Hardwood Biomass Inventories in California[1]

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Abstract: A base of information about hardwood resources in California has been accumulating as a result of on going studies as well as several which have been completed in the last three or four years. Inventory studies can be classified at three general levels: by measuring individual trees, stands of trees, or extensive forested areas. Those studies relating to tree inventory are often used for volume table development, while the second level of inventory describes stands of trees with interpretation aimed at hardwood management practices. Lastly, large-scale inventories are being conducted to determine the acreage of hardwood forest and woodland resources in selected areas of California. These inventories represent the development of an important data base necessary for management and protection of hardwood forests in California.

The first hardwood inventory in California was not published until 1950. However, in the past three years about 15 studies have either been published or are in progress. This rapid increase in studies largely stems from the increased value and utilization of wood and the decreasing hardwood land base. Even though the price of a cord of wood has quadrupled in the past three years, wood cutting suppliers are providing greater volumes of wood to consumers each year (Pillsbury and Williamson 1980; Department of Forestry 1980). It appears that using wood to supplement home heating is still an important economical and recreational use of wood for many Californians. However, the current high value of wood also encourages many landowners either to harvest their hardwoods as a one-time cash crop or as part of a long-term management plan. Interest in the management of hardwood resources for aesthetics, wildlife, range, wood products, and urban uses was expressed by many people at a recent symposium on the ecology, management, and utilization of California oaks (Plumb 1980). Unfortunately, only a small amount of hardwood management information is available about a resource that has been largely ignored or cleared in favor of competing land uses. Of primary importance is the need for a sound inventory - the data base necessary for developing management guidelines.

A review of existing studies shows that several state and federal resource agencies are becoming more supportive of hardwood resource investigations, but that our total knowledge is rudimentary and inadequate. This report traces the history of hardwood inventory research in California. The following inventory studies can be classified into three general levels: those that measure individual trees, stands of trees, and extensive forested areas.

TREE INVENTORIES

Those studies relating to tree inventory are often designed to create volume tables. Approximately five reports containing volume tables for California hardwood are in progress or have been completed. All existing tables have been developed for specific uses in a local or regional area and generally are not compatible due to different methods of measurement and utilization standards.

Unmanaged stands

Board-foot and cubic-foot volume tables were developed in 1950 by Hornibrook and others for California black oak (*Quercus kelloggii* Newb.). Oregon white oak (*Q. garryana* Dougl.), Pacific madrone (*Arbutus menziesii* Pursh) and tanoak {*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.}. Sample trees were selected along right-of-way clearings in Mendocino, Trinity, Humboldt and Del Norte counties in California and Josephine County in Oregon. The sample did not cover the complete range of each species. The volume of each tree was determined by planimetering measurements that were plotted on Forest Service Tree Measurement forms. Board-foot tables used a log scaling length of 8' and a minimum top diameter inside bark of 10 in. and the log had to contain a straight and sound 2 in x 8 in x 8 ft plank. The cubic-foot tables include all volume inside bark between stump and a 4 in top (inside bark). The form class value, diameter at breast height (d.b.h.), and height need to be determined before using the tables.

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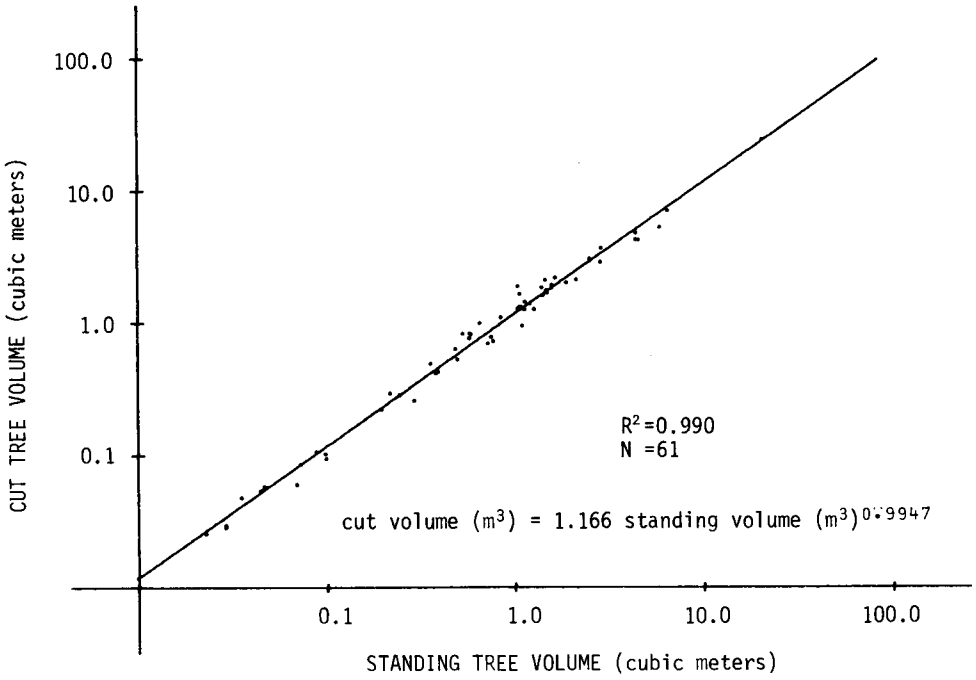

Figure 1. The relationship between tree volumes measured standing and again after being cut for San Luis Obispo, Monterey, San Benito, and Santa Cruz Counties, California.

The next study did not occur until 15 years later when papers by Wiant and Berry (1965), Berry and Wiant (1965) and Berry and Wiant (1967) discussed the development and accuracy of cubic-foot volume and tarif access tables for tanoak in Humboldt County. Cubic foot volumes were calculated from stump height (about 1 foot) to a 4-inch top (diameter inside bark) excluding bark and branches by the Huber formula for section lengths of 10 ft. or less. D.b.h. and total tree height values are necessary to use the tables. The authors found that the greatest accuracy occurred when tree-volume tarif tables were applied to stands of uniform heights.

The species measured in the studies discussed above tend to be less branchy and have fewer major forks than hardwood species growing in the southern half of California. A specialized field measurement technique was developed by Pillsbury and Stephens (1978) to construct volume and weight tables for coast live oak (*Q. agrifolia* Nee), blue oak (*Q. douglasii* Hook. & Arn.), and tanoak in Santa Cruz, San Benito, Monterey and San Luis Obispo counties. Harrington and others (1979) used the technique to develop a gross volume table for California white oak (also called valley oak, *Q. lobata* Nee) in San Luis Obispo and Monterey counties. Tree volume was determined (both outside and inside bark) by an optical dendrometer while the trees were standing, and again after felling, by calipers and tape for a sample of 61 trees. Every tree segment (from ground level to a 10 cm diameter) was measured using Smalians formula. In addition, the length of branch tips (defined as the length from the tip back to a 10 cm diameter) were estimated and volumes were computed using the formula for a cone to obtain total tree volume, excluding foliage. The volume obtained from standing trees correlated well to the volume of the trees that were cut (Figure 1). Thus, further sample tree measurements were only taken on standing trees. Trees that were felled were also cut into firewood-sized pieces and weighed (fresh green weight). Foliage and branches less than 5 an in diameter were not included in the sample (Pillsbury *et al* 1978). Standard volume and weight tables were developed for both English and metric units for each species.

In order to more rapidly inventory local woodlands, tree photo volume and weight tables were developed for Monterey, San Benito and San Luis Obispo counties in 1979 (Pillsbury and Brockhaus) for coast live oak, blue oak and valley oak. Stereo color transparencies at a scale of 1:5,000 were obtained by the U.S. Forest Service for plot sites. Visible crown diameter and total tree height were measured for each sample tree on the photo pair and correlated to sample tree gross volume and fresh green weight obtained from equations developed by Pillsbury and Stephens (1978). An aerial photo cruising example is also included in the report. The authors recommend that a subsample of field plots be obtained to adjust photo volumes to obtain more accurate volume estimates for stands of trees.

Two other volume table studies in California are currently in progress. McDonald (manuscript in preparation) is developing local volume tables for Pacific madrone, tanoak and California black

oak on high site lands in and adjacent to the Challenge Experimental Forest in Yuba County. An optical dendrometer was used to measure sections of standing trees. A computer program written by Grosenbaugh (1967) is being used to reduce field data and express volumes for different species and utilization standards. Cubic- and board-foot volumes (inside bark) will be given for each species to tree top, and to a 4-inch diameter top.

The volume tables discussed so far were developed from sample trees located in local or regional areas. Only seven of the native hardwoods in California have been included in these studies. Existing tables have used different measurement techniques and utilization standards making large scale inventories impractical. The Renewable Resources Evaluation unit, Pacific Northwest Forest and Range Experiment Station is supporting a study at California Polytechnic State University, San Luis Obispo to develop standard volume tables for 13 of the primary hardwoods in California. Species selected for volume table development are: tanoak (*Lithocarpus densiflorus* Hook. & Arn.), coast live oak (*Q. agrifolia* Nee), interior live oak (*Q. wislizenii A.DC.),* blue oak (*Q. douglasii* Hook. & Am.), Engelmann oak (*Q. engelmannii* Greene), canyon live oak (*Q. chrysolepsis* Liekm.), California black oak (*Q. kelloggii* Newb.), California white oak (*Q. lobata* Nee), Oregon white oak *(Q. garryana* Dougl.), Pacific madrone (*Arbutus menziesii* Pursh), California laurel {*Umbellularia californica* (Hook. & Arn.) Nutt}, bigleaf maple (*Acer macrophyllum* pursh), giant chinquapin {*Castanopsis chrysophylla* (Dougl.) A. DC.}.

To develop tables that can have statewide application it is necessary to sample trees throughout much of their natural range and in areas of different site quality, densities, and topography. U.S. Geological Survey 15 minute quadrangle maps were randomly chosen from each region and sample trees were selected from stands located within the map area.

Trees 12.7 cm (5 in) dbh and larger were sampled. Tree segments were measured up to a 10 cm (4 in) top using an optical dendrometer. Smalian's formula was used to compute segment volumes. Branch tips (i.e. the end of a branch having a 10 cm diameter at the large end) were tallied and an average length assigned. Branch tip volumes were computed as a cone.

Three tables for each species are being developed in units of cubic feet and cubic meters: (1) Total tree volume (volume includes all stem and branch wood plus stump and bark; excludes foliage); (2) Wood volume (volume computed from stump height up to a 10 cm top, outside bark; excludes bark); (3) Sawlog volume computed for trees 28 can (11 in) d.b.h. and larger (volume computed from stump height to a 23 cm (9 in) top for straight sections 2.5 m (8 ft) long; excludes bark).

Approximately 60 trees of each species were sampled for a total of 780 trees measured in the State. Multiple regression volume equations will be developed using d.b.h. and total height as independent variables.

Managed Stands

Most California hardwoods are not managed, however the potential for establishing plantations for rapid production of woody biomass for energy is possible in parts of California because a vast amount of land is located in a favorable growing climate. The earliest known plantation volume tables in California were developed by Margolin (1910) for blue gum (*Eucalyptus globulus,* Labill.). Over 1000 of the largest trees from groves in the southern half of California were felled and diameter measurements were taken at intervals of 10 feet along the stem of the tree. Volumes were determined by a graphical solution method for: (a) gross volume in cubic feet including bark from stump height to a 2-inch top (inside bark), (b) board-foot volume for logs having a diameter (inside bark) of 5.5 inches or more, and (c) cubic-foot volume of the parts of a merchantable tree between 5.5 inches and 2.0 inches in diameter inside bark. This is the remaining tree tops not measured in part (b). Tree spacing ranged from 6 ft x 6 ft to 12 ft x 12 ft and included ages between 1 and 40 years.

In 1974, Barrette and Jackman published cubic-foot and board-foot volume tables for blue gum in the Jackson State Forest. The trees were initially planted for windbreak protection in rows with a six foot spacing in a long narrow area consisting of about one acre. In the 75 years since then they have spread over 94 acres. Volume tables were graphically developed by plotting tree data collected from wood scaling operations. Sample tree ages ranged from 24 to 73 years.

In another plantation study, sponsored by the California Department of Forestry, twelve eucalyptus species are being grown for short rotation biomass production at California Polytechnic State University, San Luis Obispo. Volume, weight, and energy (BTU) tables will be developed for *E. camaldulensis* (Dehuh.)*, E. cinera* (F. Muell.), *E. viminalis* (Labill.), *E. polyanthemos* (Schau.) *E. pulverulenta* , *E. globulus* var. *'compacta'*, *E. citriodora* (Hook.), *E. globulus* (Labill.), *E. melliodora* (A. Cunn. ex Schau.), *E. paniculata (&n.), E. sideroxylon* (A. Cunn. ex Woolls), and *E. stellulata* for spacings ranging from 2 ft x 2 ft to 10 ft x 10 ft. The study is one year old and data is to be collected annually for approximately seven years.

STAND DENSITY INVENTORIES

The second level of inventory describes stands of trees. These inventories include stand density, volume, and growth studies for several regions in California.

Stand density characteristics for hardwoods native to San Luis Obispo, Monterey, San Benito, and Santa Cruz are described by Pillsbury (1978). Average per acre values for these counties are presented for gross volume (with and without bark), number of cords, stem surface area, fresh green weight, number of trees, and basal area. Natural stands were divided into three classes by volume and weight density. These density classes are used to indicate where the distribution of the hardwood resources discussed below under "Large Scale Inventories" occur in the Central Coast counties.

In an unpublished thesis, Nguyen (on file at Humboldt State University 1979) presented a preliminary growth and yield model on tanoak for selected sites in northern Humboldt County. Equations were developed to estimate projected cubic-foot volume, basal area growth rate, cubic-foot volume growth, board-foot yield (to a 6-inch top), and projected board-foot volume (to a 6-inch top) on a per acre basis.

Porter and Wiant (1965) published equations predicting site index for tanoak, Pacific madrone, and red alder (*Alnus rubra* Bong.). About 30 dominant trees of each species were felled and sectioned for stem analysis on a wide variety of sites in Humboldt County. Sampling was restricted to stands which approached full stocking. The equations can be used to compute site index at 50 years for any combination of total age and height.

Site index curves were developed in 1972 by Powers for California black oak, sampled in stands located in Shasta, Tehama, Butte, Yuba, Nevada, and Placer counties, California. All sample trees were located in stands of sprout origin and stems were free of forking for the first 18 feet of the bole. Stems were not sectioned for analysis, rather, sample plots associated with ponderosa pine (*Pinus ponderosa* Laws) were stratified into five pine site index classes to obtain homogeneous data sets. Separate equations were developed regressing age versus height for each stratum and the mean site index was determined by solving each equation for height at an index age 50. A procedure for using the site index curves is provided.

Currently, the U.S. Forest Service is supporting a study to obtain information about site and yield for blue oak and coast live oak in San Luis Obispo and Monterey counties. The study, being conducted at California Polytechnic State University, will provide age data, stand increment and growth dynamics, stand composition and structure, site, and general yield data. This information is needed to evaluate cutting levels, to determine rotation age, and to estimate stand growth. It will also help professionals develop stand management prescriptions for native hardwood species on the Central Coast of California.

Managed stand inventory data are also being collected at California Polytechnic State University, on their Silvicultural Biomass Energy Plantation. Average per acre data for twelve eucalyptus species (listed under "Tree Inventories") are being accumulated for stand volume, weight and energy content (BTU's). The growth response for each species is being measured for different densities (ranging from about 400 to 11,000 trees per acre), fertilizer treatments (time release tablets), and weed control techniques. The results will be used to help plan large-scale, eucalyptus plantations that will be intensively cultured and harvested on short rotations on similar climate and soil types in California.

A hardwood thinning study for the Central Coast counties area is currently being planned by the California Department of Forestry.[3] The purpose of the study is to determine growth in moderate to high density blue oak and coast live oak stands on gentle slopes following different thinning treatments. Four treatments are planned for this study: (1) leaving 100 square feet basal area/acre, (2 leaving 50 square feet basal area/acre, (3) removing all trees, (4) no cutting. Ten sites will be evaluated and each site will have four plots, one of each treatment. Growth rates will be monitored for a 10 year period.

McDonald updated the results of a long-term thinning study on the Challenge Experimental Forest in Yuba County, California at a recent oak symposium proceedings (Plumb 1980). Sixty-year-old stands of tanoak, California black oak and Pacific madrone are being studied. Seven plots were thinned from an average stocking of 198 sq ft/acre to basal areas ranging from 85 to 141 sq ft/acre. Average diameter growth doubled after 8 years while average cubic volume growth ranged from 66 to about 89 cu ft/yr. The author considers the results preliminary and any conclusions drawn from them to be speculative.

LARGE SCALE INVENTORIES r

Large scale inventories are being conducted to determine the acreage of hardwood forest and woodland resources for selected counties in California.

The U.S Geological Survey, Land Use/Land cover and Associated Maps Program (formerly called the LUDA Program) has developed a national land use and land cover classification system (Anderson 1976). This system was used to develop broad vegetation cover maps at a scale of 1:250,000 for

[3]Personal communication, 1981, Raymond Jackman, California Department of Forestry, Monterey, Calif.

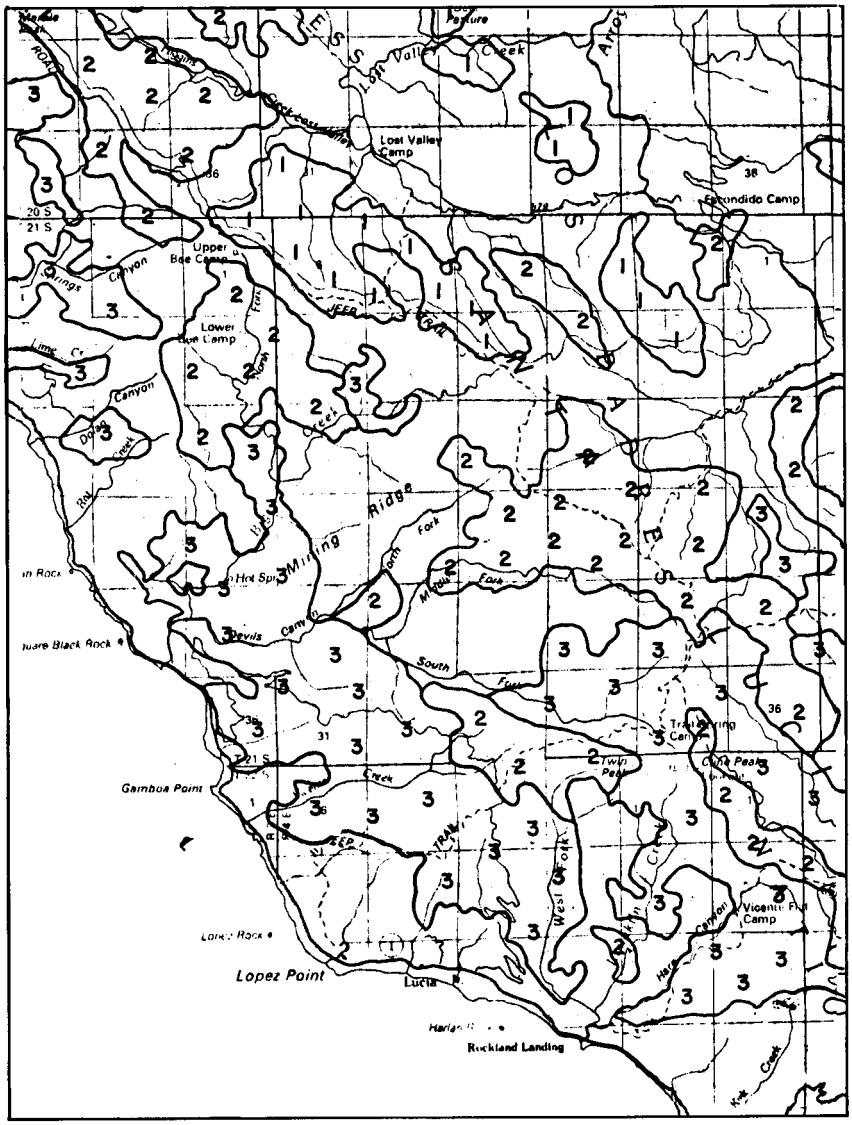

Figure 2. Hardwood fuel inventory map example for Monterey County, California. Symbols refer to stand volume classes (S = scattered trees, 1 = low, 2 = moderate, 3 = high).

California. Forest lands (i.e. lands having a 10% crown cover closure or more) are divided into deciduous, evergreen, and mixed forest lands. Deciduous forest land includes all forested areas having a predominance of trees that lose their leaves at the end of the frost-free season or at the beginning of a dry season. Evergreen forest lands are dominated by trees which remain green throughout the year, while mixed forest lands include both deciduous and evergreen trees neither of which predominates. When more than one-third intermixture of either evergreen or deciduous species occur, it is classified as mixed forest land. Cover type map resolution is 40 acres. U-2 infrared, and black and white quad centered (1:80,000) photography was used for interpretation and data transfer.

Hardwood inventory maps (Pillsbury and Brockhaus 1981) have been completed for San Luis Obispo, Monterey, San Benito and Santa Cruz counties. The USGS land use and cover maps discussed above were used as "base maps" for the inventory project. Deciduous forest lands identified by the USGS were subdivided into hardwood stand density classes discussed in part II, Stand Density Inventories. Density classes 1 (law volume), 2 (moderate volume), 3 (high volume) or S (for scattered woodlands) were mapped on 1:100,000 scale county maps at a resolution of about 10 acres (Figure 2). All USGS land cover boundaries were inspected for accuracy and refined to this resolution when necessary. These maps provide the first estimate of the hardwood volume and weight distribution for any region in California.

The Renewable Resources Evaluation Unit, Pacific Northwest Forest and Range Experiment Station, Portland, Ore. is planning a large scale

hardwood inventory to obtain information necessary for policy decisions.[4] Exact diameter increment will be measured on thousands of trees in existing plots and used to calculate growth. In addition to these plots, several hundred new plots will be established in hardwood forests that were formally classified as "noncommercial". Information on tree species, crown class, crown ratio, defect, and damaging agents will be recorded. Estimates of cubic volume by species will be computed from the plot data using volume equations being developed at California Polytechnic State University, San Luis Obispo. Tree volumes will be expanded to regional and State levels. Periodic remeasurement will provide information on growth mortality, and other trends.

The California Department of Forestry, Forest Resource Assessment Program has sponsored three pilot projects to examine the potential and to develop the methodology of using LANDSAT (LAND SATellite) data for classifying extensive areas of forest resources. The vegetation resources in two counties, Santa Cruz and Humboldt, have been classified. The hardwood signatures developed for Santa Cruz County are discussed.

The classification effort generated 41 resource classes, 13 which represented sites dominated by hardwoods. Figure 3 shows the relative brightness of reflected light for each hardwood class plotted at the four wavelengths where the reflected light was measured. The two basic trends seen for these hardwood signatures reflect the differences between classes heavily vegetated by oaks (*Quercus* spp.) mixed with lesser amounts of brush, and hardwood classes dominated by tanoak and madrone (Pillsbury *et al* 1981). The two trends shown in Figure 3 aid in the separation and identification of these resources. A verification study indicated that the ability of LANDSAT data to correctly classify the resource type is about 85%.

LANDSAT classification systems such as the one discussed above have shown their potential for fast cover type classification for extensive areas at reasonable cost.

HARDWOOD INVENTORY NEEDS

The task of inventorying the hardwood regions defined by Griffin and Critchfield (1972) needs to be completed. They have mapped the range of 86 forest and woodland species at a scale of about 1:5,000,000. A comprehensive inventory

[4]Personal communication, 1981, Charles Bolsinger, Renewable Resources Evaluation Unit, Pacific Northwest Forest and Range Experimental Station, Portland, Ore.

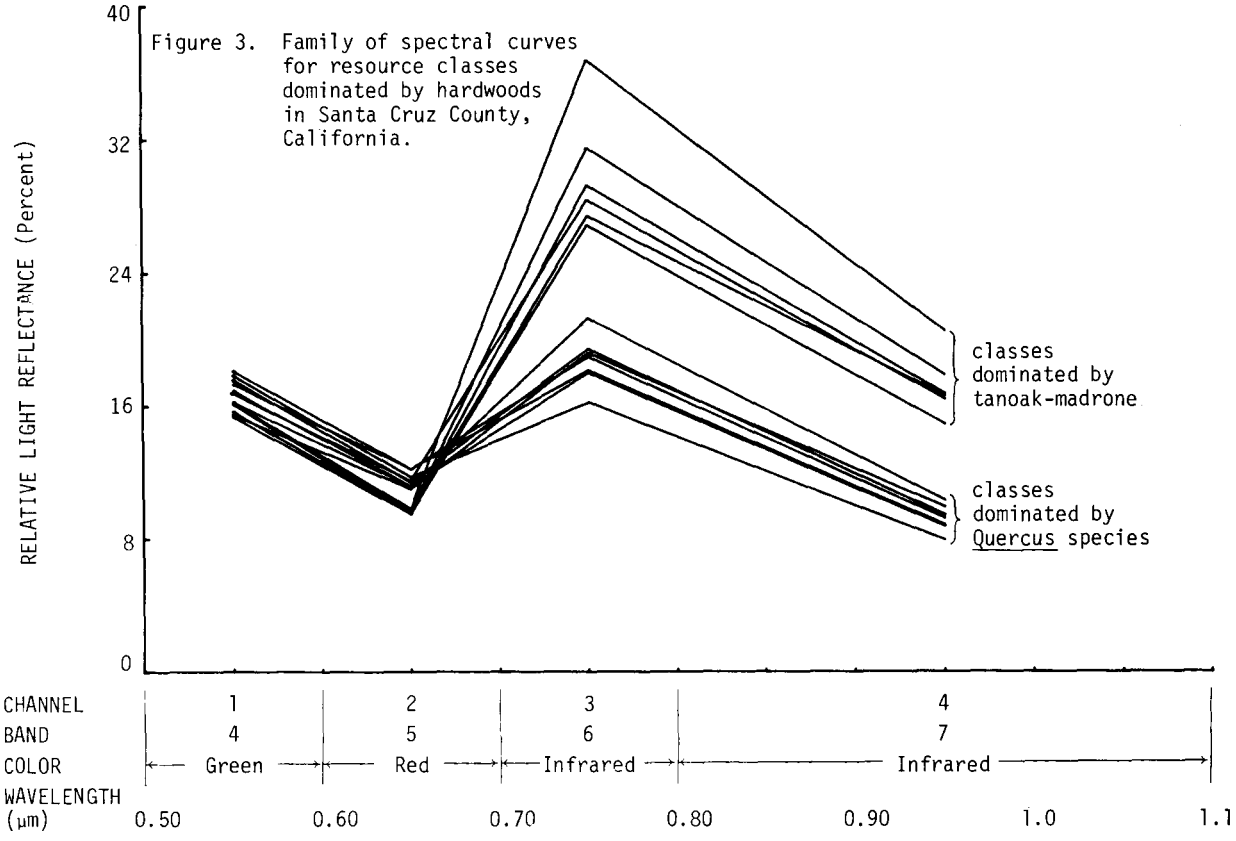

Figure 3. Family of spectral curves for resource classes dominated by hardwoods in Santa Cruz County, California.

that shows the actual location of hardwood forests is needed by land managers for resource planning and management.

Although a number of volume tables have been or are being developed, there are still a large number of important hardwood species that have not been studied in California. Efforts to generate these tables will provide information that is needed in many parts of the State.

The type of inventory that is needed most is one that will provide information useful for stand management. Only a few selected stands in California have been or are currently being measured to provide stand and stocking tables, site, and growth and yield data. Land managers need to have this information in order to make the basic land use decisions, such as, should they convert their hardwood forests and woodlands to another use or should they manage the land for forest values? Currently these decisions are being made without the benefit of adequate stand inventory information.

In addition to the inventory needs discussed here, little is known about California's hardwood forests in the general disciplines of autecology, silviculture, protection, wildlife, range, and recreation impacts. Nonetheless, the inventories discussed here represent the initial development of a data base necessary for developing a management and protection plan for the hardwood forests in California.

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