index to be used in predicting future stand volume using the stand volume equations given in Chapter VIII can be made using one of three methods.

1) Use height prediction curves (Figure 14 for blue oak and Figure 15 for coast live oak.

2) Use the appropriate height prediction intercept (a) and slope (b) coefficient table (Tables 19 (metric) or 21 (English) for blue oak and Tables 20 (metric) or 22 (English) for coast live oak.

   EXAMPLE: The height at age 80 years of the tallest element of a coast live oak stand with a known site index of 14.5 meters can be estimated by selecting the appropriate intercept (a) and slope (b) coefficients. The "a" and "b" values are substitued into the equation (Ht - 1.3) = (a + b ((SI- 0.40903)/ 1.01869) - 1.3).

$$HT - 1.3 = -1.118 + 1.434\ (((15.2 - 0.40903)/\ 1.01869) - 1.3)$$

HT - 1.3 = 17.8, therefore the predicted height at age 80 is 19.1 meters (17.8 + 1.3 = 18.7).

3) If a computer is available the appropriate height prediction equation (Eq. (41) in metric units or Eq. (42) in English units for blue oak or Eq. (43) in metric units or Eq. (44) in English units for coast live oak) may be used. An example of the full height prediction equation for coast live oak is shown below with the same plot data from the example used in option 2 above.

Coast Live Oak Height Prediction Equation

$$HT - 1.3 = (43.129421\ (1- e^{(-0.002969(80))})^{0.676188}) -$$

$$(0.283428 + 1.454074\ (1- e^{(-0.034702(80))})^{3.646735})\ (21.03) +$$

$$(0.283428 + 1.454074\ (1- e^{(-0.034702(80))})^{3.646735})$$

$$(((15.2 - 0.40903)/\ 1.01869) - 1.3)$$

HT - 1.3 = 17.8 meters, therefore the predicted height of the tallest stand element of an 80 year coast live oak stand of site index 15.2 meters is 19.1 meters (17.8 + 1.3 = 19.1).

CHAPTER VII

STAND YIELD INFORMATION

Estimates of stand volume are normally made by inputing measurable characteristics of the forest such as age, site index, and stand density information into a yield prediction equation. These estimates can be used to help make decisions about rotation age (optimum age to harvest), levels of planting density, and timings of management activities such as thinnings (Clutter _et al_, 1983).

Although this study was basically designed to develop site quality information it did allow us to test several models for predicting current yield. Total plot volumes were derived using local volume equations for each species developed from the data set used to develop standard volume equations from a study by Pillsbury and Kirkley (1984). The local volume equations are listed in Appendix A.

Two types of yield equations were developed for predicting current yield: Variable density yield equations and stand volume equations. The two types of equations can be used for predicting total cubic meter volume per hectare or cubic meter volume of trees 10, 20, or 27.5 centimeters (4, 8, and 11 inches) diameter and larger. The various diameter limits are intended to give the woodland manager flexibility in predicting yield for different cutting strategies based on diameter. The total volume equation is self-explanatory. The 27.5 centimeter (11 inch) and larger class was selected to represent approximate sawlog size as defined by Pillsbury and Kirkley (1984). The equations for diameter limits of 10 and 20 centimeters and larger were developed to provide further flexibility between total volume yield and volume yield of trees greater than 27.5 centimeters (11 inches).

Variable Density Yield Prediction Equations

A Schumacher type (1939) yield model was used:

$$\log V_{t,10,20,27.5} = b_0 + b_1 A^{-1} + b_2 SI_{50} + b_3 B_{t,10,20,27.5} + b_4 D_{t,10,20,27.5} \qquad [45]$$

where V_t = total cubic-meter outside bark volume for all trees on a per hectare basis,
A = breast high stand age (years),
SI_{50} = site index in meters, 50 year base,
B_t = basal area per ha for all trees in square meters, and
D_t = quadratic mean breast height diameter for all trees in centimeters, and
Subscripts 10.0 = for all trees 10.0 cm dbh and larger
20.0 = for all trees 20.0 cm dbh and larger
27.5 = for all trees 27.5 cm dbh and larger.

The variable density yield prediction equation coefficients are given in Table 23.

Table 23. Variable density yield equations for blue oak and coast live oak

BLUE OAK:

Volume/ha	Intercept	A^{-1}	SI_{50}	B	D	N	R^2	SE
	coefficients for							
$\log V_t$	1.32234	-9.46312	0.00848	0.02898	0.01632	25	84.9	3.9
$\log V_{10}$	1.38120	-19.87246	0.01198	0.02635	0.01762	25	85.1	4.2
$\log V_{20}$	0.72929	-23.05717	0.00653	0.07736	0.01959	25	81.8	11.8
$\log V_{27.5}$	0.36285	21.23267	0.00721	0.12182	0.00819	21	94.7	6.7

COAST LIVE OAK:

Volume/ha	Intercept	A^{-1}	SI_{50}	B	D	N	R^2	SE
	coefficients for							
$\log V_t$	1.64875	-3.16530	0.00881	0.01384	0.00918	25	94.5	1.6
$\log V_{10}$	1.61713	-1.88326	0.00605	0.01357	0.01066	25	95.9	1.4
$\log V_{20}$	1.44081	-2.20113	0.00314	0.01577	0.01397	25	95.0	2.1
$\log V_{27.5}$	1.32733	0.14962	0.00647	0.01903	0.01157	24	94.6	2.2

EXAMPLE: A stand of blue oak is sampled using a 0.1 ha. plot (about $^1/_5$ ac.) for trees 20 cm dbh or larger. The following data is collected:

a) Tallest stand element = 15.42 meters
b) Three trees are found to average 94 years in age at breast-height
c) Site index = (SI - 1.3) = -0.760 + 0.749 ((0.40903 + 1.01869(15.42)) - 1.3)) = 11.31 meters
d) The basal area for all trees 20 cm dbh and greater is 8.13 m^2/ha.
e) The quadratic mean breast height diameter for all trees 20 cm dbh and greater is 37.38 cm.

$$\log V_{20} = 0.72929 - 23.05717(^1/_{94}) + 0.00653(11.31) + 0.07736(8.13) + 0.01959(37.38) = 1.87$$

$$V_{20} = 83 \text{ m}^3/\text{ha}$$

Stand Volume Equations

A simple method for estimating yield uses basal area and height. Prediction equations of this type are referred to as stand volume equations due to their similarity to individual tree volume equations. They have the advantage of simplicity but in this study at least they do not predict current volume as well. The form of the stand volume equation used is:

$$V_{t,10,20,27.5} = b_o + b_1 B_{t,10,20,27.5} + b_2 TSE \qquad [46]$$

where V_t = per ha, total cubic-meter outside bark volume for all trees

B_t = basal area per ha for all trees in square meters

TSE = tallest stand element (tallest tree in the stand)

Subscripts 10 = for all trees 10 cm dbh and larger

20 = for all trees 20 cm dbh and larger

27.5 = for all trees 27.5 cm dbh and larger

The stand volume equation coefficients are given in Table 24.

Table 24. Stand volume equations for blue oak and coast live oak

BLUE OAK:

	coefficients for					
Volume/ha	Intercept	B	TSE	N	R^2	SE
V_t	-42.64968	4.74306	6.65125	25	78.3	19.4
V_{10}	-37.78794	5.30399	5.65481	25	79.0	19.2
V_{20}	- 1.57824	9.80943	0.55200	25	89.3	14.0
$V_{27.5}$	-11.76694	11.39649	0.58728	21	91.5	11.1

Table 24 (continued). Stand volume equations of blue oak and coast live oak.

COAST LIVE OAK:

Volume/ha	Intercept	B	TSE	N	R^2	SE
	coefficients for					
V_t	-79.53935	8.52746	5.31880	25	81.2	44.2
V_{10}	-81.02842	8.80409	4.98024	25	83.6	41.5
V_{20}	-47.47839	9.76065	2.17336	25	94.2	27.1
$V_{27.5}$	-17.0360	10.19337	0.62411	24	95.3	22.9

Prediction of present yield using a stand volume equation is illustrated below for blue oak:

Example: A 0.1 ha (about $^1/_5$ ac.) plot is established in a stand of blue oak and sampled for trees 20 cm dbh and larger. The following information is obtained:

a) Tallest stand element = 15.42 meters
b) The basal area for trees 20 cm dbh and larger is 8.13 m^2/ha.

$$V_{20} = -1.57824 + 9.80943\ (8.13) + 0.55200\ (15.42)$$

$$V_{20} = 87\ m^3/ha$$

The variable density yield and the stand volume yield equations developed in this study will give reasonable estimates of present yield provided they are used with data that is within the range of the study data listed in Table 5. The variable density yield models could be used for future yield prediction with the development of a average stand diameter and basal area prediction models.

CHAPTER IX

SUMMARY AND DISCUSSION

SUMMARY

Site index, height, and current yield prediction equations were developed for blue oak and coast live oak in Monterey and San Luis Obispo counties. In addition, stand structure data is summarized for the average stand sampled in the study. Also during the course of the study additional information on diameter growth, early height growth, and stand regeneration was collected. This information along with the site index and yield prediction equations will help woodland managers to more effectively assess and manage blue oak and coast live oak woodlands.

The site index prediction system for each species can be used to determine the potential productivity of the site. The landowner can use this information to calculate the productivity level of his land and make appropriate management decisions. Estimates of site index can be obtained when a measure of average breast-height stand age and total height of the tallest stand element among the dominant trees is measured.

Breast-height stand age can be difficult to determine for both species. For coast live oak, accurate age determination requires cutting several dominant trees to determine average stand age. Destructive sampling to determine age may not be desirable because dominant trees are often the crop trees. Cutting blue oak is not needed to determine age because an estimate of age can be determined using an increment borer and dissecting scope.

For stands of known site index, the future total height of the tallest stand element may be determined using the height prediction system for either species. Prediction of future heights can be used with the variable-density yield models to calculate future yield.

The variable density yield equations and stand volume yield equations presented in Chapter VIII can be used to estimate current stand yield. Breast-height stand age is the principle independent variable in the variable density yield prediction equations, and as discussed earlier may be difficult to determine without cutting a few trees. If models were developed to predict future basal area and average stand diameter, short-term predictions (10-20 years) of future yield could be made using the variable-density yield equations.

NEED FOR ADDITIONAL STUDY

Field data collection and data analysis uncovered other valuable insights into the ecology and growth of blue oak and coast live oak woodlands. They are briefly mentioned here and need additional study before definite conclusions can be reached.

Blue oak regeneration is a recognized problem with few stands being less than 60 years old (State Board of Forestry, California Hardwood Task Force, 1983). It appears that the regeneration problem lies in the inability of blue oak seedlings to survive and become a full-sized tree. There have been many reasons postulated for the regeneration problem and the resultant age gap, and it appears that greater levels of protection are needed. The dominant trees sampled in stands in Monterey and San Luis Obispo counties during the course of this study were all greater than 65 years with the oldest being 130 years old. If the age gap identified here is common throughout California, serious establishment efforts will be needed to maintain the long-term viability of the species. Additional study is needed to determine if the problem is as serious as in other locations in the state as it seems to be in San Luis Obispo and Monterey counties.

Coast live oak sprouts, like sprouts of a number of other coppice species, have the capacity to grow at least a meter per year and may often reach breast-height in the first year. The stump sprouting capacity of coast live oak allows vigorous regrowth, however, there are height growth problems. While stumps often produce an abundance of sprouts, deer and cattle browsing often inhibit height growth. Continual browsing results in a low-spreading shrub-like form. Eventually, the girth of the shrub-like sprout clump becomes so large that access to the inner area of the clump by animals is restricted and a few of the inner sprouts begin to grow unhindered. This process may take several years and may result in unrecoverable height growth. For stands that could be intensively managed on rotations of 50 years or less the growth loss may be considerable. Further study is necessary to develop economical sprout protection methods.

The delayed height growth problems discussed above also occur with blue oak. The early height growth problems that result from animal browsing may present difficulties when using the site index prediction equations. In order to avoid the early height growth problems the site index prediction equations were based on breast-height stand age rather than total age and site index estimates are limited to breast-height stand ages greater than 20 years. This approach significantly reduced the effect of browsing or other damage that would restrict height growth.

The diameter, height, and volume growth of individual trees and stands was not explored in depth, however some information is available. Blue oak growth is much slower than coast live oak. Blue oak diameter growth rates for all sample trees averaged 1.27 centimeters (0.5 inches) per decade through age 20 and then steadily declined to 0.48 centimeter (0.19 inch) by age 110. The breast-height diameter growth rates for all coast live oak sample trees averaged over 1.90 centimeters (0.75 inches) per decade through age fifty and declined to 1.00 centimeter (0.40 inch) at age 110. Coast live oak had early height growth rates of over 1 meter (3.3 feet) per year while blue oak early height growth rates were often less than 0.3 meter (1.0 foot) per year.

Because blue oak growth rates are very slow and its seedling survival capacity is either lacking or ineffective the opportunity for sustained yield management is very limited. Coast live oak, on the other hand, seems to offer realistic potential for sustained yield management. The reproductive ability and growth rate of coast live oak stands indicate that they can be mananged on a sustained yield basis. Because there will be additional cost for sprout protection and intensive management practices, such as thinning, additional investigation is needed to determine if sustained yield management is economical.

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APPENDIX A

LOCAL VOLUME EQUATIONS

LOCAL VOLUME EQUATIONS

Local volume equations were developed for each species to estimate individual tree volume for all trees within the plot, individual tree volumes were summed to obtain plot volume. The coefficients used for each species are given in Table 25 on the next page. The form of the equations is:

$$\text{Total Volume} = b_0 \ (DBH^{b_1}) \ (b_2 \ DBH^{b_3})^{b_4}$$

where Total Volume = volume in cubic meters including bark,

DBH = diameter at breast-height outside bark,

b_0, b_1, and b_4 are regression coefficients obtained in development of standard volume equations, and

b_2 and b_3 are regression coefficients obtained in development of height vs. diameter equations.

Table 25. Local volume equation coefficients used in estimating tree volumes.

Species	Coefficients					Height/ Diameter Equation		Standard Volume Equation	
	b_0	b_1	b_2	b_3	b_4	r^2	n	R^2	n
Blue Oak	0.0000697541	2.33089	1.60384	0.55620	0.46100	0.56	60	0.97	60
Coast live oak	0.0000446992	2.31958	1.82810	0.54427	0.62528	0.58	60	0.97	60
California white oak	0.0000334750	2.33631	1.58873	0.60397	0.74872	0.72	60	0.99	59
California black oak	0.0000870843	1.97437	2.84053	0.47358	0.85034	0.55	61	0.97	59
Tanoak	0.0000763045	1.94165	3.36101	0.49412	0.86562	0.58	60	0.97	60
Pacific Madrone	0.0000821921	1.96628	3.18237	0.50275	0.83458	0.48	60	0.97	60
California laurel	0.0000763133	1.94553	3.06013	0.51314	0.88389	0.53	60	0.97	60
Interior live oak	0.0001238312	2.02989	3.26173	0.36288	0.63257	0.36	57	0.97	58
Big leaf maple	0.0000718042	2.22462	6.62631	0.25922	0.57561	0.17	61	0.94	61
Digger pine*	-4.27672	1.87304	1.54817	0.67364	0.91188	0.60	44	0.98	36
Ponderosa pine*	-4.70848	2.01859	1.81958	0.66041	1.03906	0.60	110	0.97	101
Knobcone pine**									

* Total volume is in common logarithm (logTotal Volume). Equations were developed locally for Cal Poly forest mensuration course.

** The ponderosa pine equation was used to estimate knobcone pine volume.

APPENDIX B

AVERAGE STAND CHARACTERISTICS OF BLUE OAK AND COAST LIVE OAK SAMPLE STANDS

Table 26. Number of stems per hectare (A) and cubic meter volume per hectare (B), by species and diameter class for the average blue oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

	DBH CLASS (cm.)	BO	SPECIES CLO	DP	OTHERS	TOTAL LIVE STEMS	DEAD STEMS	TOTAL STEMS
		total number of stems per hectare						
STEMS<=	5	181.37	7.91	0.00	5.44	194.71	30.15	224.86
12.5 cm.	10	316.29	3.46	0.99	3.46	324.19	15.81	340.01
TOTAL		497.66	11.37	0.99	8.90	518.91	45.96	564.87
	15	214.48	2.47	2.97	0.99	220.91	0.49	221.40
12.6-	20	102.79	4.94	2.97	0.00	110.70	0.49	111.19
27.4 cm.	25	40.52	1.48	0.49	0.00	42.50	0.49	43.00
TOTAL		357.80	8.90	6.42	0.99	374.11	1.48	375.59
	30	14.33	0.99	0.99	0.00	16.31	0.00	16.31
	35	3.95	0.99	0.00	0.00	4.94	0.00	4.94
	40	3.95	0.00	0.49	0.00	4.45	0.49	4.94
	45	1.98	0.00	0.00	0.00	1.98	0.00	1.98
	50	1.48	0.00	0.00	0.00	1.48	0.00	1.48
	55	0.99	0.00	0.00	0.00	0.99	0.00	0.99
	60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
STEMS>=	65	0.99	0.00	0.00	0.00	0.99	0.00	0.99
27.5 cm.	70	0.99	0.00	0.00	0.00	0.99	0.00	0.99
	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	90	0.49	0.00	0.00	0.00	0.49	0.00	0.49
	95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	125	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		29.16	1.98	1.48	0.00	32.62	0.49	33.11
TOTAL		884.62	22.24	8.90	9.88	925.63	47.94	973.57

(B)

	DBH CLASS (cm.)	BO	CLO	SPECIES DP	ILO	TOTAL
		cubic meter volume per hectare				
STEMS<=	5	1.63	0.05	0.00	0.00	1.68
12.5 cm.	10	10.60	0.09	0.03	0.00	10.71
TOTAL		12.23	0.14	0.03	0.00	12.39
STEMS	15	19.87	0.26	0.20	0.00	20.33
12.6-	20	19.85	0.88	0.36	0.00	21.09
27.4 cm.	25	13.79	0.42	0.14	0.00	14.36
TOTAL		53.52	1.56	0.70	0.00	55.77
	30	8.19	0.48	0.36	0.00	9.02
	35	3.28	0.96	0.00	0.00	4.24
	40	4.74	0.00	0.34	0.00	5.08
	45	3.11	0.00	0.00	0.00	3.11
	50	3.19	0.00	0.00	0.00	3.19
	55	2.87	0.00	0.00	0.00	2.87
	60	0.00	0.00	0.00	0.00	0.00
STEMS>=	65	4.49	0.00	0.00	0.00	4.49
27.5 cm.	70	5.14	0.00	0.00	0.00	5.14
	75	0.00	0.00	0.00	0.00	0.00
	80	0.00	0.00	0.00	0.00	0.00
	85	0.00	0.00	0.00	0.00	0.00
	90	4.88	0.00	0.00	0.00	4.88
	95	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00
	125	0.00	0.00	0.00	0.00	0.00
TOTAL		39.89	1.44	0.70	0.00	42.03
TOTAL		105.63	3.13	1.42	0.00	110.19

SPECIES CODE: BO= BLUE OAK, CLO= COAST LIVE OAK, DP= DIGGER PINE
OTHERS INCLUDE INTERIOR LIVE OAK, TOYON, RED BERRY, MOUNTAIN MAHOGONY AND BUCKEYE

Table 27. Number of stems per acre (A) and cubic foot volume per acre (B), by species and diameter class for the average blue oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

	DBH CLASS (in.)	BO	SPECIES CLO	DP	OTHERS	TOTAL LIVE STEMS	DEAD STEMS	TOTAL STEMS
		total number of stems per acre						
STEMS<= 5.0 in.	2	78.40	3.20	0.00	2.60	84.20	12.40	96.60
	4	128.20	1.40	0.40	1.00	131.00	6.20	137.20
TOTAL		206.60	4.60	0.40	3.60	215.20	18.60	233.80
STEMS 5.1- 11.0 in.	6	84.40	1.00	1.40	0.40	87.20	0.20	87.40
	8	40.80	2.20	1.00	0.00	44.00	0.20	44.20
	10	15.00	0.40	0.20	0.00	15.60	0.20	15.80
TOTAL		140.20	3.60	2.60	0.40	146.80	0.60	147.40
STEMS>= 11.1 in.	12	5.60	0.40	0.40	0.00	6.40	0.00	6.40
	14	1.60	0.40	0.00	0.00	2.00	0.00	2.00
	16	1.40	0.00	0.20	0.00	1.60	0.20	1.80
	18	0.60	0.00	0.00	0.00	0.60	0.00	0.60
	20	0.60	0.00	0.00	0.00	0.60	0.00	0.60
	22	0.40	0.00	0.00	0.00	0.40	0.00	0.40
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.40	0.00	0.00	0.00	0.40	0.00	0.40
	28	0.40	0.00	0.00	0.00	0.40	0.00	0.40
	30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	0.20	0.00	0.00	0.00	0.20	0.00	0.20
	38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL		11.20	0.80	0.60	0.00	12.60	0.20	12.80
TOTAL		358.00	9.00	3.60	4.00	374.60	19.40	394.00

(B)

	DBH CLASS (in.)	BO	CLO	SPECIES DP	ILO	TOTAL
		cubic feet volume per acre				
STEMS<= 5.0 in.	2	26.12	0.71	0.00	0.04	26.86
	4	159.63	1.23	0.39	0.00	161.26
TOTAL		185.75	1.94	0.39	0.04	188.13
STEMS 5.1- 11.0 in.	6	287.34	3.68	3.50	0.00	294.52
	8	288.93	14.42	4.41	0.00	307.76
	10	187.55	4.13	2.06	0.00	193.74
TOTAL		763.82	22.23	9.97	0.00	796.02
STEMS>= 11.1 in.	12	117.12	6.89	5.11	0.00	129.12
	14	51.58	13.66	0.00	0.00	65.23
	16	63.33	0.00	4.85	0.00	68.18
	18	34.10	0.00	0.00	0.00	34.10
	20	45.66	0.00	0.00	0.00	45.66
	22	41.04	0.00	0.00	0.00	41.04
	24	0.00	0.00	0.00	0.00	0.00
	26	64.11	0.00	0.00	0.00	64.11
	28	73.47	0.00	0.00	0.00	73.47
	30	0.00	0.00	0.00	0.00	0.00
	32	0.00	0.00	0.00	0.00	0.00
	34	0.00	0.00	0.00	0.00	0.00
	36	69.72	0.00	0.00	0.00	69.72
	38	0.00	0.00	0.00	0.00	0.00
	40	0.00	0.00	0.00	0.00	0.00
	50	0.00	0.00	0.00	0.00	0.00
TOTAL		560.12	20.55	9.96	0.00	590.63
TOTAL		1509.69	44.72	20.32	0.04	1574.77

SPECIES CODE: BO= BLUE OAK, CLO= COAST LIVE OAK, DP= DIGGER PINE
OTHERS INCLUDE INTERIOR LIVE OAK, TOYON, RED BERRY, MOUNTAIN MAHOGONY AND BUCKEYE

Table 28. Cummulative frequency tables for total number of live trees per hectare (A) and total number of live trees per acre (B) by species and diameter class for the average blue oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	BO	CLO	DP	SPECIES TOY	MMGY	RB	BUCK	TOTAL	CUM. (%)
				total number of live trees per hectare					
5	181.37	7.91	0.00	0.99	0.00	0.00	3.95	194.71	21.04
10	497.66	11.37	0.99	0.99	0.49	1.98	4.94	518.91	56.06
15	712.14	13.84	3.95	0.99	0.49	1.98	5.93	739.82	79.93
20	814.93	18.78	6.92	0.99	0.49	1.98	5.93	850.52	91.88
25	855.46	20.26	7.41	0.99	0.49	1.98	5.93	893.02	96.48
30	869.79	21.25	8.40	0.99	0.49	1.98	5.93	909.33	98.24
35	873.74	22.24	8.40	0.99	0.49	1.98	5.93	914.27	98.77
40	877.70	22.24	8.90	0.99	0.49	1.98	5.93	918.72	99.25
45	879.67	22.24	8.90	0.99	0.49	1.98	5.93	920.69	99.47
50	881.16	22.24	8.90	0.99	0.49	1.98	5.93	922.17	99.63
55	882.14	22.24	8.90	0.99	0.49	1.98	5.93	923.16	99.73
60	882.14	22.24	8.90	0.99	0.49	1.98	5.93	923.16	99.73
65	883.13	22.24	8.90	0.99	0.49	1.98	5.93	924.15	99.84
70	884.12	22.24	8.90	0.99	0.49	1.98	5.93	925.14	99.95
75	884.12	22.24	8.90	0.99	0.49	1.98	5.93	925.14	99.95
80	884.12	22.24	8.90	0.99	0.49	1.98	5.93	925.14	99.95
85	884.12	22.24	8.90	0.99	0.49	1.98	5.93	925.14	99.95
90	884.62	22.24	8.90	0.99	0.49	1.98	5.93	925.63	100.00
95	884.62	22.24	8.90	0.99	0.49	1.98	5.93	925.63	100.00
100	884.62	22.24	8.90	0.99	0.49	1.98	5.93	925.63	100.00

(B)

DBH (in.)	BO	CLO	DP	SPECIES TOY	MMGY	RB	BUCK	TOTAL	CUM. (%)
				total number of live trees per acre					
2	78.40	3.20	0.00	0.40	0.00	0.40	1.60	84.20	22.48
4	206.60	4.60	0.40	0.40	0.20	0.80	2.00	215.20	57.45
6	291.00	5.60	1.80	0.40	0.20	0.80	2.40	302.40	80.73
8	331.80	7.80	2.80	0.40	0.20	0.80	2.40	346.40	92.47
10	346.80	8.20	3.00	0.40	0.20	0.80	2.40	362.00	96.64
12	352.40	8.60	3.40	0.40	0.20	0.80	2.40	368.40	98.34
14	354.00	9.00	3.40	0.40	0.20	0.80	2.40	370.40	98.88
16	355.40	9.00	3.60	0.40	0.20	0.80	2.40	372.00	99.31
18	356.00	9.00	3.60	0.40	0.20	0.80	2.40	372.60	99.47
20	356.60	9.00	3.60	0.40	0.20	0.80	2.40	373.20	99.63
22	357.00	9.00	3.60	0.40	0.20	0.80	2.40	373.60	99.73
24	357.00	9.00	3.60	0.40	0.20	0.80	2.40	373.60	99.73
26	357.40	9.00	3.60	0.40	0.20	0.80	2.40	374.00	99.84
28	357.80	9.00	3.60	0.40	0.20	0.80	2.40	374.40	99.95
30	357.80	9.00	3.60	0.40	0.20	0.80	2.40	374.40	99.95
32	357.80	9.00	3.60	0.40	0.20	0.80	2.40	374.40	99.95
34	357.80	9.00	3.60	0.40	0.20	0.80	2.40	374.40	99.95
36	358.00	9.00	3.60	0.40	0.20	0.80	2.40	374.60	100.00
38	358.00	9.00	3.60	0.40	0.20	0.80	2.40	374.60	100.00
40	358.00	9.00	3.60	0.40	0.20	0.80	2.40	374.60	100.00

SPECIES CODE: BO= BLUE OAK, CLO= COAST LIVE OAK, DP= DIGGER PINE, TOY= TOYON, MMGY= MOUNTAIN MAHOGONY, RB= RED BERRY, BUCK= BUCKEYE

Table 29. Cummulative frequency tables for basal area per hectare (A) and basal area per acre (B) by species and diameter class for the average blue oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	BO	CLO	DP	TOY	SPECIES MMGY	RB	BUCK	TOTAL.	CUM.(%)
				square meters per hectare					
5	0.50	0.02	0.00	0.00	0.00	0.00	0.01	0.53	3.29
10	2.96	0.04	0.01	0.00	0.01	0.01	0.01	3.04	18.73
15	6.63	0.09	0.06	0.00	0.01	0.01	0.03	6.84	42.12
20	9.75	0.24	0.15	0.00	0.01	0.01	0.03	10.19	62.76
25	11.66	0.30	0.17	0.00	0.01	0.01	0.03	12.18	75.07
30	12.66	0.37	0.24	0.00	0.01	0.01	0.03	13.32	82.08
35	13.03	0.47	0.24	0.00	0.01	0.01	0.03	13.80	85.02
40	13.52	0.47	0.30	0.00	0.01	0.01	0.03	14.35	88.41
45	13.83	0.47	0.30	0.00	0.01	0.01	0.03	14.65	90.28
50	14.12	0.47	0.30	0.00	0.01	0.01	0.03	14.94	92.07
55	14.36	0.47	0.30	0.00	0.01	0.01	0.03	15.19	93.58
60	14.36	0.47	0.30	0.00	0.01	0.01	0.03	15.19	93.58
65	14.71	0.47	0.30	0.00	0.01	0.01	0.03	15.53	95.70
70	15.09	0.47	0.30	0.00	0.01	0.01	0.03	15.91	98.06
75	15.09	0.47	0.30	0.00	0.01	0.01	0.03	15.91	98.06
80	15.09	0.47	0.30	0.00	0.01	0.01	0.03	15.91	98.06
85	15.09	0.47	0.30	0.00	0.01	0.01	0.03	15.91	98.06
90	15.41	0.47	0.30	0.00	0.01	0.01	0.03	16.23	100.00
95	15.41	0.47	0.30	0.00	0.01	0.01	0.03	16.23	100.00
100	15.41	0.47	0.30	0.00	0.01	0.01	0.03	16.23	100.00

(B)

DBH (in.)	BO	CLO	DP	TOY	SPECIES MMGY	RB	BUCK	TOTAL	CUM.(%)
				square feet per acre					
2	2.43	0.08	0.00	0.02	0.00	0.02	0.03	2.58	3.66
4	13.57	0.18	0.04	0.02	0.03	0.04	0.05	13.93	19.70
6	29.63	0.40	0.32	0.02	0.03	0.04	0.13	30.57	43.24
8	43.33	1.13	0.63	0.02	0.03	0.04	0.13	45.32	64.11
10	51.16	1.32	0.76	0.02	0.03	0.04	0.13	53.46	75.63
12	55.51	1.60	1.05	0.02	0.03	0.04	0.13	58.39	82.59
14	57.25	2.06	1.05	0.02	0.03	0.04	0.13	60.59	85.70
16	59.23	2.06	1.30	0.02	0.03	0.04	0.13	62.81	88.85
18	60.24	2.06	1.30	0.02	0.03	0.04	0.13	63.82	90.28
20	61.50	2.06	1.30	0.02	0.03	0.04	0.13	65.09	92.07
22	62.57	2.06	1.30	0.02	0.03	0.04	0.13	66.15	93.58
24	62.57	2.06	1.30	0.02	0.03	0.04	0.13	66.15	93.58
26	64.07	2.06	1.30	0.02	0.03	0.04	0.13	67.66	95.70
28	65.74	2.06	1.30	0.02	0.03	0.04	0.13	69.33	98.06
30	65.74	2.06	1.30	0.02	0.03	0.04	0.13	69.33	98.06
32	65.74	2.06	1.30	0.02	0.03	0.04	0.13	69.33	98.06
34	65.74	2.06	1.30	0.02	0.03	0.04	0.13	69.33	98.06
36	67.11	2.06	1.30	0.02	0.03	0.04	0.13	70.69	100.00
38	67.11	2.06	1.30	0.02	0.03	0.04	0.13	70.69	100.00
40	67.11	2.06	1.30	0.02	0.03	0.04	0.13	70.69	100.00

SPECIES CODE: BO= BLUE OAK, CLO= COAST LIVE OAK, DP= DIGGER PINE, TOY= TOYON, MMGY= MOUNTAIN MAHOGONY, RB= RED BERRY, BUCK= BUCKEYE

Table 30. Cummulative frequency tables for cubic meter volume per hectare (A) and cubic foot volume per acre (B) by species and diameter class for the average blue oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	BO	CLO	SPECIES DP	ILO	CUM.	TOTAL
			cubic meters per hectare			
5	1.63	0.05	0.00	0.00	1.68	1.53
10	12.23	0.14	0.03	0.00	12.39	11.25
15	32.10	0.39	0.22	0.00	32.72	29.70
20	51.95	1.27	0.58	0.00	53.81	48.83
25	65.74	1.69	0.72	0.00	68.16	61.86
30	73.93	2.17	1.08	0.00	77.19	70.05
35	77.21	3.13	1.08	0.00	81.43	73.90
40	81.95	3.13	1.42	0.00	86.51	78.51
45	85.06	3.13	1.42	0.00	89.62	81.33
50	88.26	3.13	1.42	0.00	92.81	84.23
55	91.13	3.13	1.42	0.00	95.68	86.84
60	91.13	3.13	1.42	0.00	95.68	86.84
65	95.62	3.13	1.42	0.00	100.17	90.91
70	100.76	3.13	1.42	0.00	105.31	95.57
75	100.76	3.13	1.42	0.00	105.31	95.57
80	100.76	3.13	1.42	0.00	105.31	95.57
85	100.76	3.13	1.42	0.00	105.31	95.57
90	105.63	3.13	1.42	0.00	110.19	100.00
95	105.63	3.13	1.42	0.00	110.19	100.00
100	105.63	3.13	1.42	0.00	110.19	100.00

(B)

DBH (in.)	BO	CLO	SPECIES DP	ILO	CUM.	TOTAL
			cubic feet per acre			
2	26.12	0.71	0.00	0.04	26.86	1.71
4	185.75	1.94	0.39	0.04	188.13	11.95
6	473.09	5.62	3.89	0.04	482.64	30.65
8	762.03	20.04	8.30	0.04	790.41	50.19
10	949.57	24.17	10.36	0.04	984.15	62.49
12	1066.69	31.06	15.47	0.04	1113.26	70.69
14	1118.27	44.72	15.47	0.04	1178.50	74.84
16	1181.60	44.72	20.32	0.04	1246.68	79.17
18	1215.70	44.72	20.32	0.04	1280.78	81.33
20	1261.35	44.72	20.32	0.04	1326.43	84.23
22	1302.40	44.72	20.32	0.04	1367.48	86.84
24	1302.40	44.72	20.32	0.04	1367.48	86.84
26	1366.50	44.72	20.32	0.04	1431.59	90.91
28	1439.98	44.72	20.32	0.04	1505.06	95.57
30	1439.98	44.72	20.32	0.04	1505.06	95.57
32	1439.98	44.72	20.32	0.04	1505.06	95.57
34	1439.98	44.72	20.32	0.04	1505.06	95.57
36	1509.69	44.72	20.32	0.04	1574.77	100.00
38	1509.69	44.72	20.32	0.04	1574.77	100.00
40	1509.69	44.72	20.32	0.04	1574.77	100.00

SPECIES CODE: BO= BLUE OAK, CLO= COAST LIVE OAK,
DP= DIGGER PINE, ILO= INTERIOR LIVE OAK

Table 31. Total number of stems per hectare by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

	DBH CLASS (cm.)	CLO	BO	VO	BLKO	SPECIES TO	TOY	BAY	OTHERS	TOTAL LIVE STEMS	DEAD STEMS	TOTAL STEMS
						total number of stems per hectare						
STEMS<= 12.5 cm.	5	51.89	0.49	0.00	0.00	3.95	9.39	0.99	1.98	68.69	32.12	100.82
	10	101.31	1.98	1.48	0.00	0.49	9.88	1.98	1.48	118.61	9.39	128.00
TOTAL		153.20	2.47	1.48	0.00	4.45	19.27	2.97	3.46	187.30	41.51	228.81
STEMS<= 12.6-27.4 cm.	15	117.13	0.99	0.99	0.00	1.48	3.46	0.99	0.49	125.53	7.41	132.94
	20	100.82	0.00	0.49	0.99	0.99	0.99	0.99	0.00	105.26	1.98	107.24
	25	76.11	0.00	0.49	0.00	0.00	0.00	0.00	0.00	76.60	0.49	77.10
TOTAL		294.05	0.99	1.98	0.99	2.47	4.45	1.98	0.49	307.39	9.88	317.28
STEMS>= 27.5 cm.	30	62.27	0.00	0.99	0.00	1.48	0.00	0.49	0.00	65.23	0.00	65.23
	35	53.87	0.00	0.49	0.00	0.99	0.00	0.00	0.00	55.35	0.00	55.35
	40	33.11	0.00	0.00	0.00	0.99	0.00	0.00	0.49	34.59	1.48	36.08
	45	18.78	0.00	0.49	0.99	0.00	0.00	0.00	0.00	20.26	0.49	20.76
	50	13.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.34	0.49	13.84
	55	8.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.40	0.00	8.40
	60	3.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.95	0.00	3.95
	65	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48	0.00	1.48
	70	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48	0.00	1.48
	75	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.99
	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.49	0.00	0.49
TOTAL		197.68	0.00	1.98	0.99	3.46	0.00	0.49	0.99	205.59	2.47	208.06
TOTAL		644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.94	700.28	53.87	754.15

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 32. Total number of stems per acre by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

	DBH CLASS (in.)	CLO	BO	VO	BLKO	SPECIES TO	TOY	BAY	OTHERS	TOTAL LIVE STEMS	DEAD STEMS	TOTAL STEMS
						total number of stems per acre						
STEMS<= 5.0 in.	2	22.80	0.20	0.00	0.00	1.80	3.65	0.40	0.80	29.65	13.40	43.05
	4	41.60	0.80	0.80	0.00	0.00	4.03	0.80	0.60	48.63	3.40	52.03
TOTAL		64.40	1.00	0.80	0.00	1.80	7.68	1.20	1.40	78.28	16.80	95.08
STEMS 5.1-11.0 in.	6	47.00	0.40	0.20	0.00	0.60	1.15	0.40	0.20	49.95	3.00	52.95
	8	41.60	0.00	0.20	0.40	0.40	0.38	0.40	0.00	43.38	0.80	44.18
	10	31.00	0.00	0.20	0.00	0.00	0.00	0.20	0.00	31.40	0.20	31.60
TOTAL		119.60	0.40	0.60	0.40	1.00	1.54	1.00	0.20	124.74	4.00	128.74
STEMS>= 11.1 in.	12	23.80	0.00	0.40	0.00	0.60	0.00	0.00	0.00	24.80	0.00	24.80
	14	22.20	0.00	0.20	0.00	0.40	0.00	0.00	0.00	22.80	0.20	23.00
	16	12.60	0.00	0.00	0.00	0.40	0.00	0.00	0.20	13.20	0.40	13.60
	18	7.40	0.00	0.20	0.40	0.00	0.00	0.00	0.00	8.00	0.20	8.20
	20	4.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.80	0.20	5.00
	22	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	0.00	3.60
	24	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	1.20
	26	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.60
	28	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.60
	30	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.20
	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.20
TOTAL		77.00	0.00	0.80	0.40	1.40	0.00	0.00	0.40	80.00	1.00	81.00
TOTAL		261.00	1.40	2.20	0.80	4.20	9.22	2.20	2.00	283.02	21.80	304.82

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 33. Cubic meter volume per hectare by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

	DBH CLASS (cm.)	CLO	BO	VO	SPECIES BLKO	TO	BAY	OTHERS	TOTAL
		cubic meter volume per hectare							
STEMS<=	5	0.34	0.01	0.00	0.00	0.05	0.02	0.00	0.42
12.5 cm.	10	3.19	0.08	0.05	0.00	0.01	0.11	0.03	3.47
TOTAL		3.53	0.08	0.05	0.00	0.07	0.13	0.03	3.89
STEMS	15	10.47	0.09	0.06	0.00	0.21	0.18	0.04	11.06
12.6-	20	18.86	0.00	0.14	0.25	0.29	0.23	0.00	19.77
27.4 cm.	25	26.15	0.00	0.20	0.00	0.00	0.00	0.00	26.35
TOTAL		55.48	0.09	0.40	0.25	0.51	0.41	0.04	57.18
	30	33.85	0.00	0.65	0.00	1.12	0.28	0.00	35.90
	35	45.15	0.00	0.49	0.00	0.94	0.00	0.00	46.58
	40	38.51	0.00	0.00	0.00	1.26	0.00	0.45	40.22
	45	30.48	0.00	0.98	1.91	0.00	0.00	0.00	33.37
	50	28.33	0.00	0.00	0.00	0.00	0.00	0.00	28.33
	55	23.06	0.00	0.00	0.00	0.00	0.00	0.00	23.06
	60	13.99	0.00	0.00	0.00	0.00	0.00	0.00	13.99
STEMS>=	65	6.37	0.00	0.00	0.00	0.00	0.00	0.00	6.37
27.5 cm.	70	8.09	0.00	0.00	0.00	0.00	0.00	0.00	8.09
	75	6.01	0.00	0.00	0.00	0.00	0.00	0.00	6.01
	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	125	0.00	0.00	0.00	0.00	0.00	0.00	8.37	8.37
TOTAL		233.85	0.00	2.11	1.91	3.31	0.28	8.82	250.29
TOTAL		292.87	0.18	2.56	2.16	3.89	0.82	8.89	311.36

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK, TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 34. Cubic foot volume per acre by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

	DBH CLASS (in.)	CLO	BO	VO	SPECIES BLKO	TO	BAY	OTHERS	TOTAL
					cubic feet volume per acre				
STEMS<= 5.0 in.	2	5.78	0.10	0.00	0.00	0.95	0.26	0.00	7.08
	4	49.30	1.09	1.16	0.00	0.00	1.56	0.40	53.52
TOTAL		55.08	1.19	1.16	0.00	0.95	1.82	0.40	60.60
STEMS 5.1- 11.0 in.	6	154.61	1.33	0.46	0.00	3.03	2.56	0.58	162.57
	8	285.92	0.00	1.95	3.51	4.19	3.34	0.00	298.92
	10	394.90	0.00	2.89	0.00	0.00	4.05	0.00	401.84
TOTAL		835.43	1.33	5.29	3.51	7.22	9.96	0.58	863.33
STEMS>= 11.1 in.	12	475.87	0.00	9.22	0.00	15.99	0.00	0.00	501.08
	14	678.22	0.00	6.98	0.00	13.44	0.00	0.00	698.63
	16	539.14	0.00	0.00	0.00	17.95	0.00	6.49	563.58
	18	442.66	0.00	13.96	27.32	0.00	0.00	0.00	483.95
	20	372.09	0.00	0.00	0.00	0.00	0.00	0.00	372.09
	22	362.80	0.00	0.00	0.00	0.00	0.00	0.00	362.80
	24	159.21	0.00	0.00	0.00	0.00	0.00	0.00	159.21
	26	98.28	0.00	0.00	0.00	0.00	0.00	0.00	98.28
	28	121.72	0.00	0.00	0.00	0.00	0.00	0.00	121.72
	30	45.05	0.00	0.00	0.00	0.00	0.00	0.00	45.05
	32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	50	0.00	0.00	0.00	0.00	0.00	0.00	119.57	119.57
TOTAL		3295.03	0.00	30.16	27.32	47.38	0.00	126.06	3525.96
TOTAL		4185.55	2.52	36.61	30.84	55.54	11.78	127.05	4449.89

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK, TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 35. Cummulative frequency tables for total number of live trees per hectare (A) and total number of live trees per acre (B) by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	SPECIES CLO	BO	VO	BLKO	TO	TOY	BAY	OTHERS	TOTAL	CUM. (%)
	total number of live trees per hectare									
5	51.89	0.49	0.00	0.00	3.95	9.39	0.99	1.98	68.69	9.81
10	153.20	2.47	1.48	0.00	4.45	19.27	2.97	3.46	187.30	26.75
15	270.33	3.46	2.47	0.00	5.93	22.73	3.95	3.95	312.83	44.67
20	371.14	3.46	2.97	0.99	6.92	23.72	4.94	3.95	418.09	59.70
25	447.25	3.46	3.46	0.99	6.92	23.72	4.94	3.95	494.69	70.64
30	509.52	3.46	4.45	0.99	8.40	23.72	5.44	3.95	559.93	79.96
35	563.39	3.46	4.94	0.99	9.39	23.72	5.44	3.95	615.28	87.86
40	596.50	3.46	4.94	0.99	10.38	23.72	5.44	4.45	649.87	92.80
45	615.28	3.46	5.44	1.98	10.38	23.72	5.44	4.45	670.13	95.70
50	628.62	3.46	5.44	1.98	10.38	23.72	5.44	4.45	683.48	97.60
55	637.02	3.46	5.44	1.98	10.38	23.72	5.44	4.45	691.88	98.80
60	640.98	3.46	5.44	1.98	10.38	23.72	5.44	4.45	695.83	99.36
65	642.46	3.46	5.44	1.98	10.38	23.72	5.44	4.45	697.31	99.58
70	643.94	3.46	5.44	1.98	10.38	23.72	5.44	4.45	698.80	99.79
75	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.45	699.79	99.93
80	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.45	699.79	99.93
85	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.45	699.79	99.93
90	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.45	699.79	99.93
95	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.45	699.79	99.93
100	644.93	3.46	5.44	1.98	10.38	23.72	5.44	4.94	700.28	100.00

(B)

DBH (in.)	SPECIES CLO	BO	VO	BLKO	TO	TOY	BAY	OTHERS	TOTAL	CUM. (%)
	total number of live trees per acre									
2	22.80	0.20	0.00	0.00	1.80	3.65	0.40	0.80	29.65	10.48
4	64.40	1.00	0.80	0.00	1.80	7.68	1.20	1.40	78.28	27.66
6	111.40	1.40	1.00	0.00	2.40	8.83	1.60	1.60	128.23	45.31
8	153.00	1.40	1.20	0.40	2.80	9.22	2.00	1.60	171.62	60.64
10	184.00	1.40	1.40	0.40	2.80	9.22	2.20	1.60	203.02	71.73
12	207.80	1.40	1.80	0.40	3.40	9.22	2.20	1.60	227.82	80.50
14	230.00	1.40	2.00	0.40	3.80	9.22	2.20	1.60	250.62	88.55
16	242.60	1.40	2.00	0.40	4.20	9.22	2.20	1.80	263.82	93.22
18	250.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	271.82	96.04
20	254.80	1.40	2.20	0.80	4.20	9.22	2.20	1.80	276.62	97.74
22	258.40	1.40	2.20	0.80	4.20	9.22	2.20	1.80	280.22	99.01
24	259.60	1.40	2.20	0.80	4.20	9.22	2.20	1.80	281.42	99.43
26	260.20	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.02	99.65
28	260.80	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.62	99.86
30	261.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.82	99.93
32	261.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.82	99.93
34	261.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.82	99.93
36	261.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.82	99.93
38	261.00	1.40	2.20	0.80	4.20	9.22	2.20	1.80	282.82	99.93
40	261.00	1.40	2.20	0.80	4.20	9.22	2.20	2.00	283.02	100.00

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK, TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 36. Cummulative frequency tables for basal area per hectare (A) and basal area per acre (B) by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	CLO	BO	VO	BLKO	TO	TOY	BAY	OTHERS	TOTAL	CUM. (%)
					square meters per hectare					
5	0.13	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.17	0.47
10	0.95	0.02	0.01	0.00	0.01	0.09	0.02	0.01	1.12	3.13
15	3.04	0.04	0.03	0.00	0.04	0.15	0.04	0.03	3.35	9.42
20	6.18	0.04	0.05	0.03	0.07	0.17	0.07	0.03	6.64	18.64
25	9.93	0.04	0.07	0.03	0.07	0.17	0.07	0.03	10.41	29.25
30	14.27	0.04	0.14	0.03	0.19	0.17	0.10	0.03	14.96	42.04
35	19.46	0.04	0.19	0.03	0.28	0.17	0.10	0.03	20.30	57.03
40	23.55	0.04	0.19	0.03	0.40	0.17	0.10	0.10	24.58	69.04
45	26.53	0.04	0.27	0.20	0.40	0.17	0.10	0.10	27.80	78.10
50	29.12	0.04	0.27	0.20	0.40	0.17	0.10	0.10	30.39	85.38
55	31.10	0.04	0.27	0.20	0.40	0.17	0.10	0.10	32.37	90.94
60	32.22	0.04	0.27	0.20	0.40	0.17	0.10	0.10	33.50	94.10
65	32.71	0.04	0.27	0.20	0.40	0.17	0.10	0.10	33.99	95.48
70	33.30	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.57	97.12
75	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.99	98.31
80	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.99	98.31
85	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.99	98.31
90	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.99	98.31
95	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.10	34.99	98.31
100	33.72	0.04	0.27	0.20	0.40	0.17	0.10	0.70	35.60	100.00

(B)

DBH (in.)	CLO	BO	VO	BLKO	TO	TOY	BAY	OTHERS	TOTAL	CUM. (%)
					square feet per acre					
2	0.64	0.01	0.00	0.00	0.05	0.09	0.01	0.01	0.82	0.53
4	4.44	0.08	0.09	0.00	0.05	0.42	0.09	0.06	5.23	3.37
6	13.75	0.16	0.12	0.00	0.17	0.63	0.19	0.11	15.13	9.76
8	28.12	0.16	0.20	0.14	0.32	0.76	0.31	0.11	30.12	19.43
10	45.19	0.16	0.31	0.14	0.32	0.76	0.44	0.11	47.43	30.59
12	63.58	0.16	0.63	0.14	0.82	0.76	0.44	0.11	66.63	42.97
14	87.19	0.16	0.84	0.14	1.22	0.76	0.44	0.11	90.85	58.59
16	104.45	0.16	0.84	0.14	1.73	0.76	0.44	0.42	108.93	70.25
18	117.50	0.16	1.19	0.85	1.73	0.76	0.44	0.42	123.03	79.35
20	127.78	0.16	1.19	0.85	1.73	0.76	0.44	0.42	133.32	85.98
22	137.18	0.16	1.19	0.85	1.73	0.76	0.44	0.42	142.72	92.04
24	141.03	0.16	1.19	0.85	1.73	0.76	0.44	0.42	146.57	94.53
26	143.29	0.16	1.19	0.85	1.73	0.76	0.44	0.42	148.83	95.98
28	145.94	0.16	1.19	0.85	1.73	0.76	0.44	0.42	151.48	97.69
30	146.90	0.16	1.19	0.85	1.73	0.76	0.44	0.42	152.43	98.31
32	146.90	0.16	1.19	0.85	1.73	0.76	0.44	0.42	152.43	98.31
34	146.90	0.16	1.19	0.85	1.73	0.76	0.44	0.42	152.43	98.31
36	146.90	0.16	1.19	0.85	1.73	0.76	0.44	0.42	152.43	98.31
38	146.90	0.16	1.19	0.85	1.73	0.76	0.44	0.42	152.43	98.31
40	146.90	0.16	1.19	0.85	1.73	0.76	0.44	3.04	155.05	100.00

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK, TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

Table 37. Cummulative frequency tables for cubic meter volume per hectare (A) and cubic foot volume per acre (B) by species and diameter class for the average coast live oak woodland sampled in Monterey and San Luis Obispo counties, California.

(A)

DBH (cm.)	CLO	BO	VO	SPECIES BLKO	TO	BAY	OTHERS	TOTAL	CUM. (%)
				cubic meters per hectare					
5	0.34	0.01	0.00	0.00	0.05	0.02	0.00	0.42	0.14
10	3.53	0.08	0.05	0.00	0.07	0.13	0.00	3.89	1.25
15	14.01	0.18	0.11	0.00	0.28	0.31	0.04	14.95	4.80
20	32.87	0.18	0.25	0.25	0.57	0.54	0.04	34.72	11.15
25	59.01	0.18	0.45	0.25	0.57	0.54	0.04	61.07	19.61
30	92.87	0.18	1.10	0.25	1.69	0.82	0.04	96.97	31.14
35	138.02	0.18	1.58	0.25	2.63	0.82	0.04	143.55	46.10
40	176.53	0.18	1.58	0.25	3.89	0.82	0.50	183.77	59.02
45	207.01	0.18	2.56	2.16	3.89	0.82	0.50	217.14	69.74
50	235.34	0.18	2.56	2.16	3.89	0.82	0.50	245.47	78.84
55	258.41	0.18	2.56	2.16	3.89	0.82	0.50	268.54	86.25
60	272.39	0.18	2.56	2.16	3.89	0.82	0.50	282.52	90.74
65	278.77	0.18	2.56	2.16	3.89	0.82	0.50	288.90	92.78
70	286.86	0.18	2.56	2.16	3.89	0.82	0.50	296.99	95.38
75	292.87	0.18	2.56	2.16	3.89	0.82	0.50	303.00	97.31
80	292.87	0.18	2.56	2.16	3.89	0.82	0.50	303.00	97.31
85	292.87	0.18	2.56	2.16	3.89	0.82	0.50	303.00	97.31
90	292.87	0.18	2.56	2.16	3.89	0.82	0.50	303.00	97.31
95	292.87	0.18	2.56	2.16	3.89	0.82	0.50	303.00	97.31
100	292.87	0.18	2.56	2.16	3.89	0.82	8.86	311.36	100.00

(B)

DBH (in.)	CLO	BO	VO	SPECIES BLKO	TO	BAY	OTHERS	TOTAL	CUM. (%)
				cubic feet per acre					
2	5.78	0.10	0.00	0.00	0.95	0.26	0.26	7.08	0.16
4	55.08	1.19	1.16	0.00	0.95	1.82	1.82	60.60	1.36
6	209.69	2.52	1.62	0.00	3.97	4.38	4.38	223.17	5.02
8	495.61	2.52	3.57	3.51	8.17	7.73	7.73	522.09	11.73
10	890.51	2.52	6.45	3.51	8.17	11.78	11.78	923.93	20.76
12	1366.38	2.52	15.68	3.51	24.16	11.78	11.78	1425.01	32.02
14	2044.60	2.52	22.65	3.51	37.59	11.78	11.78	2123.64	47.72
16	2583.74	2.52	22.65	3.51	55.54	11.78	11.78	2687.22	60.39
18	3026.40	2.52	36.61	30.84	55.54	11.78	11.78	3171.17	71.26
20	3398.50	2.52	36.61	30.84	55.54	11.78	11.78	3543.27	79.63
22	3761.29	2.52	36.61	30.84	55.54	11.78	11.78	3906.06	87.78
24	3920.50	2.52	36.61	30.84	55.54	11.78	11.78	4065.27	91.36
26	4018.78	2.52	36.61	30.84	55.54	11.78	11.78	4163.55	93.57
28	4140.50	2.52	36.61	30.84	55.54	11.78	11.78	4285.27	96.30
30	4185.55	2.52	36.61	30.84	55.54	11.78	11.78	4330.32	97.31
32	4185.55	2.52	36.61	30.84	55.54	11.78	11.78	4330.32	97.31
34	4185.55	2.52	36.61	30.84	55.54	11.78	11.78	4330.32	97.31
36	4185.55	2.52	36.61	30.84	55.54	11.78	11.78	4330.32	97.31
38	4185.55	2.52	36.61	30.84	55.54	11.78	11.78	4330.32	97.31
40	4185.55	2.52	36.61	30.84	55.54	11.78	131.36	4449.89	100.00

SPECIES CODE: CLO= COAST LIVE OAK, BO= BLUE OAK, VO= VALLEY OAK, BLKO= CALIFORNIA BLACK OAK, TO= TANOAK, TOY= TOYON, BAY= LAUREL, OTHERS INCLUDE RED BERRY, BIG LEAF MAPLE, COFFEE BERRY AND KNOBCONE PINE

APPENDIX C

SIMPLE CORRELATION MATRIX FOR BLUE OAK AND COAST LIVE OAK SAMPLE VARIABLES

Table 38. Simple correlation matrix for blue oak stand variables (n = 25).

	NUMBER OF STEMS	BREAST-HEIGHT STAND AGE	BASAL AREA	AVERAGE STAND DIAMETER	AVERAGE DOMINANT HEIGHT	TOTAL VOLUME	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT
NUMBER OF STEMS	1.0000	−0.5397	0.3504	−0.8316	−0.2507	−0.0844	−0.2208	0.1141	0.3311	0.2268	0.2342
BREAST-HEIGHT STAND AGE		1.0000	−0.2284	0.5005	0.1606	0.0003	0.1826	−0.4067	−0.3399	−0.1995	−0.3499
BASAL AREA			1.0000	−0.0142	0.1909	0.8789	0.1726	0.2939	0.6630	−0.0871	0.1061
AVERAGE STAND DIAMETER				1.0000	0.3078	0.3983	0.2918	−0.0020	0.0207	−0.3603	−0.2707
AVERAGE DOMINANT HEIGHT					1.0000	0.3750	0.9826	0.8117	0.0803	−0.1927	−0.0667
TOTAL VOLUME						1.0000	0.3485	0.3295	0.5245	−0.2084	−0.0032
TALLEST STAND ELEMENT							1.0000	0.8090	0.0976	−0.1768	−0.0718
SITE INDEX (50)								1.0000	0.2836	−0.0711	0.1301
CROWN CLOSURE									1.0000	−0.0821	0.1704
SLOPE										1.0000	0.0050
ASPECT											1.0000

Table 39. Simple correlation matrix for coast live oak stand variables (n = 25).

	NUMBER OF STEMS	BREAST-HEIGHT STAND AGE	BASAL AREA	AVERAGE STAND DIAMETER	AVERAGE DOMINANT HEIGHT	TOTAL VOLUME	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT
NUMBER OF STEMS	1.0000	−0.1855	0.5584	−0.7407	−0.0315	0.1658	−0.0360	0.0664	0.6140	0.0406	0.0200
BREAST-HEIGHT STAND AGE		1.0000	0.3285	0.4667	0.4060	0.4621	0.4133	−0.0230	0.0899	0.0075	−0.0907
BASAL AREA			1.0000	0.0118	0.6203	0.8391	0.6278	0.5339	0.7940	−0.0138	−0.0552
AVERAGE STAND DIAMETER				1.0000	0.5266	0.4073	0.5111	0.3169	−0.1579	0.0217	−0.1197
AVERAGE DOMINANT HEIGHT					1.0000	0.7371	0.9794	0.8765	0.4265	0.2023	−0.1992
TOTAL VOLUME						1.0000	0.7448	0.5867	0.6557	0.0090	−0.0819
TALLEST STAND ELEMENT							1.0000	0.8971	0.4068	0.1884	−0.2002
SITE INDEX (50)								1.0000	0.4013	0.2344	−0.1609
CROWN CLOSURE									1.0000	−0.2605	0.0795
SLOPE										1.0000	−0.3247
ASPECT											1.0000

APPENDIX D

BLUE OAK AND COAST LIVE OAK HEIGHT/AGE DATA

Table 40. Summary of blue oak decadal height-age data by plot in metric units (A) and English units (B).

(A)

PLOT #	DECACAL BREAST-HEIGHT STAND AGE 10	20	30	40	50	60	70	80	90	100	110	120	130
	TOTAL HEIGHT (meters)												
1	3.94	6.24	6.80	8.08	9.44	10.08	11.03	12.27	12.90	13.86	14.90	15.93	0.00
2	5.08	7.38	9.97	10.25	10.81	12.19	12.70	13.56	15.87	16.26	16.67	17.11	17.56
3	6.85	9.94	12.09	14.85	16.36	19.13	22.84	24.39	0.00	0.00	0.00	0.00	0.00
4	6.15	8.67	10.63	12.29	13.34	15.09	16.14	17.45	0.00	0.00	0.00	0.00	0.00
5	5.48	6.02	7.42	8.15	8.78	9.80	10.85	11.70	0.00	0.00	0.00	0.00	0.00
6	3.31	6.80	9.34	10.78	11.75	13.13	14.43	15.66	0.00	0.00	0.00	0.00	0.00
7	6.44	7.30	8.62	10.25	11.05	11.64	12.61	13.69	14.09	14.50	14.90	0.00	0.00
8	4.56	8.62	11.17	12.98	17.20	19.13	21.33	22.75	24.33	25.92	0.00	0.00	0.00
9	5.64	7.41	10.41	11.01	11.46	12.06	13.21	15.21	16.03	16.86	0.00	0.00	0.00
10	7.57	10.08	12.36	13.21	14.88	16.63	17.93	0.00	0.00	0.00	0.00	0.00	0.00
11	7.87	8.95	11.83	14.06	15.05	18.11	20.36	21.48	0.00	0.00	0.00	0.00	0.00
12	3.34	5.74	7.63	8.37	9.13	10.01	10.87	11.68	0.00	0.00	0.00	0.00	0.00
13	4.19	7.15	9.09	10.68	11.94	13.85	15.06	0.00	0.00	0.00	0.00	0.00	0.00
14	5.67	8.49	13.19	15.11	18.25	19.25	21.37	23.78	0.00	0.00	0.00	0.00	0.00
15	6.04	6.83	7.58	8.03	8.48	8.93	10.17	11.60	0.00	0.00	0.00	0.00	0.00
16	6.88	7.97	10.27	11.37	12.34	13.27	14.06	14.76	16.20	17.61	18.96	0.00	0.00
17	5.78	6.81	7.74	9.21	9.61	10.01	10.40	11.08	11.88	13.32	0.00	0.00	0.00
18	4.99	6.82	9.21	10.57	11.39	12.27	13.44	14.49	16.24	18.72	0.00	0.00	0.00
19	5.62	7.75	8.84	10.31	12.12	14.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	2.58	5.70	7.42	8.93	10.11	10.85	11.41	12.04	13.33	14.25	15.12	15.91	16.96
21	6.53	7.98	10.97	13.02	15.50	17.55	18.78	0.00	0.00	0.00	0.00	0.00	0.00
22	6.39	7.92	10.02	12.45	15.50	16.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	6.89	10.06	12.75	14.76	15.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	2.82	5.81	7.86	10.87	13.28	15.19	16.44	17.46	18.49	19.62	20.25	0.00	0.00
25	4.88	7.65	9.55	11.43	12.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(B)

PLOT #	DECACAL BREAST-HEIGHT STAND AGE 10	20	30	40	50	60	70	80	90	100	110	120	130
	TOTAL HEIGHT (feet)												
1	12.93	20.48	22.32	26.51	30.96	33.08	36.19	40.26	42.33	45.48	48.88	52.27	0.00
2	16.68	24.20	32.72	33.62	35.46	39.99	41.68	44.50	52.06	53.36	54.70	56.15	57.60
3	22.48	32.60	39.68	48.74	53.66	62.78	74.94	80.02	0.00	0.00	0.00	0.00	0.00
4	20.18	28.44	34.86	40.34	43.78	49.52	52.94	57.25	0.00	0.00	0.00	0.00	0.00
5	17.99	19.76	24.33	26.73	28.81	32.15	35.61	38.39	0.00	0.00	0.00	0.00	0.00
6	10.86	22.31	30.65	35.36	38.57	43.08	47.35	51.38	0.00	0.00	0.00	0.00	0.00
7	21.12	23.94	28.27	33.62	36.26	38.18	41.38	44.91	46.24	47.57	48.90	0.00	0.00
8	14.97	28.27	36.64	42.60	56.44	62.77	70.00	74.65	79.84	85.03	0.00	0.00	0.00
9	18.49	24.30	34.17	36.13	37.61	39.55	43.34	49.90	52.61	55.32	0.00	0.00	0.00
10	24.83	33.08	40.57	43.34	48.83	54.57	58.84	0.00	0.00	0.00	0.00	0.00	0.00
11	25.81	29.36	38.82	46.12	49.39	59.43	66.80	70.48	0.00	0.00	0.00	0.00	0.00
12	10.94	18.85	25.02	27.46	29.95	32.85	35.66	38.33	0.00	0.00	0.00	0.00	0.00
13	13.74	23.45	29.84	35.04	39.17	45.44	49.43	0.00	0.00	0.00	0.00	0.00	0.00
14	18.59	27.86	43.27	49.57	59.88	63.17	70.10	78.03	0.00	0.00	0.00	0.00	0.00
15	19.82	22.41	24.88	26.36	27.83	29.31	33.37	38.07	0.00	0.00	0.00	0.00	0.00
16	22.59	26.14	33.70	37.29	40.48	43.55	46.14	48.42	53.17	57.77	62.21	0.00	0.00
17	18.97	22.34	25.39	30.23	31.53	32.83	34.13	36.35	38.98	43.71	0.00	0.00	0.00
18	16.37	22.39	30.21	34.69	37.37	40.27	44.10	47.53	53.29	61.43	0.00	0.00	0.00
19	18.45	25.43	29.02	33.84	39.77	46.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	8.46	18.70	24.36	29.29	33.18	35.60	37.44	39.50	43.75	46.77	49.62	52.20	55.65
21	21.41	26.17	35.99	42.73	50.86	57.58	61.62	0.00	0.00	0.00	0.00	0.00	0.00
22	20.97	25.97	32.89	40.85	50.87	55.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	22.59	33.02	41.83	48.44	51.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	9.25	19.07	25.77	35.68	43.59	49.83	53.93	57.27	60.66	64.38	66.45	0.00	0.00
25	16.01	25.10	31.33	37.50	41.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 41. Summary of coast live oak decadal height-age data by plot in metric units (A) and English units (B).

(A)

PLOT #	DECACAL BREAST-HEIGHT STAND AGE 10	20	30	40	50	60	70	80	90	100	110	120	130
	TOTAL HEIGHT (meters)												
1	4.64	5.87	8.01	8.85	10.33	10.86	11.39	12.12	12.87	13.70	14.52	15.18	0.00
2	2.23	3.01	3.51	4.02	4.53	5.04	5.56	6.09	6.74	7.36	7.60	7.85	8.09
3	4.31	5.66	6.53	7.20	8.01	8.95	9.48	10.06	11.50	0.00	0.00	0.00	0.00
4	3.07	4.31	6.15	6.61	7.07	7.52	8.02	8.52	9.03	9.71	0.00	0.00	0.00
5	2.94	4.58	4.95	5.45	6.03	6.61	7.18	8.03	9.27	0.00	0.00	0.00	0.00
6	3.87	5.60	6.81	8.33	9.66	10.60	11.77	12.78	13.70	14.45	15.20	0.00	0.00
7	3.98	5.36	6.69	7.74	8.33	8.91	9.35	9.75	10.16	10.56	10.95	11.35	0.00
8	4.44	5.23	5.96	6.43	6.87	8.04	9.12	9.76	10.40	11.31	12.29	0.00	0.00
9	2.19	3.10	3.61	4.12	4.66	5.42	6.17	6.82	7.48	0.00	0.00	0.00	0.00
10	2.79	5.50	7.69	9.08	10.13	11.04	11.85	12.49	13.05	13.62	0.00	0.00	0.00
11	3.60	5.45	6.97	8.12	9.14	9.84	10.54	11.93	14.32	0.00	0.00	0.00	0.00
12	3.87	5.89	6.92	7.71	8.26	8.81	9.80	10.99	12.05	13.14	0.00	0.00	0.00
13	4.38	6.24	7.79	9.52	10.55	11.28	12.00	12.73	13.45	14.18	0.00	0.00	0.00
14	3.45	4.67	5.46	6.35	7.58	8.27	8.97	10.58	11.50	0.00	0.00	0.00	0.00
15	3.80	6.12	7.23	8.31	9.33	10.27	11.25	12.24	13.54	14.93	0.00	0.00	0.00
16	6.38	7.78	8.84	9.39	9.81	10.23	10.61	10.89	11.17	11.45	11.73	12.01	12.53
17	2.42	3.65	4.71	5.49	6.18	6.64	7.11	7.55	7.82	8.08	8.47	0.00	0.00
18	2.51	3.39	4.07	4.74	5.30	5.86	6.80	7.89	8.96	0.00	0.00	0.00	0.00
19	2.48	3.37	4.45	5.45	6.45	7.45	8.39	9.15	9.48	0.00	0.00	0.00	0.00
20	6.73	7.23	7.77	8.37	8.97	9.72	10.48	0.00	0.00	0.00	0.00	0.00	0.00
21	3.58	4.79	5.94	6.84	7.74	8.75	9.75	10.76	11.84	12.75	13.61	0.00	0.00
22	4.63	6.98	8.31	8.79	9.31	9.89	10.47	10.97	11.46	0.00	0.00	0.00	0.00
23	3.49	4.19	4.80	5.33	5.87	6.53	7.25	7.96	8.68	9.38	10.08	10.77	0.00
24	3.22	4.59	6.08	6.63	7.58	8.13	8.69	9.29	9.94	10.60	11.32	12.04	12.80
25	3.35	4.27	5.43	6.33	6.87	7.41	8.16	9.04	9.75	10.46	11.05	0.00	0.00

(B)

PLOT #	DECACAL BREAST-HEIGHT STAND AGE 10	20	30	40	50	60	70	80	90	100	110	120	130
	TOTAL HEIGHT (feet)												
1	15.23	19.25	26.29	29.03	33.88	35.62	37.36	39.76	42.23	44.95	47.63	49.79	0.00
2	7.31	9.86	11.52	13.19	14.85	16.55	18.24	19.99	22.13	24.14	24.94	25.74	26.55
3	14.15	18.56	21.44	23.63	26.27	29.37	31.11	33.00	37.74	0.00	0.00	0.00	0.00
4	10.08	14.15	20.19	21.69	23.19	24.69	26.33	27.97	29.61	31.87	0.00	0.00	0.00
5	9.65	15.04	16.24	17.89	19.78	21.68	23.57	26.33	30.41	0.00	0.00	0.00	0.00
6	12.68	18.39	22.35	27.32	31.69	34.77	38.63	41.93	44.95	47.41	49.87	0.00	0.00
7	13.06	17.59	21.96	25.39	27.32	29.24	30.68	32.01	33.33	34.65	35.94	37.23	0.00
8	14.55	17.15	19.57	21.10	22.53	26.39	29.93	32.03	34.14	37.12	40.33	0.00	0.00
9	7.19	10.17	11.84	13.51	15.28	17.80	20.24	22.39	24.53	0.00	0.00	0.00	0.00
10	9.14	18.04	25.22	29.78	33.24	36.22	38.87	40.97	42.82	44.67	0.00	0.00	0.00
11	11.81	17.89	22.87	26.66	30.00	32.28	34.57	39.14	46.99	0.00	0.00	0.00	0.00
12	12.69	19.33	22.69	25.30	27.10	28.90	32.14	36.05	39.55	43.12	0.00	0.00	0.00
13	14.38	20.48	25.57	31.24	34.63	37.01	39.39	41.77	44.15	46.52	0.00	0.00	0.00
14	11.33	15.31	17.91	20.83	24.88	27.15	29.42	34.72	37.73	0.00	0.00	0.00	0.00
15	12.45	20.07	23.71	27.25	30.62	33.69	36.91	40.17	44.43	49.00	0.00	0.00	0.00
16	20.95	25.54	29.01	30.81	32.18	33.56	34.80	35.72	36.65	37.57	38.49	39.42	41.10
17	7.94	11.96	15.47	18.02	20.27	21.79	23.32	24.77	25.65	26.52	27.78	0.00	0.00
18	8.24	11.13	13.36	15.55	17.39	19.23	22.31	25.90	29.39	0.00	0.00	0.00	0.00
19	8.15	11.07	14.59	17.89	21.16	24.44	27.53	30.01	31.10	0.00	0.00	0.00	0.00
20	22.07	23.72	25.50	27.47	29.43	31.88	34.38	0.00	0.00	0.00	0.00	0.00	0.00
21	11.73	15.72	19.50	22.46	25.41	28.70	31.99	35.32	38.84	41.82	44.66	0.00	0.00
22	15.17	22.90	27.26	28.85	30.53	32.44	34.36	36.00	37.62	0.00	0.00	0.00	0.00
23	11.44	13.73	15.76	17.50	19.25	21.42	23.78	26.13	28.47	30.78	33.06	35.33	0.00
24	10.56	15.07	19.93	21.77	24.85	26.69	28.52	30.48	32.63	34.79	37.14	39.49	42.00
25	10.98	14.01	17.82	20.78	22.55	24.32	26.77	29.67	32.00	34.33	36.26	0.00	0.00

APPENDIX E

EQUATION CONDITIONING

Conditioning Equation (8)

Equation (8) was used to model the slope ($\hat{b}$) parameter for the blue oak site index prediction equation. The conditioning constraint is that $\hat{b} = 1$ when age = 50.

The general model is:

$$\hat{b} = a + b_1 AGE + \frac{b_2}{AGE - b_3} \qquad [47]$$

With the constraint, $\hat{b} = 1$ when AGE = 50, Equation (47) becomes:

$$1 = a + b_1 50 + \frac{b_2}{50 - b_3} \qquad [48]$$

Equation (48) is then subtracted from Equation (47) to eliminate the intercept coefficient (a), yielding Equation (49):

$$\hat{b} - 1 = b_1 AGE + \frac{b_2}{AGE - b_3} - b_1 50 + \frac{b_2}{50 - b_3} \qquad [49]$$

The 1 is then moved to the other side to obtain Equation (50), the conditioned form of the general model (Eq. 47), which has three coefficients (b_1, $b_2$2, and b_3) to be estimated using non-linear regression:

$$\hat{b} = 1 + b_1 AGE + \frac{b_2}{AGE - b_3} - b_1 50 + \frac{b_2}{50 - b_3} \qquad [50]$$

After fitting Equation (50) the first and the last terms are combined to obtain the intercept (a) in final model.

Conditioning Equation (9)

Equation (15) was used to model average decadal height ($\hat{HT}$). The model was condtioned such that $\hat{HT}$ equaled mean site index at the base age. The model was also constrained so that height was equal to 0 when breast-height age was 0.

The general model is:

$$\hat{HT} = b_1(1-e^{b_2 AGE})^{b_3} \qquad [51]$$

Substituting the constaints into Equation (51) yields,

$$\overline{SI} = b_1(1- e^{b_2 50})^{b_3} \qquad [52]$$

Solving for b_1 gives,

$$b_1 = \frac{\overline{SI}}{(1- e^{b_2 50})^{b_3}} \qquad [53]$$

Equation (53) is substituted into Equation (51) yielding,

$$\hat{HT} = \frac{\overline{SI}}{(1- e^{b_2 50})^{b_3}} (1- e^{b_2 AGE})^{b_3} \qquad [54]$$

Simplifying gives,

$$\hat{HT} = \overline{SI} \left(\frac{1- e^{b_2 AGE}}{1- e^{b_2 50}}\right)^{b_3} \qquad [55]$$

Equation (55) meets the constaints that $\hat{HT}$ equals 0 feet at breast-height age 0 and $\overline{SI}$ at age 50 years. After fitting Equation (55) using non-linear regression the first term and the denominator are multiplied to determine the value of b_1 yielding the average height prediction model.

APPENDIX F

SUMMARY OF BLUE OAK AND COAST LIVE OAK STAND VARIABLES

Table 42. Summary of blue oak stand data by plot in metric units.

PLOT #	STEMS	B.H.STD. AGE	BASAL AREA	AVE.STD. DIAMETER	AVERAGE DOM.HT.	TOTAL VOLUME	AVERAGE VOLUME GROWTH	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT Az.
	#/ha	(years)	sq.m./ha	(cm)	(m)	cu.m/ha	cu.m/ha/yr	(m)	(m)	(%)	(%)	(deg)
1	865	119	24.48	18.98	13.48	175.78	1.48	15.11	8.4	80	25	90
2	494	130	13.89	18.91	12.31	114.73	0.88	13.25	6.8	60	25	360
3	939	88	20.86	16.82	9.85	133.54	1.52	10.45	6.5	95	12	90
4	1791	94	16.89	10.96	8.04	114.13	1.21	9.30	5.4	90	40	270
5	395	81	7.27	15.31	7.58	42.20	0.52	8.15	5.0	50	3	290
6	531	104	17.53	20.50	13.39	180.80	1.74	14.75	8.9	75	25	40
7	1371	115	21.80	14.23	10.18	164.64	1.43	11.15	6.0	100	0	350
8	729	84	17.07	17.27	9.88	130.29	1.55	11.90	7.9	80	15	320
9	309	85	6.35	16.17	6.35	40.57	0.48	7.15	4.1	40	0	360
10	1569	93	22.66	13.56	12.38	134.44	1.45	13.22	8.4	95	35	320
11	507	84	14.14	18.85	12.38	116.72	1.39	12.83	8.7	70	43	286
12	1223	93	17.62	13.54	11.40	101.98	1.10	12.38	7.8	65	30	12
13	1804	96	27.24	13.87	12.59	159.14	1.66	13.89	8.7	95	20	335
14	2422	82	18.21	9.79	9.70	89.64	1.09	10.50	6.9	95	20	50
15	1359	92	20.25	13.77	12.70	123.34	1.34	13.82	8.9	85	25	87
16	383	112	16.66	23.53	11.73	128.03	1.14	13.35	7.5	55	18	140
17	1421	107	17.05	12.36	7.60	90.17	0.84	8.27	4.3	50	35	330
18	1149	89	15.94	13.29	7.68	127.28	1.43	8.85	5.3	50	33	85
19	852	81	7.68	10.71	8.20	35.78	0.44	9.18	5.9	40	32	72
20	1100	67	11.28	11.43	8.63	58.33	0.87	10.25	7.6	35	40	238
21	334	102	15.05	23.97	12.65	135.00	1.32	12.92	7.7	45	52	50
22	605	83	11.49	15.54	9.40	79.15	0.95	11.12	7.3	45	30	292
23	482	119	11.78	17.65	9.35	85.09	0.72	10.70	5.6	50	35	61
24	840	121	17.24	16.16	10.52	103.43	0.85	12.00	6.4	50	30	94
25	865	103	15.29	15.00	9.33	90.53	0.88	10.65	6.1	65	37	8
AVERAGE	974	97	16.23	15.69	10.29	110.19	1.14	11.41	6.9	66	26	185

NOTE: STEMS = TOTAL LIVE + TOTAL DEAD
NOTE: AVERAGE VOLUME GROWTH WAS DETEMINED USING TOTAL VOLUME/ AVERAGE BREAST-HEIGHT STAND AGE

Table 43. Summary of blue oak stand data by plot in English units.

PLOT #	STEMS	B.H.STD. AGE	BASAL AREA	AVE.STD. DIAMETER	AVERAGE DOM.HT.	TOTAL VOLUME	AVERAGE VOLUME GROWTH	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT Az.
	#/ac	(years)	sq.ft/ac	(in)	(ft)	cu.ft/ac	cu.ft/ac/yr	(ft)	(ft)	(%)	(%)	(deg)
1	350	119	106.64	7.47	44.24	2511.87	21.11	49.58	27.4	80	25	90
2	200	130	60.49	7.45	40.39	1639.46	12.61	43.47	22.4	60	25	360
3	380	88	90.88	6.62	32.32	1908.22	21.68	34.29	21.5	95	12	90
4	725	94	73.57	4.31	26.38	1630.96	17.35	30.51	17.8	90	40	270
5	160	81	31.69	6.03	24.87	603.03	7.44	26.74	16.5	50	3	290
6	215	104	76.36	8.07	43.94	2583.57	24.84	48.39	29.2	75	25	40
7	555	115	94.96	5.60	33.40	2352.71	20.46	36.58	19.7	100	0	350
8	295	84	74.35	6.80	32.43	1861.80	22.16	39.04	25.9	80	15	320
9	125	85	27.64	6.37	20.84	579.80	6.82	23.46	13.3	40	0	360
10	635	93	98.71	5.34	40.60	1921.18	20.66	43.37	27.6	95	35	320
11	205	84	61.61	7.42	40.60	1667.97	19.86	42.10	28.4	70	43	286
12	495	93	76.76	5.33	37.40	1457.22	15.67	40.62	25.5	65	30	12
13	730	96	118.66	5.46	41.29	2274.10	23.69	45.57	28.7	95	20	335
14	980	82	79.33	3.85	31.83	1280.95	15.62	34.45	22.6	95	20	50
15	550	92	88.21	5.42	41.67	1762.51	19.16	45.34	29.3	85	25	87
16	155	112	72.58	9.27	38.47	1829.61	16.34	43.80	24.8	55	18	140
17	575	107	74.26	4.87	24.94	1288.58	12.04	27.13	14.2	50	35	330
18	465	89	69.46	5.23	25.18	1818.77	20.44	29.04	17.3	50	33	85
19	345	81	33.46	4.22	26.90	511.24	6.31	30.12	19.2	40	32	72
20	445	67	49.14	4.50	28.30	833.58	12.44	33.63	24.9	35	40	238
21	135	102	65.56	9.44	41.50	1929.10	18.91	42.39	25.3	45	52	50
22	245	83	50.03	6.12	30.84	1131.08	13.63	36.48	24.1	45	30	292
23	195	119	51.32	6.95	30.68	1215.89	10.22	35.11	18.4	50	35	61
24	340	121	75.10	6.36	34.52	1478.07	12.22	39.37	20.9	50	30	94
25	350	103	66.61	5.91	30.60	1293.60	12.56	34.94	19.9	65	37	8
AVERAGE	394	97	70.70	6.18	33.77	1574.60	16.24	37.42	22.6	66	26	185

NOTE: STEMS = TOTAL LIVE + TOTAL DEAD
NOTE: AVERAGE VOLUME GROWTH WAS DETEMINED USING TOTAL VOLUME/ AVERAGE BREAST-HEIGHT STAND AGE

Table 44. Summary of coast live oak stand data by plot in metric units.

PLOT #	STEMS	B.H.STD. AGE	BASAL AREA	AVE.STD. DIAMETER	AVERAGE DOM.HT.	TOTAL VOLUME	AVERAGE VOLUME GROWTH	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT Az.
	#/ha	(years)	sq.m./ha	(cm)	(m)	cu.m/ha	cu.m/ha/yr	(m)	(m)	(%)	(%)	(deg)
1	420	111	21.10	25.29	14.05	180.90	1.63	15.00	11.0	70	30	45
2	432	131	35.98	32.55	16.79	346.33	2.64	17.60	11.8	90	0	0
3	766	73	31.34	22.82	22.63	268.44	3.68	23.30	19.9	65	25	360
4	469	79	42.78	34.06	16.53	428.56	5.42	17.30	14.4	95	40	45
5	1124	72	32.39	19.15	10.08	251.34	3.49	11.00	9.9	100	55	300
6	1161	73	32.97	19.01	13.62	224.45	3.07	14.80	12.9	100	66	300
7	247	105	18.07	30.52	13.79	160.04	1.52	14.70	11.1	50	35	30
8	494	92	33.11	29.21	22.61	289.03	3.14	24.65	18.5	100	30	50
9	581	92	45.68	31.65	14.46	402.84	4.38	16.20	12.6	100	25	30
10	680	68	48.07	30.01	16.77	493.18	7.25	17.80	15.9	100	5	350
11	556	60	38.07	29.53	19.06	363.82	6.06	20.92	19.8	100	28	10
12	1038	79	54.70	25.91	10.93	439.88	5.57	11.60	10.0	100	20	235
13	469	60	33.80	30.27	12.84	308.72	5.15	13.85	13.3	100	12	350
14	692	72	44.07	28.48	20.35	404.06	5.61	21.85	18.8	100	18	358
15	457	73	15.59	20.84	9.14	107.72	1.48	10.60	9.5	48	30	305
16	222	109	22.00	35.49	15.63	216.62	1.99	18.82	13.3	98	15	360
17	297	95	24.51	32.44	10.53	237.51	2.50	12.52	10.0	80	26	2
18	371	91	36.20	35.26	15.24	348.58	3.83	16.49	12.9	100	20	126
19	865	56	41.16	24.62	12.30	323.81	5.78	13.42	13.3	100	40	168
20	507	129	43.25	32.97	15.33	403.84	3.13	16.83	11.5	90	34	352
21	1989	60	45.43	17.05	14.72	330.30	5.50	17.55	16.7	100	45	292
22	1359	57	39.07	19.13	14.49	302.67	5.31	16.41	16.1	100	23	193
23	346	45	33.43	35.08	14.81	341.27	7.58	15.32	16.8	95	45	285
24	605	106	39.91	28.97	17.45	415.48	3.92	20.00	14.2	70	50	38
25	2706	43	37.23	13.24	10.77	194.71	4.53	12.09	13.7	100	27	205
AVERAGE	754	81	35.60	27.34	15.00	311.36	3.83	16.42	13.9	90	30	192

NOTE: STEMS = TOTAL LIVE + TOTAL DEAD
NOTE: AVERAGE VOLUME GROWTH WAS DETEMINED USING TOTAL VOLUME/ AVERAGE BREAST-HEIGHT STAND AGE

Table 45. Summary of coast live oak stand data by plot in English units.

PLOT #	STEMS	B.H.STD. AGE	BASAL AREA	AVE.STD. DIAMETER	AVERAGE DOM.HT.	TOTAL VOLUME	AVERAGE VOLUME GROWTH	TALLEST STAND ELEMENT	SITE INDEX (50)	CROWN CLOSURE	SLOPE	ASPECT Az.
	#/ac	(years)	sq.ft/ac	(in)	(ft)	cu.ft/ac	cu.ft/ac/yr	(ft)	(ft)	(%)	(%)	(deg)
1	170	111	91.89	9.96	46.11	2585.05	23.29	49.22	36.2	70	30	45
2	175	131	156.72	12.81	55.10	4948.98	37.78	57.75	38.9	90	0	0
3	310	73	136.53	8.99	74.25	3836.04	52.55	76.45	65.3	65	25	360
4	190	79	186.34	13.41	54.23	6124.16	77.52	56.76	47.3	95	40	45
5	455	72	141.08	7.54	33.07	3591.59	49.88	36.09	32.3	100	55	300
6	470	73	143.64	7.49	44.68	3207.38	43.94	48.56	42.4	100	66	300
7	100	105	78.72	12.01	45.24	2286.93	21.78	48.23	36.3	50	35	30
8	200	92	144.22	11.50	74.17	4130.23	44.89	80.88	60.6	100	30	50
9	235	92	198.98	12.46	47.45	5756.65	62.57	53.15	41.5	100	25	30
10	275	68	209.40	11.82	55.01	7047.56	103.64	58.40	52.3	100	5	350
11	225	60	165.82	11.62	62.54	5198.93	86.65	68.64	65.1	100	28	10
12	420	79	238.27	10.20	35.88	6285.85	79.57	38.06	32.7	100	20	235
13	190	60	147.22	11.92	42.14	4411.67	73.53	45.44	43.7	100	12	350
14	280	72	191.97	11.21	66.78	5773.97	80.19	71.69	61.8	100	18	358
15	185	73	67.91	8.20	29.99	1539.36	21.09	34.78	31.1	48	30	305
16	90	109	95.83	13.97	51.27	3095.53	28.40	61.75	43.8	98	15	360
17	120	95	106.75	12.77	34.53	3393.98	35.73	41.08	32.8	80	26	2
18	150	91	157.70	13.88	50.01	4981.17	54.74	54.10	42.3	100	20	126
19	350	56	179.30	9.69	40.36	4627.22	82.63	44.03	43.8	100	40	168
20	205	129	188.39	12.98	50.28	5770.85	44.74	55.22	37.9	90	34	352
21	805	60	197.91	6.71	48.29	4719.97	78.67	57.58	54.9	100	45	292
22	550	57	170.19	7.53	47.53	4325.16	75.88	53.84	52.7	100	23	193
23	140	45	145.61	13.81	48.59	4876.80	108.37	50.26	55.3	95	45	285
24	245	106	173.85	11.41	57.25	5937.16	56.01	65.62	46.7	70	50	38
25	1095	43	162.16	5.21	35.33	2782.43	64.71	39.67	44.9	100	27	205
AVERAGE	305	81	155.06	10.76	49.20	4449.39	54.77	53.89	45.7	90	30	192

NOTE: STEMS = TOTAL LIVE + TOTAL DEAD
NOTE: AVERAGE VOLUME GROWTH WAS DETEMINED USING TOTAL VOLUME/ AVERAGE BREAST-HEIGHT STAND AGE