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Introduction
Since the completion of the first edition of this book much time and effort has been spent developing more accurate and efficient means of mapping vegetation. At the same time a similar amount of energy has been expended on vegetation classification. Vegetation classification was not directly discussed in the first edition (Colwell 1977). However, in current thinking, the two subjects are intimately related. Both will be discussed herein. The development in the 1980s of Geographic Information Systems (GIS) has revolutionized vegetation mapping. Likewise, the development of the personal computer in the past 20 years has revolutionized the ability to analyze large data sets for vegetation classification. Since the writing of the manuscripts for the first edition of this book, the establishment of environmental laws at both state (California Environmental Quality Act, California Endangered Species Act, Natural Communities Conservation Act, etc.) and federal (National Environmental Planning Act, Endangered Species Act, Resources Planning Act, Forest Planning Act, etc.) levels, regulating the conservation and use of natural resources both within the state of California and nationally, has mandated more accurate assessment of vegetation as a measure of ecosystem health and species conservation.

Great advances have been made in both classification and mapping vegetation. Many of the seminal developments in both subjects took place in California. For vegetation mapping, these include the development and production of updates to large-scale maps of forested lands using satellite-based remote sensing techniques headed up by the U.S. Forest

European phytosociological research has continued in California with several useful publications emerging since the early 1990s (Peinado et al. 1994, 1997; Rodríguez-Rojo et al. 2001a, 2001b).

Combination of Mapping and Classification of Vegetation

Today both mapping and classification of vegetation are regularly used in tandem. Since the 1990s, several large California projects have used the approach of first developing a quantitative classification through field sampling and analysis. From such a specific classification and additional field inventory, a mapping classification is derived, which is used to label the map. The value of this approach lies in the action of simultaneously quantifying a field-based classification specific to the area and ground-checking the accuracy of the vegetation map. This type of approach has now been used for mapping many large natural areas of the state including Yosemite (Keeler-Wolf et al. 2002), Sequoia and Kings Canyon (Haultain, Keeler-Wolf and Evens 2004), Joshua Tree (Keeler-Wolf et al. 2005), and Death Valley (Thomas et al. 2004) National Parks, Santa Monica Mountains (Keeler-Wolf and Evens), Whiskytown (Lee 2003), and Golden Gate National Recreation (Keeler-Wolf et al. 2003) areas, as well as large state parks such as Anza-Borrego Desert (Keeler-Wolf, Roye, and Lewis 1998) and other large public lands such as the central Mojave Desert (Thomas et al.), and Point Reyes National Seashore (Keeler-Wolf et al. 2003). Regional planning efforts are also developing maps and classifications in tandem including the multi-species habitat conservation plan for Western Riverside County (Evens et al. 2005), and multijurisdictional monitoring and management such as for Suisun Marsh (Keeler-Wolf et al. 2000, Vaghti and Keeler-Wolf 2004).

MAPPING AND CLASSIFICATION OF VEGETATION TODAY HAS TAKEN ON A MORE QUANTITATIVE APPROACH BECAUSE OF THE IMPORTANCE BOTH HAVE FOR THE REGULATORY ASPECTS OF PLANNING AND CONSERVATION AND THE VALUE QUANTIFICATION HAS IN MONITORING AND CHANGE DETECTION (Thorne et al. 2004, National Park Vegetation Mapping Web site: http://biology.usgs.gov/npsveg/). Defensible definitions of vegetation and vegetation mapping units are needed to substantiate decisions about management and conservation of high-quality natural landscapes, which often run into the many millions of acquisition and management dollars. Because quantitative (defensible) vegetation classification has not been completed throughout the state, the fine-scale mapping of vegetation can only be done following a classification effort.

Purpose of Classification

Mapping and classification of vegetation are in essence very different activities, despite their regular interactive use today. The practical purpose of classifying vegetation is often to develop a means to define differences among vegetation for management activities (Allen and Diaz 1987, Grossman et al. 1998). However, description of vegetation has been a natural offshoot of the activities of humans for many years because vegetation is one of the most obvious and ubiquitous features of the land virtually anywhere on earth (Fosberg in Muller-Dombois and Ellenberg 1974). There are many different classification systems for vegetation because of the many uses we have applied to vegetation. Classifications may be based on life form, on floristic similarity, on water relations of plants, on the marketability of the vegetation (e.g., timberlands vs. rangelands) and even on more specific needs such as physiological criteria (e.g., C3 vs. C4 plants; see Rowlands 1995). The main purpose of classifying vegetation is to catalog the different types and provide a means to differentiate them.

Quantitative Versus Qualitative Classifications

The salient facets of a vegetation classification require description of each unit and a means to differentiate one unit from another. Vegetation units can be either qualitative or quantitative. Both have their advantages. Both may be hierarchical and have progressively more detailed levels nested within coarser levels, a facet very useful for scoping the most appropriate scale of the classification based on needs and objectives. Qualitative vegetation classifications are easy to develop and usually are based on some intuitive life-form approach such as comparing woodlands versus forests, and scrub versus grasslands. This approach appeals to most people because we can all readily understand such strong patterns. However, the more detail we try to draw from such classifications, the more we rely on incomplete existing knowledge to do so, and the less certainty we have.

What kinds of forests or scrublands are there in a given area? Such a question depends on one’s level of interest and one’s level of understanding. Is coastal sage scrub (sensu Mooney 1977) different from chaparral scrub (sensu Hanes 1977)? If we agree that they are, then chamise chaparral...
(Adenostoma fasciculatum) is different from black sage (Salvia mellifera) coastal scrub. However, is a vegetation that is co-dominated by both chamise and black sage a coastal scrub or a chaparral type? These kinds of questions arise regularly in such classification schemes. If we encounter a new scrub that does not meet any descriptions in our qualitative classification, do we ignore it and try to “force” it into an existing category or do we develop a new name for it?

To address such vagaries, the quantitative approach to classification sets certain rules based on usually the percentage of cover or other biomass measure of either species or life forms present in a stand of vegetation. In California where vegetation classification is still a growing, dynamic activity, some of these rules must be general and applied at a coarser level of the classification. We have not quantitatively defined all forests, shrubs, or grasslands in the state, but we can first make rules to differentiate what we consider vegetation characterized by trees, vegetation characterized by shrubs, and vegetation characterized by grasses and herbs. Then we can apply our growing knowledge of more specific vegetation types to this system. This kind of combined top-down and bottom-up classification system is mirrored in the current National Vegetation Classification System (Grossman et al. 1998, ESA Panel 2004). A more pure approach to classification and one advocated by some (Rejmenek 1997, Sanchez-Mata et al. 1998, etc.) is to classify all vegetation from the bottom-up starting with analysis of samples of individual stands, and allow the floristic relationships defining the upper levels of the hierarchy to develop when the information arises. This approach, though scientifically satisfying, is frustrating to managers and conservationists who need to assess and make decisions about vegetation in large and disparate areas of the state today, often well before sound scientific decisions about the stability of the classification hierarchy can be made. Consequently, a hybrid approach has developed, which relies on flexibility at both the top-down and the bottom-up to adjust to new information in this active field of classification. This is the approach advocated by the National Vegetation Classification and followed in the current revision of the California Vegetation Classification (Sawyer and Keeler-Wolf ms).

**Purpose of Mapping**

The purpose of mapping vegetation goes beyond cataloging and identifying all the vegetation types in an area. The purpose of a map is to graphically display the location of the different vegetation types and emphasize their spatial relationships. With the advent of GIS not only can the location of these types be displayed, but also their extent (area), their relationship to other geographic factors (such as soils, roads, geology, elevation, development threats), can also be displayed and analyzed. Mapping vegetation can also serve as a monitoring tool if the map is “refreshed” using the same rules applied to the original product.

**How Mapping and Classification Differ**

Mapping and classification of vegetation are clearly related; however, they are distinctly different exercises. A classification of vegetation may apply to all stands of vegetation, whether small or large. Minute alpine rock crevice and snowmelt communities well under 100 m² can be classified as easily as large stands of desert scrub or grassland over 100 ha. Conversely, a map is a depiction of the “real world” and is limited by scale. Although very detailed vegetation maps have been produced showing the fine-scale patterning of vegetation at the stand level, these usually are limited to very small areas by matters of cost and efficiency. In essence, a map is a “picture” of vegetation taken at a given distance with a given set of parameters that limit its resolution. Even with the graphical flexibility of GIS there are usually cost and accuracy considerations which preclude a 1:1 representation of stands of vegetation on the ground to mapping units. As a result, a map is usually a compromise. The compromise is between what the purpose of the map is (such as showing the location of all types of vegetation as a basis for an environmental planning document) and the effort and feasibility of producing such a product. The larger and more ecologically complex an area is, the more likely it is that this compromise will be substantial.

The recent estimates of producing very detailed maps for National Parks in California range between $5 and $10 per hectare, whereas the cost of making maps of vegetation on large tracts of National Forest lands is an order of magnitude less (Ralph Warbington, personal communication 2004). Such products differ substantially in their resolution, their accuracy, and their ability to depict specific types of vegetation, and thus answer specific questions. Thus, serious planning and needs assessment must take place before a useful map is to be produced.

The mapping units defined from most vegetation maps have other spatial considerations that restrict their ability to depict stands as they exist on the ground. Even large stands easily above the minimum unit size of a map product (the so-called minimum mapping unit or MMU) can be difficult to depict. They can be so physically similar to other stands that there is no reliable means to individuate them, or they can have such indistinct ecotonal boundaries with adjacent stands that a line defining the boundary is only approximate. For reasons of distinctiveness and size, a vegetation mapper may decide to aggregate two or more vegetation classification units that are perfectly distinct on the ground into a “vegetation-mapping unit.” Such mapping units may be an aggregation of two or more very similar types that are not generally considered to be strongly ecologically different, or they may be aggregations of more dissimilar vegetation types such as small riparian forest stands and adjacent wet or dry meadow stands, simply because there is no reliable means to distinguish them given the scale and cost considerations (Table 1.1).
Discussion of Mapping and Classification as Treated in This Chapter

Because of the natural interplay of vegetation classifications and mapping, it is difficult to discuss one without the other. However, in this treatment I will somewhat artificially divide those efforts. One faction that focuses primarily on mapping vegetation with the development of a classification relating primarily to the need of an interpretable legend for the mapping efforts and the other faction that focuses primarily upon classifying vegetation as a natural field-based exercise without direct regard to a map. This following section discusses the mapping-based focus, followed by a second section that focuses primarily on field classification. A third section focuses on the methods that relate to both simultaneously.

Early Mapping Efforts

The early explorers left records describing California’s vegetation in broadest of terms. In the late 1800s, descriptions by Brewer (1966), Kellogg and Greene (1889), and Sudworth (1908) mentioned oak woodlands, grasslands, chaparral, and conifer forests, but these accounts lacked precision. Interestingly, the first real efforts involving vegetation in California revolved around mapping and not on classification.

Beginning in 1887, forest mapping was done on small-scale county maps (1: 506,880 or 1 inch = 8 miles, 1 cm = 5 km)
and covered the more heavily forested portions of the counties in northern California. Later, a system of symbols for commercial conifers and certain hardwood stands was used to indicate dominant species in township maps at a larger scale (1 inch = 1 mile, 1 cm = 0.6 km). Densities of the stands were shown by stippling and shading of a green color on the map (Colwell 1977).

In the early 1900s, many vegetation classification systems in the United States were associated with Clements’ concept of stratifying the world’s vegetation into large-scale climatic zones (Clements 1916, 1920; Weaver and Clements 1938). Cooper (1922) was interested in characterizing California’s communities dominated by plants with relatively stiff thick leaves with a waxy cuticle (the so-called sclerophylls) occurring in its Mediterranean-type climate. Within the two main sclerophyll groups, the California chaparral formation and the Broad sclerophyll forest formation, he made further divisions into units representing distinctive categories. These units he called associations or consociations, if the unit was dominated by a single species. Because it is a useful way of accounting for vegetation without the need to know the identity of the smallest units, Cooper’s approach has been followed and extended over the years. This approach can be naturally extended to mapping and is seen in the system developed by Wieslander in his Vegetation Type Map Survey of California (Wieslander 1935, Critchfield 1971).

The Vegetation Type Map Survey

The work of the U.S. Forest Service beginning in 1928 and continuing until the early 1940s, and collectively called the Vegetation Type Map survey (or VTM survey), remains to this date the most exhaustive and detailed effort of mapping vegetation in the state. Dr. Albert Everett Wieslander was the coordinator of this very large project with far-reaching uses. The initial purpose, not unlike the purpose of today’s mapping and classification, was to provide data to aid in the development of statewide land use and fire protection policies. It was set into motion by the establishment of a nationwide Forest Survey authorized by the McSweeney-McNary Research Act.

The Wieslander mapping effort was a landmark achievement. Between 1928 and 1940 almost half of the state (about 40 million acres, ca 16 million ha) was mapped by USDA Forest Service field crews who combed California using a specific protocol (Fig. 1.1). Because this project was initiated before the widespread availability of aerial photos, the crews worked from the prominent peaks and ridges to gain the perspective needed to draw and label the individual patches of vegetation. The Wieslander survey created a relatively fine-grained snapshot of California’s natural vegetation—an invaluable resource for change analysis and assessment of habitat loss and vegetation dynamics.

Although the original goal of the VTM survey of mapping vegetation embracing 28 million ha in all of California, excluding the desert and agricultural lands, was never reached, much valuable information is available for the areas completed (Fig. 1.1).

In addition to mapping, the VTM survey collected data from approximately 13,000 individual plots, which further characterized and documented this dominance-based system. These data, now over 70 years old, have provided a valuable resource for further studies of the relationships of vegetation in cismontane California. Allen et al. (1990) have taken advantage of the VTM vegetation plots to develop classification systems of California’s oak and other hardwood rangelands. Griffin and Critchfield (1976) used the species identifications of the VTM survey and the succeeding Soil Vegetation Survey maps to develop atlases for forest trees in California. Minnich et al. (1994) showed the effects of 60 years of fire suppression on mixed coniferous forests in southern California by resampling plots established in the 1930s by the VTM crews. Allen, Holtzman, and Evett (1989), and Allen et al. (1991) have resampled blue oak (Quercus douglasii) woodlands originally sampled in the 1930s by the VTM crews. Taylor (2004) has done the same for coastal sage scrub vegetation in San Diego County. A team of wildlife researchers from the State Department of Fish and Game are currently involved in the relocation of VTM plots from the central Sierra Nevada montane hardwood and conifer belt to quantify habitat differences between the 1930s and current conditions (Barry Garrison, personal communication 2004). Bouldin (2001) reanalyzed data from the central Sierra Nevada, and Walker (1999) re-digitized and rectified the portion of the vegetation map from Yosemite National Park. Peggy Moore (1997) entered all VTM plot data from Yosemite into a database and Borchert did the same for plot data in the Los Padres National Forest.

All told, the VTM project included five major types of information. The collective value of these data is immense and underscores their long-term significance. The following summary has been kindly provided by Maggi Kelly, Barbara Allen-Diaz, and Norma Kobzina of UC Berkeley school of Forestry with additional information from Jeff Kennedy and Jim Thorne of UC Davis:

Plot Data

About 13,000 sample plots were located in the central and southern coastal ranges and in the Sierra across a gradient of vegetation types. The plot sites were carefully selected to be representative of the major types and subtypes mapped in a geographical area and were used to document otherwise omitted species and to check the field mappers’ vegetation classification. Generally, one plot was set up for every 800 ha mapped (60-90 plots were taken per 15-minute quad), and it was located and numbered on a topographical quadrangle map.

Detailed information about species composition, plant size, stand density of shrubs and trees, thickness of leaf litter, soil character, and type of parent material was collected.
For tree and shrub types, 0.04-ha (0.1-acre) rectangular plots were sampled to record the dominant species. At the same time, trees >10 cm dbh were tallied by diameter classes within a 0.08-ha plot. For herbaceous areas, such as burned-over shrub types and natural grassland, all species intercepted along a 101-m line transect were listed. In the tree and shrub plots average heights and cover are taken for all strata, including the understory. Additional data include Township, Range, Section, quad name, elevation, percentage of slope, aspect, date, mapping unit, litter depth, soil depth and texture, geologic parent material, year of last burn, tree site index, and vegetation penetrability.

**Plot Maps**

The original plot locations were stamped in red ink on U.S. Geological Survey (USGS) topographic maps that had been cut into sections, mounted on canvas, and folded to facilitate use. The plot map collection comprises about 150
fifteen-minute (1:62,500 scale) and 30-minute (1:125,000 scale) USGS quadrangles. Unfortunately, the resulting maps were not dimensionally stable, and 80 years of use, temperature changes, and other factors have warped many of the maps.

Vegetation Maps

VTMs showing hand-drawn polygons of forest type and associated species were drawn in the field by direct observation and by "sketching from ridges, peaks, and other vantage points." Some areas have larger scale maps drawn on 6- and 7.5-minute USGS quads. In the later years of the project some aerial photography was used to refine the field sketches (Colwell 1977).

Wieslander (1935b) developed a flexible scheme of type classification simple enough to allow a reasonable rate of mapping progress with accuracy and consistency. The general MMU prescribed by the survey was 16 ha (40 acres); however, in many cases the mappers delineated and labeled smaller units. The resulting maps use approximately 220 mapping units (mapped vegetation types) with an effective MMU of approximately 7.5 acres (3 ha).

The major vegetation types were subdivided into pure and mixed stands with notation on species composition and grouped by fire hazard characteristics, use, or economic importance. There are about 350 of these detailed and beautiful maps in the collection. Only 23 have been previously published. The major vegetation types are shown in different colors and are separated by ink lines. The types are further divided into units of different species composition in which the dominant species of trees, shrubs, and some herbs and grasses are indicated by inked letter symbols (Fig. 1.2).

The published 23 sheets cover about 2.8 million ha, including most of the chaparral lands in southern California. The sheets are printed in color as overprints on regular USGS 15-minute and 30-minute topographical quadrangles at scales of 1: 62,500 and 1: 125,000, respectively. Eight of the maps are on 30-minute quadrangle bases.

The colors show the general or broad vegetation types having similar use, economic importance, or fire hazard characteristics. For each separately colored type area, there may be one or more subtypes within which the dominant species symbols are listed. Map margins contain (1) color legends of the types mapped in the quadrangle; (2) a list of plant species and symbols; (3) brief descriptions of the type classification methods and of the types mapped in the quadrangle; (4) a table summarizing type areas by counties, national forests, and parks; and (5) elevational profiles illustrating the local relation of vegetation types to elevation and slope exposure. Additional profiles have been published separately (Critchfield 1971).

The notion of dominance was used in map labeling. Dominant species were defined as those occupying 20% or more of the canopy of trees as a group or shrubs as a group (Wieslander 1961). Understory vegetation was not a major consideration for mapping tree types. Two major vegetation categories were established: single-element type and mosaic or composite type having more than one element.

The single-element types consist of areas where the dominant vegetation is purely shrubby, arborescent, or herbaceous and occupy 80% or more of the vegetation cover to be designated. Mosaic types consist of two or more elements, each of which the overall vegetation cover.

The single-element types were further subdivided into pure and mixed stands. The pure-stand subtype is a unit in which two or more species each occupy at least 20% of the cover. Species are listed in order of decreasing abundance.

In the mosaic types, the percentage of species' occurrence is applied in the same manner to each class or element of vegetation separately. Thus in a tree-shrub mosaic the tree component can have tree species recorded in order of abundance if each occupies more than 20% of the tree canopy. The same applies to the shrub component.

When the VTM survey was discontinued in 1941, it had segregated vegetation into 21 major and 3 miscellaneous types (Table 1.2). Of the major types, 18 were considered dominant natural plant associations made up of one element, such as herbaceous, shrub, or tree type. The other 3 major vegetation types represented the mosaic category of two or more elements: woodland-grass, woodland-sagebrush, and woodland-chaparral. As other mosaics occurred, they were designated as subtypes of the nearest related major type. For example, a shrub-herb mosaic was recorded as a subtype of the nearest related shrub type. These major types are designated on the map by a color legend. All of the vegetation-type field maps and the 23 published maps have this standard color legend.

Although the dominant plant species were ordinarily listed in decreasing order of abundance, there were exceptions (Colwell 1977). In certain mosaic types in which combinations of trees, shrubs, or herbs were mapped, tree species were given first priority in the symbol designation. This is similar to the notion of “dominance by layer” used in the current National Vegetation Classification System (FGDC 1997). However, due to the emphasis of the use by foresters, in tree types, “commercial” conifers were listed before other noncommercial tree species included in the mosaic unit, regardless of their relative abundance in the type. Thus trees were always listed before shrubs; and commercial trees, before other trees. For types having more than one commercial conifer tree, the trees were listed in order of decreasing economic importance rather than in order of abundance. For example, in the redwood belt, redwood was listed first, regardless of the abundance of other conifers present. In mixed conifer types, dominant conifers were listed in order of commercial economic importance, rather than in order of relative abundance of the species, as follows: sugar pine, ponderosa pine, Jeffery pine, Douglas-fir, white fir, red fir, and incense-cedar. This is an important consideration to understand when using these maps as a baseline comparison to existing dominant species today.
FIGURE 1.2 A copy of the original hand-delineated and labeled vegetation map produced by the VTM survey crew for the Murphy's Quadrangle, Sierra Nevada Foothills, Calaveras County. Exceptional draftsmanship as well as an ecological eye for detail were necessary to fit so much information onto a two dimensional map 30' map. Small circled "X"s marked the location of various sample plots. The coding system is described in Wieslander (1935).
| Major Vegetation Classes and Type Definitions of the Vegetation Type Map Survey |
|---------------------------------|---|
| **Herbaceous**                  |  |
| Marshland                       | Marshes and perpetual wet meadows |
| Grassland and meadowland        | Grasses and other herbaceous vegetation not under cultivation |
| **Shrub**                       |  |
| Sagebrush                       | Low-growing, slenderly branched shrubs (Artemisia, Salvia, Eriogonum, Baccharis, etc.) |
| Chamise chaparral               | Chamise is one of the dominants in chaparral association. Dense, tall, heavily branched shrubs (Ceanothus, Arctostaphylos, shrub Quercus, etc.) exclusive of sagebrush, chamise, and semidesert chaparral |
| Semidesert chaparral            | Open chaparral associations on slopes bordering desert or within range of desert climatic influence |
| Timberland chaparral            | Transition or Canadian life zone shrubs in areas capable of growing commercial conifers removed by fire, logging, or chemicals |
| **Tree-woodland**               |  |
| Woodland                        | Dense Stands of broad-leaved trees comprising the only dominants; may be in association with Digger pine; includes steam bottom hardwoods |
| Woodland-chaparral              | Mosaic types of both woodland and chaparral species; may include Digger pine or some herbaceous constituents |
| Woodland-sagebrush              | Mosaic types of woodland and sagebrush species; may include herbaceous species |
| Woodland-grass                  | Mosaic of open stands of woodland species or Digger pine with herbaceous species |
| Pinyon and juniper              | Stands of pinyon or juniper or mixture of both |
| Miscellaneous conifers          | Conifers other than pinyon or juniper, or subalpine tree types; includes Monterey, bishop, knobcone, and Coulter pines, big-cone spruce, and similar conifers having little to no value for timber purposes |
| **Tree-commercial Conifer**     |  |
| Redwood belt                    | Redwood or giant Sequoia species as a dominant in stands of coniferous trees to the exclusion of 20% or more of Douglas fir; includes Redwood-Douglas fir subtype if both species occupy 20% or more of coniferous tree species |
| Douglas fir belt                | Douglas fir species occupy 20% or more of coniferous tree species, excluding 20% or more of Sequoia or commercial species |

(continued)
Photographs and Associated Data

There are approximately 3,100 black-and-white photographs taken during 1920–1941, with their photo points and floristic associates noted. In addition there are approximately 100 color topographic maps. The photographs document the typical and atypical subtype, species, timber stand conditions, range of variation, consequence of land use and cultivation, grazing, logging, mining and fire. Wieslander was the main photographer with a second series photographed by Richard C. Wilson (Class of 1934, past Director, California Dept. Forestry and Fire Protection), C. Raymond Clar (Class of 1927, past Chief Deputy State Forester), and others.

Herbarium Specimens

Some 30,000 mounted plant specimens were collected during the survey (Wieslander 1961). Representative types were photographed and were recorded on a topographical quadrangle map. Herbarium specimens were collected for every species recorded on the vegetation maps or in the sample plots. These are now on record at the University (UCB) and Jepson Herbaria and available through the SMASCH database (Web site). Kelly, Allen-Diaz, and Kobzina (2005, Madrono in press) are endeavoring to make all parts of this collection digital, linked, and available via the web. Current efforts to make these data available to the general public are on-going through several related projects at UC Berkeley and UC Davis. The 13,000 plots of data have been recently entered into a database through the efforts of Barbara Allen-Diaz (UCB) and Aysik Solomeshch (UCD). Scanning of the original maps has been completed through the efforts of Jeff Kennedy and Jim Thorne of UC Davis, and scanning and archiving of all the original photographs of the plots has been completed by the UCB Digital Library under the guidance of Norma Kobzina.

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**TABLE 1.2 (continued)**

<table>
<thead>
<tr>
<th>Pine Belt</th>
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<tbody>
<tr>
<td>One or more pines (sugar, ponderosa, or Jeffrey pine) and incense cedar are dominant to exclusion of true firs; includes pine-Douglas fir subtype Pine-fir belt Pines associated in joint dominance with true firs; includes pine-Douglas fir-fir subtype when all occupy 20% or more of coniferous tree species</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Fir belt</th>
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</thead>
<tbody>
<tr>
<td>True firs either individually or mixed occupying over 80% of coniferous tree species</td>
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</tbody>
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<table>
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<tr>
<th>Spruce belt</th>
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<tbody>
<tr>
<td>Sitka spruce is dominant in stands of coniferous trees to the exclusion of 20% or more of redwood or Douglas fir</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tree-subalpine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lodgepole pine-white pine belt</td>
</tr>
<tr>
<td>Lodgepole pine, western white pine, or mountain hemlock are dominant in stands of coniferous tree species excluding commercial trees (other than true firs) or whitebark-foxtail pine type</td>
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</tbody>
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<thead>
<tr>
<th>Whitebark-foxtail pine</th>
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</thead>
<tbody>
<tr>
<td>Whitebark pine, foxtail pine, limber pine, or bristlecone pine are dominant in a stand of coniferous tree species</td>
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<tr>
<th>Miscellaneous</th>
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<tbody>
<tr>
<td>Barren Areas</td>
</tr>
<tr>
<td>Practically devoid of vegetation: beaches, rocks, etc.; semibarren areas occur within any of above vegetative types where ground is less than 50% covered: rocky or eroded slopes, badlands, etc.; desert areas are indicated by dominance of distinctive desert species</td>
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<table>
<thead>
<tr>
<th>Cultivated and urban</th>
</tr>
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<tbody>
<tr>
<td>Cultivated areas such as cropland, orchards, natural hay lands Res-Residential, business, and industrial</td>
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<table>
<thead>
<tr>
<th>Plantations</th>
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</thead>
<tbody>
<tr>
<td>Areas artificially planted with trees other than horticultural crops, usually eucalyptus, Monterey pine, or Monterey cypress</td>
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</tbody>
</table>

**NOTE:** Summarized from Colwell 1977.
Additional work has begun on the task of rectifying the original published and unpublished maps to current geographic standards. The value of this effort has been assumed to be great, as once it is accomplished, it should be possible to compare extent of vegetation types from the 1930s to current conditions through GIS analysis. Several pilot tests have been undertaken to understand the most efficient means of accomplishing the georectification process (J. Thorne and J. Kennedy personal communication 2004). A consortium of cooperators is working to create a complete, linked, and readily accessible database of vegetation plots and maps, indexing each component by its location, and developing a Web tool for users to query, view, and download plot data from the Access database (the above mostly from forestry@berkeley July 2004, Volume 5, Issue 2. Making a Historic Vegetation Dataset Digital and Available to the World by Maggi Kelly, Barbara Allen-Diaz, and Norma Kobzina).

**State Cooperative Soil-Vegetation Survey and Soil-Vegetation Survey**

Following World War II, and the dissolution of the VTM survey, another effort began. In 1947, the Cooperative Soil-Vegetation survey (hereafter referred to as the S-V survey) at the California (now Pacific Southwest) Forest and Range Experiment Station began mapping vegetation. This survey mapped both soils and vegetation, providing more complete resource information for the management of wildlands (Colwell 1977). The work was done primarily on privately owned and state-owned lands, and the survey was financed by appropriations of the California Legislature to the State Division of Forestry. In addition to the Experiment Station and the Division of Forestry, other organizations cooperating in the survey were the Departments of Agronomy and Range Science and of Soils and Plant Nutrition at the University of California, Davis, and the Department of Forestry and Conservation at the University of California, Berkeley. As of 1977, more than 4.6 million ha of wildland were mapped with the S-V survey, including about 0.8 million ha on National Forest lands (Colwell 1977).

Three kinds of maps were published in the S-V survey: timber stand-vegetation cover maps, soil-vegetation maps, and generalized county maps of upland soils (State Cooperative Soil-Vegetation Survey 1958). Both the soil-vegetation and timber stand-vegetation cover maps were published on a standard 7.5-minute quadrangle unit at a scale of 1:31,680 (2 inches = 1 mile, 1 cm = 0.3 km). The generalized county maps are at a scale of 0.5 inch to 1 mile (1 cm = 2 km) and show upland soils grouped by color according to normally associated broad vegetation types. They were published for Mendocino, Glenn, and Lake counties.

**Timber Stand-Vegetation Cover Maps**

A total of 467 map sheets covering about 5.8 million ha were published during the period from 1948 to 1962 (Fig. 1.3). They include much of the woodland, chaparral, and commercial forestlands of the state and privately owned lands outside national forest boundaries in northern California. Portions of some national forests have timber stand maps (Sierra, Mendocino, Shasta-Trinity, and Lassen). The maps, with legends, quadrangle checklist, and tables, are archived in the U.S. Forest Service Pacific Southwest Research Station, Albany, CA, and are also in the UC Berkeley Forestry Library.

In general, the timber stand-vegetation cover maps show information obtained mainly from study and interpretation of vegetation patterns on stereo-pairs of vertical aerial photographs and supplementary field observations. The information is shown on the map in three categories: (1) broad vegetation types and other land units in order of abundance, (2) age class of commercial timber, and (3) “density” (actually, cover) of commercial timber by two size classes and total “density” (cover) of all woody vegetation. The broad vegetation groups (grass, shrubs, trees, and miscellaneous), previously subdivided into major types for the VTM survey, are now called elements. They are summarized here: C = Commercial conifers, K = Noncommercial conifers, G = Grass, M = Marsh, H = Hardwoods (Hy = Hardwoods/young and Ho = Hardwoods/old, S = Chaparral, T = Sagebrush, F = Bushy herbs, B = Bare ground, R = Rock, A = Cultivated, U = Urban. With this basic group of symbols, it was thought that any land area could be easily classified and delineated on vertical aerial photographs according to the elements present and their order of abundance (Jensen 1947).

The second category gives more detail on the age structure of the commercial conifer tree element (C) on areas considered suitable for growing commercial conifer trees. The age structure is based on the age–size class of individuals that makes up the stands: mature (old) and immature (young). Mature trees are those considered as having passed their optimum growth, whereas immature trees are those not yet past their optimum. Four age classes are defined: old growth, old growth-young growth, young growth-old growth, and young growth (U.S. Forest Service, California Forest and Range Experiment Station 1954).

The third category is the designation of the “density” or percent cover of the canopies occupied by the various elements. Symbols range from 1 (crows >80% cover) to 5 (<5% cover). “Density” is determined for both sawlog size trees over 27 cm dbh and all size timber trees, and for all woody vegetation.

The symbols for all three categories are shown as fractions on the map with age class and “density” in the numerator, and the elements in the denominator. In areas considered unsuitable for growing commercial timber crops, an “N” replaces the age and timber “density” symbols in the numerator (U.S. Forest Service, California Forest and Range Experiment Station 1949).

Certain requirements were established for recognition of elements in the aerial photo delineation process. They are very similar to those used in the earlier VTM survey, but differ in that the elements shown in the timber stand map are always in order of decreasing abundance. However, the tree
elements (C, H, and K) are emphasized under certain “density” requirements. To be recognized, an individual element could occupy from 5% to 100% of the ground area, depending on the kind of element and combinations. Crowns of commercial conifers (C) must occupy at least 5% or more of the ground space. Hardwoods (H) and minor conifers (K) each must occupy at least 5%, or 20% when in combination with 20% or more of commercial conifers. Shrubs (S), sagebrush (T), and bushy herbs (F) each must also occupy 5% to be indicated, but must occupy 20% when in combination with 20% or more of any tree element (C, K, or H). All other elements must occupy at least 20% to be indicated in a delineated area.

The Forest Survey used the timber stand-vegetation cover maps in 1946 to provide an age class and “density” stratification of commercial timber areas to a minimum of 16 ha for the purposes of sampling and locating growth and vol-

FIGURE 1.3 Quadrangle index key for published timber stand and soil-vegetation maps of California (from Colwell 1977).
volume plots and of estimating timber volume. When the Cooperative Soil-Vegetation Survey was started in 1947, the timber stand maps were intensified to a 4 ha minimum and provided a framework for vegetation and soil mapping and for determining forest productivity.

In 1958, the U.S. Forest Service’s California Region started soil-vegetation surveys on national forests. About 0.5 million ha were mapped on portions of the Eldorado, Mendocino, Six Rivers, and Stanislaus National Forests, and all of the Cleveland National Forest. The S-V maps summarized a great deal of information in a detailed and complex coding system for each polygon delineated (Fig. 1.4). For each of the published quadrangles an accompanying set of tables translating codes to soil series/phases and their characteristics, plant species and other elements mapped, summary information for type-acre sampling plots, and a complete list of plant species observed per quadrangle was produced. The latter information was taken advantage of by Griffin and Critchfield (1976) to produce an atlas of California tree species.

The soil-vegetation and timber stand maps were combined into a single 7.5-minute quadrangle and titled

FIGURE 1.4 Example of Soil-Vegetation mapping product for an area of the North Coast Ranges (from Colwell 1977).
“Soil-Vegetation and Timber Stand Map.” The maps were published during the period 1962–1978. Although these detailed soil-vegetation surveys have been discontinued, the maps, their descriptive summary tables, and a quadrangle checklist are available at the California Region headquarters in San Francisco. The maps are similar in procedures of mapping and in scale to the blue-line soil vegetation map sheets issued by the state cooperative Soil-Vegetation Survey. These maps differ by having the symbols and lines overprinted on USGS topographical contour maps, making it easy to locate mapping units in the field (Fig. 1.5).

**Value of the Combined S-V Survey Maps**

Unlike the VTM maps of the Wieslander (1935b, Wieslander and Storie, 1952) survey, the S-V maps (including soil-vegetation maps, timber stand-vegetation cover maps, and Soil-Vegetation and Timber Stand Maps) have not been mined as extensively for information, nor do they hold as much promise for comparative studies of current and past conditions, because they were begun more recently. The S-V surveys covered a less extensive area, focused primarily in the NW portion of the state in forested landscapes. The collective S-V maps are on average coarser in resolution to the VTM maps of the Wieslander surveys. Minimum map unit size was typically >4 ha. There was more of a strict economic focus on these surveys to identify timber stands and less information was mapped for nontimber vegetation compared to the VTM survey. However, over 3,000 sample plots were conducted for the survey in a standardized way (Colwell 1977). These plots were chosen to represent the full array of wildland soils and vegetation types encountered during the survey efforts. Standard environmental variables (slope, aspect, elevation, erosion, drainage, and surface rockiness) were collected, and a soil pit was dug with the soil profile described. For wooded plots ocular estimates were made of total woody plant cover, range of height of the understory and overstory, herbaceous species listed; and in commercial forest areas height and age measurements were taken from representative economic species to determine site indices. In nonwoody herbaceous stands, her cover and species composition were obtained using step-point (Evans and Love 1957) transects and herb cover estimated in 30-cm square point frames for every 10th step point. Data from these 0.4-ha circular plots are archived at the U.S. Forest Service PSW Research Station in Albany, CA (Colwell).

**Large Regional Remote Sensing Efforts**

During the 1970s while work continued through the statewide efforts of the S-V Survey, additional research began on making use of the first imaging satellites to
produce vegetation maps in the state. Because of the relatively low-cost and high frequency of repeat images provided by the orbiting satellites, this medium quickly replaced the aerial photo interpretation methods for large regional or statewide efforts in mapping of vegetation.

In 1972, ERTS-1 (Earth Resources Technology Satellite), later called LANDSAT-1, was launched to become the first of a series of satellites especially designed to obtain remotely sensed data for use in the inventory and monitoring of natural resources. Because California has a wide range of climatic and topographical conditions, it proved to be an ideal testing site for conducting integrated remote sensing research in water supply, timber, range, chaparral fuels, agriculture, and recreation (Colwell 1977). Many such studies were conducted by the Remote Sensing Research Program of the Department of Forestry and Conservation, and by the Space Sciences Laboratory, both of the University of California, Berkeley, under National Aeronautic and Space Administration (NASA) grants, and cooperative agreements with the Forest Service and with the Bureaus of Land Management, Reclamation, and Outdoor Recreation.

LANDSAT imagery could be enhanced from magnetic and color composite processes to show different features correlated with plant productivity and structure. In these early studies LANDSAT imagery served as the first stage of stratification in multilevel sampling designs. In conjunction with this process, aerial photography (both high-altitude color-infrared and low-altitude color) and systematically collected ground data were used to provide additional sampling levels. The information collected was used in equations to estimate the condition and volume of a vegetative resource. These estimates were made for timber volume, range productivity (Carnegie et al. 1974), or fuel hazard ratings (Nichols 1974, DeGloria et al. 1975).

The LANDSAT-I multispectral scanner detected differences among trees, shrubs, grass, and bare ground. Some distinctions could also be made of shrub maturity classes, such as pioneer, immature, and mature. In some homogeneous areas, types could be separated by species composition. Major forest types and some broad timber volume classes could be separated (Gialdini et al. 1975).

In its early years, imagery from spacecraft was used primarily as the first stage of stratification for various sampling designs requiring additional photography for ground truth and more detailed sampling. In the early phases of its use, satellite imagery was considered useful in the separation of broad vegetation types, condition classes, and other contrasting land conditions.

**Hardwood Rangeland Mapping**

One of the first regional approaches combining satellite and aerial photography was the Pillsbury Hardwood Rangeland Map (Pillsbury et al. 1991, Pacific Meridian Resources 1994). Hardwood rangelands below 5,000-foot elevation were originally mapped by Dr. Norm Pillsbury (Cal Poly SLO) under contract by California Department of Forestry and Fire Protection (CDF). Polygons were delineated on 1981 1:24,000 scale black-and-white air photos, transferred to 1:100,000 scale base maps, and digitized. The data were updated by Pacific Meridian Resources under contract from CDF using 1990 LANDSAT TM imagery. This GRID format data represent the base classification data used to update delineated polygons (polygons are provided as an additional layer). Each pixel was coded based on species group, tree size, and canopy closure class.

**CALVEG and the U.S. Forest Service Remote Sensing Lab**

The Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) system was originally developed by the U.S. Forest Service Pacific Southwest Region’s Ecology Program in 1978 (Parker and Matyas 1979, USDA Forest Service 1981). CALVEG mapping of the entire state was done between 1979 and 1981 by U.S. Forest Service personnel by photo interpretation of 1:250,000 scale color infrared prints of LANDSAT Multispectral Scanner imagery acquired between 1977 and 1979 (Parker and Matyas 1979). Image interpretation was guided by existing soil and vegetation maps, field checking, and by personal contact with vegetation experts throughout the state (Parker and Matyas 1981). The minimum mapping unit was 400–800 acres, but the spatial resolution of the resulting map was very coarse. Average polygon size of the map mosaic is 38,000 acres for the entire state. The resulting map provides statewide land cover/land use polygons mapped from 1:1,000,000 scale maps. The data contain vegetation attributes for series-level species groups only.

With the development of several future generations of satellite based scanners vegetation (LANDSAT 1 through 7, and the French 10-m pixel SPOT satellite) mapping of vegetation in California in the 1980s and 1990s became largely a satellite-based operation. Satellite-based mapping had the distinct advantage over aerial photography of having repeat images of the land surface captured regularly throughout the year for a relatively low cost given the size of the area covered. With an ever-increasing technological effort put into the refinement of computer image processing in the 1980s, it became feasible to develop mapping protocols that relied less on the trained eyes of air-photo interpreters and more on the interaction of computer image-recognition software and ecological models to develop refined vegetation mapping rules.

The most influential and widely used vegetation mapping program relying largely on LANDSAT imagery and image processing is the ongoing mapping conducted through the Remote Sensing Laboratory (RSL) of the U.S. Forest Service in Sacramento. The original CALVEG product formed the basis for the development of the coordinated mapping program within the California Region of the U.S. Forest Service, whose specific mission was to maintain and update vegetation maps.
for the jurisdictional portion of the state shared by the U.S. Forest Service and the California Department of Forestry and Fire Protection (Schwind and Gordon 1999, 2001).

Since 1988, the RSL has had an active and scheduled program for creating and maintaining existing vegetation data layers of National Forest lands. These layers have been developed by the classification and modeling of a variety of remotely sensed and ancillary data. The RSL has developed the use of computer-assisted image processing to develop LANDSAT into multipurpose vegetation maps for all of the major wooded parts of the state (Fig. 1.6). The main purposes of these maps are to assess wildlife habitats, late successional old growth, forest health, mortality, growth, and standing forest volumes for the needs dictated by the Natural Resource Planning Act, Forest Resource Management plans, Northwest Forest Monitoring Plan, Sierra Nevada Framework Monitoring Plan, and other bioregional assessments, and more localized watershed and county planning efforts. The RSL operates a coordinated schedule of updating their products with the goal of having vegetation maps no older than 5 years, updating map areas where changes to vegetation and surface fuels has occurred from various causes. And for these same change areas, re-measured inventory plots using a nationally established system of forest inventory plots (FIA 2002). To achieve a coordinated cycle, baseline vegetation maps and FIA grid inventory plots need to be completed to a common standard and common source dates within a province as much as possible, balancing workloads and budget constraints.

The CALVEG mapping classification is being maintained and updated at RSL and currently has 178 distinct vegetation and land use types (CALVEG geo-book, Gordon 2002). CALVEG alliances are similar in resolution (though not always in formal definition) to those in the uppermost floristic level (i.e., alliance) of the National Vegetation Classification hierarchy (see below). Both are based on dominant and existing vegetation components in a given area, but mapping units stress woody economically important types and tend to aggregate or overlook vegetation that typically does not attain stands of the minimum mapping unit of 2.5 ha. Other themes in the database include forest stand characteristics such as tree size and density and relative percentages of conifers and hardwoods in mixed stands (Table 1.3).

The methods for developing classified images for CALVEG mapping follow a prescribed sequence of steps including...
region delineation, life form classification, data collection and descriptions, terrain model development, field verification and map editing, and accuracy assessment.

**NATURAL REGION DELINEATION**

With the implementation of the National Hierarchical Framework of Ecological Units, sections and subsections of California divisions are now used to determine appropriate natural regions initially (Goudey and Smith 1994), with further refinements as necessary. The following brief methodological description, describing a six-step process, is taken from the RSL Web site (http://www.fs.fed.us/r5/rsi/). It begins with “life-form classification” and ends with “accuracy assessment.”

**LIFE-FORM CLASSIFICATION**

Prior to modeling ecological relationships for vegetation type, a LANDSAT Thematic Mapper image is classified into several life forms: conifer, hardwood, mixed, shrub, wet herbaceous, dry herbaceous, barren, water, snow, agricultural, and urban. Other more specific vegetation types that

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**TABLE 1.3**

CalVeg Mapping Criteria and Attributes Used by Region 5 Forest Service Remote

<table>
<thead>
<tr>
<th>Minimum Mapping Size</th>
<th>2.5 acres for contrasting vegetation conditions based on vegetation type, tree canopy closure, and overstory tree size. No minimum mapping unit for lakes and conifer plantations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life-Form Classes</td>
<td>Conifer: greater than 10% conifer cover as the dominant type. Mix: greater than 10% tree cover and 20% to 90% hardwood cover. Hardwood: greater than 10% percent hardwood cover as the dominant type. Shrub: greater than 10% shrub cover as the dominant type. Grass: greater than 10% grass cover as the dominant type. Barren: less than 10% cover of any natural vegetation.</td>
</tr>
</tbody>
</table>
| Attributes Mapped within Life-Form Classes | Vegetation Type (CALVEG)\(^a\)
  
  Tree Density: tree density (crown cover) mapped as canopy closure in ten-percent classes\(^b\)
  
  Overstory Tree Size: mapped as crown diameters of overstory trees interpreted from aerial photography and satellite imagery\(^c\)

| Additional Mapping Items | Ecological Tile: The basic landscape units used to organize existing vegetation layers within a statewide existing vegetation library (Goudey and Smith 1994). WHR Type, Size, Density, and Range: Corresponding parameters from the California Wildlife Habitat Relationships classification system.

| Northwest Size, Northwest Structure | Size and structural attributes specific to monitoring requirements for the Northwest Forest Plan and not present in Forest vegetation layers outside the Klamath Province. |
| Update Attributes | Update Source Date (date of the imagery used to revise the mapping information). Update Source (specifications of the imagery used to revise the map). |

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\(^a\)Rules have been developed by Vegetation Zone for setting parameters for CALVEG mapping (Schwind and Gordon 2002). \(^b\)In conifer/hardwood mixtures, relative density of each is mapped as well as total tree canopy closure, with conifer tree density stored in item DENSITY, hardwood tree density stored in DENSITY2, and total tree density stored in DEN_TOTAL. \(^c\)The plurality size condition of the predominant, dominant, and co-dominant trees in a stand is assigned a Regional size class.
have unique spectral properties may be mapped at this time as well.

Image classification occurs on individual pixels, not on stands. Therefore, an additional step utilizes an image segmentation procedure, which delineates stand boundaries based on spectral similarities. When combined with the pixel classification, a “stand-based” land cover map is produced. This map is generated through a decision rule process, which utilizes analyst-specified decision rules to label the stands or polygons, based on the membership of classified pixels. Editing is then carried out on these stands or polygons to resolve any ambiguous results for life form. This stand life-form map is then used as input to the ecological terrain model.

Data Collection and Descriptions: Field and existing data-collection drives the classification system to enable the development of models that predict the occurrence of existing vegetation alliances. This process provides updated alliances for the CALVEG classification system as areas across the state are systematically mapped within regional or Ecological Unit boundaries. Extensive field time is allocated to collect new information throughout the project's mapping boundaries, including, at the minimum, slope angle, elevation, slope aspect, and dominant species for each alliance in its varied expression throughout the mapping area. In many cases, areas are “masked” in the models to exclude alliances that are restricted in extent. Alliances are then described for the general mapping area or CALVEG zone, often with the inclusion or updating of a general dichotomous key to the alliances.

TERRAIN MODEL DEVELOPMENT

In addition to floristic information, terrain variables such as elevation, slope angle, slope aspect, soil and geologic or land-form type, precipitation averages, fire history, and so on are addressed in the vegetation predictive models in ARC Macro Language scripts. Models are processed separately for each of four life form types—conifer, hardwood, mixed conifer/hardwood, and shrub. Herbaceous types are usually assessed from remotely sensed imagery corrected and edited by interpreting information from aerial photos. In cases where vegetation cannot be modeled, such as in serpentinite or other edaphically defined vegetation types, ancillary data are used and supercedes the model's output. Model results are analyzed for conformance with new field data and field observations. A final “run” of the model merges output from the four life-form models with land cover classifications derived from edited remotely sensed data to assure the labeling of all map areas.

FIELD VERIFICATION AND FINAL EDITING

Maps are provided for field reviewers and brought into the mapping area for comments and corrections, and these are added to the final CALVEG data layers. The models are corrected and rerun, or the needed edits are made on the computer screen in ARC/INFO to produce a final CALVEG map product. The final completed map includes the incorporation of a plantations layer, the results of tree crown and density models and tree size estimate Crosswalks to the California Wildlife Habitat Relationships (WHR), and regional descriptions of the vegetation alliances are supplied with the final map products.

FOREST STAND STRUCTURE

In addition to mapping the floristic composition of a stand, the structural characteristics of canopy closure and overstory tree size are also mapped for the tree land-cover types. Stands that have been mapped as conifer, hardwood, or conifer/hardwood mix are used as stratifications for independent canopy and size mapping approaches. Canopy closure is derived from a geometric optical canopy model that estimates canopy closure within each tree stand as a percentage of the cover value. The resulting estimates of canopy closure in forested stands are evaluated using aerial photography, and errors are subsequently corrected in a GIS environment. Overstory tree size estimates are generated from Landsat TM imagery using a combination of supervised and unsupervised image classification techniques in conjunction with aerial photography. As with canopy closure, size estimates are reviewed against aerial photography, and anomalous errors are corrected.

ACCURACY ASSESSMENT

The two primary accuracy assessment methods used in the lab are the error matrix and the fuzzy set. Error (or confusion) matrices are developed for all of the mapping units and fuzzy logic (Gopal and Woodcock 1994; Milliken, Beardsley, and Warbington 1997) models are developed for a more realistic assessment of interpreting results. Forest inventory information (Bechtold and Zarnoch 1999) is used as the primary reference for field-testing accuracy assessments. Accuracy assessments are rated on map products for life-form categories, vegetation-type alliances, tree size classes, and tree canopy closure classes.

Discussion of Change Detection from Remote Sensing

Implicit in the regularly scheduled updating of the mapping through the RSL is the need to detect and quantify changes based on the 5-year updates. In 1998, the California Department of Forestry and Fire Protection and the Regional Office of the U.S. Forest implemented a long-term, remotely sensed monitoring program (Levien et al. 1999). Its purpose was to identify trends in forest health, assess changes in vegetation extent and composition, and provide data for updating regional vegetation and fire perimeter maps. This program provides current monitoring information across all ownerships and vegetation types represented on Forest Service and Hardwood Range lands in California. The process has been promoted as a low-cost and high-quality landscape-level monitoring tool.
Landscape changes are detected through two phases. In Phase I, a Multitemporal Kauth-Thomas (MKT) transform (Kauth and Thomas, 1976) is employed to create a landscape-level change map that identifies increases and decreases in vegetation along a continuum of change classes (Table 1.4). In Phase II, the causes of change are quantified using ancillary information, GIS, and fieldwork. Imagery that has been registered, normalized, and subset into processing areas is ready for input into the change-detection process. The process involves segmentation of Landsat TM imagery and statistical transformation of these data. Image segmentation creates polygons based on spectral similarity from TM bands 3 and 4, and a texture band generated from band 4 (Ryherd and Woodcock, 1990). Texture is a spatial component that enhances subtle edges in the scene over large areas. Generally, polygons range from 15 to 50 acres. The Multitemporal Kauth–Thomas (Kauth and Thomas, 1976) linear transformation reduces several TM bands into brightness, greenness and wetness components. Brightness identifies variation in reflectance, greenness is related to the amount of green vegetation present in the scene and wetness correlates to canopy and soil moisture. The transform is applied to the two dates of imagery that have been merged into a single 12-band image. The result is a change image representing changes in brightness, greenness, and wetness values between the two dates.

In the second phase of the analysis change classes based on the change image are identified using an unsupervised classification of the change image. Image appearance, photo interpretation, vegetation, and topographic maps, GIS coverages and bispectral plots (i.e., greenness vs. wetness) aid in identifying levels of change. This classification results in 50 change classes. Each change class is labeled according to its level of change based on a gradient of change classes from large decreases in vegetation to large increases in vegetation (Table 1.4).

Causes of change are quantified using ancillary information, GIS, and fieldwork. Vegetation type and ownership are used to stratify the change map. National Forest lands and hardwood rangeland areas are extracted from the change map using a hardwood layer and National Forest vegetation layer as a mask. Areas of known change, primarily those attributable to management activities, are identified using fire and harvest layers. GIS overlay analysis readily attributes these areas of change. Once these areas are identified, 7.5-minute quadrangle-size change maps are plotted for National Forest land, National Park land, and hardwood rangelands. Forest resource managers interpret these maps by applying local knowledge regarding sources of change. Similarly, UC Integrated Hardwood Rangeland Management Program (IHRMP) personnel consult private landowners to identify sources of change in hardwood rangelands. Areas without a causal agent identified by the above processes become the focus of field efforts.

Collecting field data on National Forest land and hardwood rangelands further aids in interpreting natural and human-induced change. Fieldwork conducted by IHRMP personnel in hardwood rangelands identified causes of changes in canopy cover due to fire, thinning, harvest, urban development, mortality, regeneration, and tree planting. Areas of mortality were identified on National Forest lands and a sample surveyed. Information on mortality and live vegetation was collected at each plot, resulting in the identification and quantification of vegetation change due to conifer mortality.

**TABLE 1.4**

<table>
<thead>
<tr>
<th>Class</th>
<th>Explanation</th>
<th>Quantitative Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large decrease in vegetation</td>
<td>−71 to −100 % CC*</td>
</tr>
<tr>
<td>2</td>
<td>Moderate decrease in vegetation</td>
<td>−41 to −70 % CC</td>
</tr>
<tr>
<td>3</td>
<td>Small decrease in vegetation</td>
<td>−16 to −40 % CC</td>
</tr>
<tr>
<td>4</td>
<td>Little or no change</td>
<td>+15 to −15 % CC</td>
</tr>
<tr>
<td>5</td>
<td>Small increase in vegetation</td>
<td>+16 to +40 % CC</td>
</tr>
<tr>
<td>6</td>
<td>Moderate increase in vegetation</td>
<td>+41 to +70% CC</td>
</tr>
<tr>
<td>7</td>
<td>Large increase in vegetation</td>
<td>+71 to +100 % CC</td>
</tr>
<tr>
<td>8</td>
<td>Nonvegetative change</td>
<td>Change in nonvegetated land cover</td>
</tr>
<tr>
<td>9</td>
<td>Terrain shadow or wet (ss)</td>
<td>Uninterpretable with imagery</td>
</tr>
<tr>
<td>15</td>
<td>Terrain shadow or wet (ne)</td>
<td>Uninterpretable with imagery</td>
</tr>
</tbody>
</table>

*CC, canopy cover.
This is a broad area analysis conducted with classification-based data; thus acreage numbers are not absolute. Classifications are not without error; however, these errors are usually known and for large area analysis, use of these data is appropriate. Also, acreage calculations are based on pixels classified as a particular cover type. Pixels may be classified as a certain hardwood cover type but are actually a mixture of the cover type and another cover type, such as grass.

Once vegetation change has been detected, it is important to determine the causes of these changes. The identification process is useful to verify the accuracy of the change (whether change occurred or not) and in generating a clearer understanding of the variables affecting the landscape. For this project, not all change polygons have been assigned a causal agent, as this is unfeasible given available staff resources, time and money constraints. The causes of many change areas have been identified by GIS analysis, National Forest resource managers, and consultation of private landowners within the hardwood rangelands by IHRMP staff.

Large changes in vegetation cover, such as those caused from harvests and fires, are easily and most frequently detected using this change-detection process. Smaller canopy alterations, such as thinning, selective harvesting, brushing for defensible space and mortality (which have a lower contrast between different time periods in TM data) were also detectable. Principal categories quantified include change due to development, timber harvesting, wildfire, prescribed burning, and regeneration. These changes differ on a county-by-county level based on management.

California Gap Analysis

Gap analysis is a national program headed by the USGS (Scott et al. 1993; Scott, Tear, and Davis 1996) to spatially define vegetation and habitat for animal species to quantify the need for further representation of preserves for species conservation. It was the first national program to attempt a relatively detailed vegetation map for the United States (base resolution 1:100,000). Each state embarked on its own program to accomplish their piece of the mapping puzzle. The California Gap (CA-GAP) program began in late 1990 and was spearheaded by Frank Davis of UC Santa Barbara. California was one of the first states to complete its first iteration of the program in 1996.

For CA-GAP, vegetation types were identified by one to three overstory species, each contributing greater than 20% of relative canopy cover. The 20% cover criterion, which we selected to be consistent with the California VTM survey (Wieslander 1946), is lower than typically applied to define canopy dominance. For example, the CALVEG classification defines dominant as > 50% (Parker and Matyas 1981). Pay- sen et al. (1980) define Series based on a single dominant overstory species or genus. The California Native Plant Society (Sawyer and Keeler-Wolf 1995) identifies Series primarily based on a single, overstory dominant, although a few series are based on two co-dominant species, and others are defined by environment (e.g., Alpine Series). At the 1:100,000 mapping scale, CA Gap found that use of single canopy dominants to produce names of vegetation mapping units produced an unacceptable simplification of vegetation composition and pattern. For example, much of the chaparral vegetation in the Southwestern California Region would be mapped as Chamise or Scrub oak chaparral, masking systematic, regional variation in community composition. By using the 20% cover threshold, they retained information on one to three dominant or co-dominant canopy species over several to many hectares. This area is much larger than plot sizes used in traditional vegetation studies. To avoid confusing these vegetation types with Series (Alliances) or Associations as defined by other systems, GAP refers to these combinations as “Species Assemblages.” In the field, species in an assemblage may be uniformly mixed or in a fine mosaic of patches, depending on the scale at which the pattern is observed. This means that in practice, species assemblages in our database can be a series recognized by existing classification systems, a combination of two or three recognized series, or previously unrecognized species combinations.

GAP METHODS

A map of actual vegetation was produced using summer 1990 Landsat Thematic Mapper (TM) satellite imagery, 1990 high altitude color infrared photography (1:58,000 scale), VTM maps based on field surveys conducted between 1928 and 1940, and miscellaneous recent vegetation maps and ground surveys. Details of the mapping process are provided in Davis et al. (1995).

GAP project researchers attempted to delimit “landscapes,” defined as areas of one to many square kilometers in extent with uniform climate, physiography, substrate and disturbance regime, and covered by a single species assemblage or by a mosaic of a few species assemblages associated with different sites (e.g., riparian zones, mesic slopes, xeric slopes). Landscape boundaries were mapped subjectively by photo-interpretation of patterns in the satellite imagery. Final delineation of a landscape unit was an iterative process based on evidence from the satellite imagery, 1990 air photos, existing vegetation maps, and field reconnaissance. The map was produced using a minimum mapping unit of 100 ha (1 km). The state was mapped into greater than 21,000 landscape units, or polygons, with a mean size of approximately 1,950 ha.

TM imagery was resampled to the Albers equal-area projection with 100-m resolution (i.e., 1-ha pixels), and a false color composite of red, near-infrared, and mid-infrared reflectance images was displayed on a video monitor. Obvious landscape boundaries were digitally drafted over the imagery based on image tone and texture. Ancillary information, especially air photos and VTM maps, was used to capture additional compositional changes in vegetation that were not visually obvious in the TM imagery. VTM
maps were used to position landscape boundaries on vegetation gradients where no obvious break was visible on either the satellite imagery or in air photos. Two hundred and thirty polygons (excluding urban and agricultural areas), or about 1% of all polygons, were checked in the field, primarily by roadside reconnaissance.

Using these various sources, a large amount of information was collected for each landscape unit (Table 1.5). Based on the landscape-scale concept, a primary species assemblage, which was the most widespread vegetation type or land use/land cover type in the polygon was recorded along with a secondary and tertiary type, and the fraction of the landscape covered by each type. The most widespread wetland assemblage, which was usually riparian vegetation, was also recorded. Each species assemblage was defined by up to three dominant species. Minor overstory species of special conservation concern (e.g., *Juglans californica*, *Quercus engelmannii*, *Cupressus forbesii*) were also recorded.

Species data were derived from field survey, air photos or from the VTM and other detailed maps. VTM information was used for areas where air photos provided no evidence of recent disturbance, based on the questionable assumption that canopy dominants observed by VTM field crews did not change over the past 50–60 years. Minor field checking found that the assumption was usually valid for forest and hard chaparral types. Although the relative dominance of species may have changed over the interval, species that were mapped as co-dominants by VTM crews in the 1930s are usually still canopy dominants across the same landscape. The composition of shrubland and grassland types is not as stable over the same interval, and GAP researchers made special efforts to view these types in the field or to find more current maps. The GAP landscape units are many square kilometers in extent, and canopy composition can vary greatly from site to site within a landscape. Thus the mapped species assemblages record those species that most frequently dominate most sites in that landscape.

An attempt to account for fire dynamics was made by recording recent burns and by retaining information on the preburn dominants (e.g., an area of recently burned chamise chaparral that is presently dominated by herbs would be recorded as sparse chamise canopy co-dominated by annual herbs).

Rather than a multicolored vegetation map, the information is better treated as a vegetation database linked to a set of areas. One can retrieve distribution data on individual species, unique combinations of species, or vegetation types defined by physiognomy and/or composition (Stoms, Davis, and Cogan 1992; Davis et al. 1995). Although the database approach provides a more flexible framework for representing vegetation variation than the traditional vegetation map, it does not eliminate the need for classification to simplify and communicate results.

Many thousands of unique species (or species/landuse) combinations in over 21,000 polygons. Many unusual species combinations occurred at the margins of regions in transitional environments.

GAP summarized distribution data for individual dominant species and based on plant communities as defined in the list of preliminary vegetation types of California

| Attribute | Polygon ID number | Primary vegetation | Dominant species 1 | Codominant species 2 | Codominant species 3 | Canopy closure (4 classes) | Fraction of polygon occupied by primary type (10% intervals) | Primary CNDDB community type | WHR habitat type | Secondary vegetation | Dominant species 1 | Co-dominant species 2 | Co-dominant species 3 | Canopy closure | Fraction of polygon occupied by type | Secondary CNDDB community type | WHR habitat type | Tertiary vegetation | Dominant species 1 | Co-dominant species 2 | Codominant species 3 | Canopy closure | Fraction of polygon occupied by type | Tertiary CNDDB community type | WHR habitat type | Presence/Absence of 9 wetland habitat types (CA WHR types) | Primary wetland vegetation | Dominant species 1 | Co-dominant species 2 | Co-dominant species 3 | Presence of canopy species of special status (narrow endemics, rare species) |
(Holland 1986), which were derived from the database by an equivalence table (or cross-walk), assigning each species combination to a unique Holland community type. The criteria for class assignment in the Holland classification system are qualitative and often not explicitly based on dominant overstory species. Where ambiguities existed, species combinations were assigned to more general types. For example, Holland identified several pinyon and/or juniper community types in the Mojave Desert region that were aggregated into a single type at his next higher level of classification (pinyon and juniper woodlands).

Several procedures were implemented to ensure quality in the final map. The distribution of each dominant plant species in the coverage was compared to the documented distribution recorded in the CalFlora database (http://www.calflora.org/species/), which was derived from the Munz (1959) flora and revised with some more current data. Apparent outlying locations of species in the GAP database were reexamined either to confirm that the location was documented in the data source or to change the species code if it appeared to be an incorrect interpretation or a data input error. A similar comparison was made for each community type with the written description in Holland (1986).

**Vegetation Classification in California**

**Nonquantitative Classifications**

The following discussion of several early vegetation classification systems for the state all share their basis in a qualitative description of vegetation types. All were developed for different purposes and vary somewhat in their resolution (from 29 to 150 distinct units defined).

Jensen (1947) developed a methodology for classifying California’s vegetation in several ways based on the previously discussed VTM survey and presents three classifications useful for different purposes. The first section is a vegetation cover and land status classification including 12 categories, such as chaparral, commercial conifers, bare ground, and cultivated areas. The second section is a system of the “species units,” including single species, mixed species, or “mosaic mixtures” where two or more elements are involved. These species units are analogous to the mapping units in the original VTM survey. The third section is a synthesis of the first two, grouping the 32 main types, including commercial conifer, noncommercial conifer, hardwood, and nontree types. This latter synthesis was developed into a statewide vegetation map (Wieslander and Jensen 1946).

In contrast to the map-based efforts of Wieslander and Jensen (1946), the next statewide California vegetation classification developed was based on broad climatically inferred plant communities (Munz and Keck 1949, 1950). It was meant to aid in the discussion of habitat and distribution of species in the book, *A California Flora* (Munz 1959). This classification identified 29 plant communities within 11 vegetation types, distributed among five biotic provinces. The names, familiar to many contemporary botanists, sometimes use names of dominant species, whereas others invoke habitat characteristics or physiognomy (foothill woodland, valley grassland, coastal strand, and alkali sink). Although the Munz and Keck (1949, 1950) plant communities form a useful tool for understanding the statewide distribution of plants, the system omits numerous ecologically distinctive habitat types (Table 1.6).

In the 1970s, heightened interest in vegetation within California resulted in two books (Barbour and Major 1977, Ornduff 1974—recently republished as Ornduff, Faber, and Keeler-Wolf 2004), a number of descriptions of local vegetation (e.g., Hanes 1976, Minnich 1976, Sawyer and Thornburgh 1977, Vogl 1976), and two statewide classification systems that refined the Munz and Keck (1949, 1950) approach to finer levels and developed many new types (Cheatham and Haller 1975, Thorne 1976). The two books describe California’s vegetation on various scales of knowledge and were not intended as a formal classification.

Thorne’s system was published by CNPS for purposes of plant conservation. Cheatham and Haller’s (1975) system was never published and was specifically designed for the identification of University of California natural reserves. The Thorne system is more detailed than Munz and Keck’s (1949, 1950), but is more general than Cheatham and Haller’s (1975). Both divide broad habitats, including dunes, scrub and chaparral, bogs and marshes, riparian, woodlands, and forests into finer divisions based on species composition and geographic location. The more recent effort by Holland and Keil (1995) is a similar, though more detailed overview of the range of vegetation in the state and is intended to be largely a companion text to an introductory course on California vegetation and field botany, not a formal classification.

Following the enactment of the state and federal endangered species acts and the California Environmental Quality Act, among other environmental legislation of the early to mid-1970s the California Heritage Program’s Natural Diversity Database (NDDB) instituted by The Nature Conservancy and soon to become part of the California Department of Fish and Game, began developing classifications of Natural Communities that were to be used for targeting good examples of rare and common vegetation and habitat to assist in various conservation efforts. These classifications were all anecdotal and qualitative, but treated the vegetation of the state at a finer scale that earlier efforts.

Arising directly from the Cheatham and Haller system was the classification used by the California Natural Diversity Data Base (NDDB) to identify rare natural communities. The unpublished Holland (1986) classification, a refined version of the NDDB system, is structurally identical with Cheatham and Haller (1975), but it defines more types and, for the first time, assigns rarity ranks and conservation status to units of the hierarchy.
An advantage of the Cheatham and Haller (1975) and Holland (1986) classifications is that they are specific and differentiate among similar, but geographically isolated types. A disadvantage lies in the lack of uniform criteria in distinguishing units. Some are defined by location, some by structure, others by specific taxa. Although descriptions of most types indicate dominant and characteristic species and distribution, the accounts are general and tend to overlap. Although the Holland system is hierarchically arranged, it is of uneven resolution with coarse as well as fine scales of vegetation defined at the lowest units of the system (Keeler-Wolf 1993).

Another concern with such classifications as Cheatham and Haller (1975) and Holland (1986) arises with the increasing importance of vegetation units as indicators of ecosystems. The need to unequivocally define these units, and to relate them to similar units across state boundaries has risen through regional conservation planning efforts in the 1990s. As land has increased in both real estate and conservation value the burden of proof regarding identity of habitat and vegetation types of true conservation value has begun to rest on the conservation planners and biologists defining the types. This situation requires quantitatively definable definitions for vegetation types as the most important units of conservation.

A system to classify California wildlife habitats was developed in the early 1980s (Mayer and Laudenslayer 1988). This is the California Wildlife Habitat Relationships System (WHR), and it consists of about 55 types intermediate in scale and definition between Munz and Keck’s (1949, 1950) and Thorne’s (1976) community types. The WHR system also consists of some nonnative vegetation types, including eucalyptus groves and several types of agricultural and developed habitats not treated in other classifications.

The WHR system was developed primarily to classify and predict habitat value for vertebrate animals. It is one of the few systems that identifies structural stages in various tree, shrub, and herb-dominated types. Because it establishes cover class and size rules, the system has use in predicting habitat value based on management practices (Table 1.7). It has been widely used as a mapping classification because it developed a guidebook (Mayer and Landenslayer 1988) which establishes quantitative rules for membership and shows a relational “cross-walk” between it’s classification and other commonly used classifications for California (Table 1.8).

WHR has been less successful in differentiating between vegetation types. Because the habitat types are inconsistently defined, a broad familiarity of its detailed descriptions is needed to differentiate among types of similar structure. Although mappers have constructed rules for discriminating among types, difficulties still remain because species dominance varies substantially within some types and broad overlaps in dominant plants occur among types. Other problems arise due to the small number of classes and the inconsistencies in scale among them.

At approximately the same time that Thorne’s (1976) and Cheatham and Haller’s (1975) classifications were introduced, the USDA Forest Service was coming to grips with the need to manage their California lands in a way that would sustain natural resources and underscore the potential of different environments to support timber removal,

### Table 1.6

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<tr>
<th>Vegetation Type</th>
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<td>5. Coastal Sage Scrub</td>
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<td>21. Southern Oak Woodland</td>
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<td>22. Foothill Woodland</td>
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<td>VIII. Chaparral</td>
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<td>IX. Grassland</td>
<td>24. Coastal Prairie</td>
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<td>25. Valley Grassland</td>
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<td>X. Alpine Fell-fields</td>
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<td>XI. Desert woodland</td>
<td>Northern Juniper Woodland</td>
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<td>28. Pinyon-Juniper Woodland</td>
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<td>29. Joshua Tree Woodland</td>
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**Note:** From Munz and Keck 1968.
### TABLE 1.7
WHR Habitat Stages and Size Classes for Tree Types

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<tr>
<td>VOW Valley Oak Woodland</td>
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### Standards For Tree Size

<table>
<thead>
<tr>
<th>WHR Size Class</th>
<th>Conifer Crown Diameter</th>
<th>Hardwood Crown Diameter</th>
<th>dbh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling Tree</td>
<td>n/a</td>
<td>n/a</td>
<td>&gt;1”</td>
</tr>
<tr>
<td>Sapling Tree</td>
<td>n/a</td>
<td>&lt;15”</td>
<td>1”–6”</td>
</tr>
<tr>
<td>Pole Tree</td>
<td>&lt;12’</td>
<td>15’–30’</td>
<td>6”–11”</td>
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<tr>
<td>Small Tree</td>
<td>12’–24’</td>
<td>30’–45’</td>
<td>11”–24”</td>
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<tr>
<td>Medium/Large Tree</td>
<td>&gt;24”</td>
<td>&gt;45’</td>
<td>&gt;24”</td>
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</table>

### Standards For Canopy Closure

<table>
<thead>
<tr>
<th>WHR Closure Class</th>
<th>Ground Cover (Canopy Closure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Sparse Cover 10–24%</td>
</tr>
<tr>
<td>P</td>
<td>Open Cover 25–39%</td>
</tr>
<tr>
<td>M</td>
<td>Moderate Cover 40–59%</td>
</tr>
<tr>
<td>D</td>
<td>Dense Cover 60–100%</td>
</tr>
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*Source: Mayer and Laudendlayer (1998).*
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<tr>
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<tbody>
<tr>
<td>Red Fir (RFR)</td>
<td>Red Fir Forest (8.531)</td>
<td>Red Fir Forest (85310)</td>
<td>Red Fir (207)</td>
<td>Coast Range Montane Forest (14)</td>
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(continued)
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<tbody>
<tr>
<td>Lodgepole Pine (LPN)</td>
<td>Lodgepole Pine (8.61)</td>
<td>Lodgepole Pine Forest (86100)</td>
<td>Lodgepole Pine (218)</td>
<td>Upper Montane—Subalpine Forests (17)</td>
<td>Lodgepole Pine Forest (16)</td>
<td>Lodgepole Pine Forest (14c1)</td>
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<td>no corresponding vegetation type</td>
<td>Lodgepole Pine forest (14c1)</td>
</tr>
<tr>
<td>Whitebark Pine</td>
<td>Lodgepole Pine—Lodgepole Pine Forest (86220)</td>
<td>Sierra Nevada Mixed Conifer (243)</td>
<td>Lodgepole Pine</td>
<td>Lodgepole Forest (18)</td>
<td>Fontaine (84250)</td>
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<td>no corresponding vegetation type</td>
<td>Lodgepole Pine forest (14c1)</td>
</tr>
<tr>
<td>Lodgepole Pine Forest</td>
<td>Lodgepole Pine</td>
<td>Lodgepole Pine Forest (86100)</td>
<td>Lodgepole Pine (218)</td>
<td>Upper Montane—Subalpine Forests (17)</td>
<td>Lodgepole Pine Forest (16)</td>
<td>Lodgepole Pine Forest (14c1)</td>
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<td>no corresponding vegetation type</td>
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<tr>
<td>Ultraform White</td>
<td>Pacific Ponderosa Pine—Douglas-Fir (244)</td>
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<td>Mixed Conifer</td>
<td>not applicable</td>
<td>Yellow Pine forest (14a2)</td>
<td>Mixed conifer forest (14a3)</td>
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<td>Yellow Pine forest (14a2)</td>
</tr>
<tr>
<td>Mixed Conifer Forest</td>
<td>Mixed Conifer</td>
<td>Mixed Conifer</td>
<td>Mixed Conifer</td>
<td>not applicable</td>
<td>Yellow Pine forest (14a2)</td>
<td>Mixed conifer forest (14a3)</td>
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<td>Yellow Pine forest (14a2)</td>
</tr>
<tr>
<td>Sierra Big Tree (8.425)</td>
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<td>Mixed Conifer</td>
<td>Mixed Conifer</td>
<td>not applicable</td>
<td>Yellow Pine forest (14a2)</td>
<td>Mixed conifer forest (14a3)</td>
<td>Mixed Conifer</td>
<td>not applicable</td>
<td>Yellow Pine forest (14a2)</td>
</tr>
</tbody>
</table>

grazing, recreational use, and other human activities. To accomplish this goal they recognized that classification of ecosystems was a high priority. Much of their effort in the 1970s and 1980s was directed toward classification (Paysen et al. 1980; Paysen 1982; Paysen, Derby, and Conrad, 1982; Hunter and Paysen 1986; Allen 1987).

The purpose of these efforts was to develop a land classification that could be applied to both research and management activities. Their approach differs fundamentally from earlier classifications of California’s vegetation because it relies on field samples (plots) of the vegetation to build the bottom layers of the hierarchy. Consequently the basic taxonomic units of the system were not identified by arbitrarily assigning a name to what is generally perceived as a unique type. Instead, the basic units are defined after a number of plots are analyzed over a large area. Rather than qualitative and anecdotal, this classification is quantitative and driven by the availability of data.

Quantitative Classifications

Until recently, California has lagged behind Oregon, Washington, Idaho, and Montana in developing data-driven vegetation classifications. Efforts by Daubenmire (1952); Daubenmire and Daubenmire (1968); Franklin, Dymess, and Moir (1971); Pfister and Arno (1980); and others set the standards for the USDA Forest Service, Pacific Southwest Region classification of forests, woodlands, and scrublands in California. Because the focus on quantification of vegetation on Forest Service lands was largely for management of forested landscapes for timber production, the concept of “potential natural vegetation” was used to define the vegetation types. Potential natural vegetation (PNV) is the vegetation that would become established if all successional sequences were completed without human interference under present climatic and edaphic conditions (Brohman and Bryant 2004, Winthers et al. 2004).

The larger floristic units of these efforts became known as series and the smaller basic units as associations. Series were identified by the dominant plants in the overstory, which would be likely to occur in mature (PNV) stands; whereas the associations were identified by characteristic species in the understory layers. There is an ecological basis for grouping associations into a series. For example, although there are many associations of white fir forest in the Sierra Nevada, all occupy sites that are warmer than the red fir-dominated forests. Red fir typically occurs at higher elevations or on cooler exposures, so the dominant overstory species reflect broad-scale environmental differences. The presence of certain understory species reflects more localized differences related to microclimate and soil. However, the implications of “potential” vegetation were difficult to come to grips with in many cases, particularly in light of more recent studies suggesting that there were usually an array of natural processes including fire, flood, disease, climatic shifts, and so on, which would alter detailed long-term linear predictability of the chronological evolution of a given stand of vegetation (Westoby, Walker, and Noy-Meir 1989; Briske, Fuhlendorf, and Smeins 2003).

The framework of the classification system adhered to by the USDA Forest Service in California is described by Allen (1987). This project, most active in the early 1990s, entails eight different Forest Service zone ecologists developing classifications of targeted areas. The work includes extensive sampling of the vegetation, soils, and other environmental characteristics followed by quantitative analysis using multivariate statistical programs, which became more common and useful during the 1980s. Classifications are completed for Port Orford-cedar forests (Jimerson 1994, Jimerson and Daniel 1999). Douglas-fir and tanoak forests (Jimerson 1993) and serpentine vegetation (Jimerson et al. 1995) of the western Klamath Mountains. Classifications for blue oak woodlands and redwood forests in the Central Coast region have been developed (Borchert, Segotta, and Purser 1988; Borchert et al. 1993), for mixed conifer forests of the northern Sierra Nevada (Fites 1993) and red fir forests (Potter 1994) of the central and southern Sierra Nevada, for eastside pine forests of the Cascade Range, Modoc Plateau, and northern Sierra Nevada (Smith 1994), and for chaparral types of the Transverse and Peninsular Ranges (Gordon and White 1994). Recently, classifications for the herbaceous upland vegetation of the North Coast Ranges (Jimerson et al. 2002), the northern oak woodlands of the inner north Coast Ranges (Jimerson et al. 2003), the chaparral and coastal scrub of the Los Padres National Forest (Borchert et al. 2004) and the riparian vegetation of the Sierra Nevada (Potter 2004 MS) have also been completed.

All of these efforts relied on quantitative plot-based sampling and analysis of representative stands of mature vegetation (again in keeping with the notion of potential vegetation as opposed to existing vegetation, which would include stands subject to recent disturbance). Regular meetings and discussion among the zone ecologists with reference to standards for classification and nomenclature assisted in developing a unified resolution and set of definitions for each of the types defined.

The Manual of California Vegetation

In 1991, the California Native Plant Society convened a committee to develop a standardized vegetation classification system for the state. The underlying assumption would be that a unified classification treating the entire state with quantitative rules would provide the necessary means to develop defensible definitions for vegetation and natural communities, which could be used to further statewide multispecies conservation goals. This was also collectively agreed on by many state and federal agencies and academics, as well as by several organizations with conservation.
The advent of new state legislation such as the Natural Community Conservation Planning Act in 1991 furthered the importance of this committee. In 1995 under the auspices of the CNPS Vegetation Committee (Barbour and Keeler-Wolf 1993, Keeler-Wolf 1994, Barbour 1995), the first edition of the Manual of California Vegetation (Sawyer and Keeler-Wolf 1995) was published.

This classification was a synthetic effort to compile all information known about the state’s vegetation into a unified framework that relied on quantitative defensible descriptions to arrive at an unequivocal definition of the major vegetation types (called “series” in the first edition). The classification relied heavily on the U.S. Forest Service’s and the budding National Vegetation Classification System’s (Bourgeron et al. 1994) notion of dominance by layer (tree, shrub, or herb) to define the major types of vegetation. However, it differed philosophically, in that it attempted a classification of existing vegetation regardless of its potential outcome. Thus, several of the series identified by Forest Service Ecologists were treated somewhat differently within the MCV. For example the Tanoak (Lithocarpus densiflorus) alliance was treated very broadly by Jimerson et al. (1995) to include many plant associations that were strongly dominated by Douglas-fir (Pseudotsuga menziesii). They were so included because of the premise that Tanoak is really the predominant late seral species and indicative of the PNV environment. In the MCV a Tanoak, a Tanoak-Douglas-fir, and a Douglas-fir alliance were recognized to indicate the range of current conditions expressed by dominance in the tree layer of the vegetation. Individual plant associations defined within the Jimerson et al. descriptions could easily be translated into the appropriate MCV alliance based on the quantitative descriptions stating such things as overstory dominance and constancy of major species.

Although the first edition of the MCV defined 245 series and other categories, it did not purport to be a final classification. In reality, the authors realized that it might take many years for a “final” classification for the complex vegetation of the state to be completed. The main purpose of the first edition was to provide a framework on which further descriptions could be built. The vegetation of the state had not been fully quantified; thus it was impossible to develop quantitative rules for all of the types in the state. In most cases the best quantitative descriptions could be developed for the wooded (forest and woodland) vegetation because of the ongoing focus by the U.S. Forest Service on the economically important forested vegetation types. Some shrub types had also been defined quantitatively, particularly chaparral of the south coastal area, and some herbaceous types, as well. However, in many cases the rules of dominance or the natural range of variation was not well enough understood to develop series-level descriptions for them. Thus, there were several other categories besides series that were used as provisional “place holders” for widely recognized, but quantitatively poorly understood vegetation.

Principal among them was a category known simply as “habitats.” These included such complex fine-scale matrices as alpine vegetation, montane and subalpine meadow and wetland scrub habitat, and subalpine upland shrub habitat. All of these types were thought to be composed of individual alliances and associations, which had not yet been further refined by quantitative vegetation analysis. Complex patterning of vegetation in the wide range of the state’s vernal pools was also left open to broader interpretation, as insufficient information was available at the time to define individual patterns of floristic variation analogous to series. The MCV relied on the existing Holland (1986) classification for vernal pools with some minor modification. One final category was also defined: “unique stands.” Unique stands are defined as one-of-a-kind types of vegetation that are not known to have one of the classic features of real vegetation—they do not display stand redundancy—repeating stands within similar ecological settings. Unique stands have been defined for locally dominant populations of rare species, for example several cypress species (Cupressus goveniana, C. forbesii, C. arizonica subsp. arizonica, C. arizonica subsp. nevadensis). They also have been defined for unique structural situations such as Holly-leaf cherry “forests” where due to very long intervals between fire, Prunus ildicifolia stands, typically shrubby, have grown into stands of tree-size individuals in rare instances. The California Natural Diversity Database considers all types of unique stands as having conservation value.

Philosophically, the MCV was a combination of a “top-down” and a “bottom-up” classification with emphasis on the finer resolution series and associations. The members of the CNPS vegetation committee and the authors believed it was most important to set up a standardized floristic basis for quantitatively defining the full variation of vegetation within the state. The inductive approach supported by most phytosociologists (e.g., see Major 1988) emphasizes the fine-scale associations as the basis of the classification and these are aggregated into larger floristic units (the series). However, some of the series and the other units such as the habitats, vernal pools, and unique stands had no quantitative data and were defined tentatively based on expert opinion, using the basic rules of dominance to define them. These rules identify dominant species as comprising greater than 50% relative cover of the top-most layer of vegetation. If there are several co-dominants, these species are listed together defining the name of the type. The authors expected these and other categories to be considered “place-holders” until further quantitative data and analysis replaced them.

The National Vegetation Classification System

Among the criticisms of the first edition of the MCV was the fact that it did not identify a classification hierarchy within which the relatively fine-scale classification units of series and associations could be placed. This classification hierarchy
was being worked out by a consortium of ecologists working with a panel of the Ecological Society of America (ESA Panel 2004). In 1997 a prototype national vegetation classification was unveiled by The Nature Conservancy, which drew on the advice of the ESA panel. This classification system was also adopted by the Federal Geographic Data Committee (FGDC) on vegetation as the standard for all national and federal projects relating to vegetation (FGDC 1997). A year later the first version of the entire National Vegetation classification system (NVCS) complete from associations up through all seven levels of the hierarchy was published by The Nature Conservancy (Grossman et al. 1998).

The lowest level of the NVCS hierarchy is the fundamental level of the association, defined in the same way as it was in the MCV. The alliance was the next level up and was defined in the same way as the series was in the MCV. The principal difference was semantic. Series was thought by the ESA Panel to have too much of a connection with the notion of Potential Natural Vegetation, since the term was first popularized by forest ecologists working with potential vegetation concepts. Alliance was a term that arose from the European school of phytosociology (Braun-Blanquet 1932/1951, Muller-Dombois and Ellenberg 1974) and implied existing, not potential, vegetation. In the way that the term was applied in the MCV, there was no real philosophical difference between series and alliance. Above the level of the alliance the national classification shifted from a floristic to a physiognomic basis for classification. Starting with the next level up from alliance—the formation, all other classification units were based on a combination of life form of the predominant species in the stands and subdivisions of those life forms based on plant size, leaf morphology, phenology (e.g., deciduousness), or hydrology (Table 1.9). Current revisions of the MCV are well underway, and every effort was made to make the upcoming second edition compliant with the National Classification. For example, all series described in the first edition will be re-described as alliances, and the alliances and associations treated will be discussed within the framework of the NVCS.

The advent of the new state and national vegetation classification standards spurred a number of significant events within the state. These included the first integrated mapping and classification projects (Keeler-Wolf 1994; Keeler-Wolf et al. 2000; Keeler-Wolf, Roye, and Lewis 1998; NatureServe 2003). It also enabled agreement and cooperation between state and federal agencies doing mapping and classification work within the state to agree to a set of standards for mapping and classification of vegetation (Vegetation Memorandum of Understanding 2001) adhered to by all major agencies and organizations involved in state vegetation classification and mapping.

**Integrated Vegetation Mapping and Classification**

Within a few months following the publication of the MCV, a project was started at Anza-Borrego Desert State Park, which for the first time integrated a field-based vegetation sampling and classification scheme with a detailed GIS-based map of the vegetation using the new standards for quantification of vegetation set forth in the MCV and the National Vegetation Classification system (Keeler-Wolf, Roye, and Lewis 1998). Over 500 relevé samples were taken using a gradient-directed approach (Austin and Heyligers 1991, Gillison and Brewer 1985). These samples were analyzed using classification programs such as TWINSPAN (Hill 1979) and a quantitative key was developed which enabled all types of vegetation in the park to be identified. This latter asset was particularly valuable when applied to an accuracy assessment of the concomitantly developed map of the park. Some 95 individual vegetation-mapping units were defined and mapped. Mapping was done using traditional air-photo interpretation methods with the hand-delineated polygons digitally transferred and orthocorrected to a standard map base derived from orthorectified satellite imagery. About 28,000 individual polygons were retained in the mapping area of approximately 930,000 acres. A partial accuracy assessment of the mapping product showed mean accuracy among the types to be 82% (range 78%–100%) using a standard binomial distribution algorithm (Cochran 1977, Meidinger 2003).

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**TABLE 1.9**

Example of the National Vegetation Classification

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
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</thead>
<tbody>
<tr>
<td><strong>Physiognomic Categories</strong></td>
<td></td>
</tr>
<tr>
<td>Class</td>
<td>Open Tree Canopy</td>
</tr>
<tr>
<td>Subclass</td>
<td>Evergreen Open Tree Canopy</td>
</tr>
<tr>
<td>Group</td>
<td>Temperate or Subpolar Needle-leaved Evergreen Open Tree Canopy</td>
</tr>
<tr>
<td>Subgroup</td>
<td>Natural/Seminatural</td>
</tr>
<tr>
<td>Formation</td>
<td>Rounded-crowned temperate or subpolar needle-leaved evergreen open tree canopy</td>
</tr>
<tr>
<td><strong>Floristic Categories</strong></td>
<td></td>
</tr>
<tr>
<td>Alliance</td>
<td><em>Pinus jeffreyi</em> Woodland Alliance</td>
</tr>
<tr>
<td>Association</td>
<td><em>Pinus jeffreyi/Quercus vaccinifolia-Arctostaphylos nevadensis/Festuca idahoensis</em></td>
</tr>
</tbody>
</table>
One of the most important developments came as a result of a well-funded initiative by the National Park Service to develop a new standard for mapping and classifying vegetation throughout all national park units (http://biology.usgs.gov/npsveg/standards.html). From 1996 through the present, several National Park units within California began active mapping and classification programs. The first to finish were Point Reyes National Seashore, Golden Gate National Recreation Area, and Yosemite National Park. Other similar projects were instituted within the past several years. These included mapping and classifying the vegetation of the majority of the Mojave Desert (Thomas et al. 2004), Western Riverside County (DFG-CNPS 2004), and Suisun Marsh (Keeler-Wolf et al. 2000). Each of these projects used a gradient-driven sampling program, quantitative analysis, and air-photo interpretation-based vegetation mapping in a GIS environment (Fig. 1.7).

Standardized data collection procedures were developed through state and national efforts. These included relevé sampling protocols developed cooperatively by state and national programs (see both the national park vegetation mapping program website and the CNPS Vegetation Program sampling protocol Web site: http://www.cnps.org/programs/vegetation/protocol.htm).

There are several significant advantages to these integrated mapping and classification projects. From the sampling and classification standpoint they provide significant new baseline field data for long-term monitoring as each sample point is located using GPS at a minimum and in some cases have additional permanent markers. The sample allocation process uses the gradient-driven approach to develop a series of samples representative of the full array of vegetation in a given area. Thus, each area is thoroughly sampled. These samples are analyzed using a standardized protocol that includes the following steps:

a. Screen all sample-by-species data for outliers. Samples that are more than 3 standard deviations (SDs) away from the mean are removed, and species that are in fewer than three samples are removed.

b. Run presence-absence Cluster Analysis (typically Sorensen’s flexible beta method) to determine general arrangement of samples.

c. Run cover class category Cluster Analysis to display a more specific arrangement of samples based on species presence and abundance.

d. Run Indicator Species Analysis (Dufrène and Legendre 1997) at each of the successive group levels in the Cluster Analysis output, from two groups up to the maximum number of groups (all groups have at least two samples).

e. Settle on the final representative grouping level of each Cluster Analysis to use in the preliminary labeling.

f. Preliminary label alliance and association for each of the samples, and denote indicator species from the ISA.

g. Run TWINSPAN (Hill 1979) to test congruence with the subsetted Cluster analysis divisions, comparing the general arrangement of samples with both methods.
h. Develop decision rules for each association and alliance based on most conservative group membership possibilities based on review of species cover on a plot-by-plot basis.

i. Relabel final alliance labels for each sample and arrange in table of database.

j. Use decision rules developed in the new data to assign alliance and association names to all analyzed data and all outlier samples removed from data set.

In some cases, ordination techniques such as Bray-Curtis or Nonmetric Multidimensional Scaling (McCune and Grace 2002) are also used to further define the environmental correlations with the vegetation classification units described. Keys to the vegetation are written and standardized descriptions are also written for each of the newly defined associations or alliances. These descriptions are sent to the western regional office of NatureServe where they are subjected to a review process and if ratified and considered new, entered into the National Vegetation Classification System (NatureServe 2004). Because the projects are usually funded over a time frame of 1 to 3 years, the data are collected, entered, and analyzed in relatively short order, becoming available to the parks and to other organizations relatively quickly.

Recent projects such as The Santa Monica Mountains National Recreation Area (Evens and Keeler-Wolf 2005) and Western Riverside County (Klein and Evens 2005), have taken advantage of the CNPS Rapid Assessment sampling approach for a number of vegetation types that tend to have relatively low within stand species diversity, such as chaparral and coastal scrub types. This technique allows for salient environmental variables to be collected along with a stand-based plotless estimate of cover of all major plant species in different strata (CNPS 2004). The number of samples has increased to well over 1,000 for projects using the Rapid Assessment technique. Higher sample sizes for each vegetation type enables richer description of the variation of all vegetation types and also allows for a more detailed accuracy assessment of the map, since the Rapid Assessment technique also doubles as an accuracy assessment protocol. Releve samples using the CNPS relevé protocol (CNPS 2003), are used for vegetation with more floristic diversity such as woodlands, forests, grasslands, and wetlands.

From the mapping point of view, the map products are very detailed and spatially accurate compared to most other currently available products (Fig. 1.8). The minimum map unit is usually 0.25–0.5 ha. The maps line-up well with standard digital orthophoto quarter quadrangles and therefore provide a satisfying fine scale resolution product suitable for use with standard USGS mapping products such as 7.5-minute quadrangles (Fig. 1.9).

The process of developing the maps accompanying these detailed classifications has taken two directions depending upon whether stereo aerial photo pairs or digital orthophoto-graphs are the basis of the imagery. Classic photo-pair interpretation using the high-resolution diapositives of either true color or color infrared photos usually of from 1:9600 to 1:24,000 still provide the best baseline for these detailed maps. These have been the basis for all of the National Park Service mapping done in the state since 1996. However, the process of taking hand-delineated polygons, usually drawn on acetate or velum affixed to the photo image, then georeferencing, scanning, and orthorectifying the polygon boundaries and mosaicking those individual air-photo scannings into a GIS layer with attributes for each polygon takes much time and money.
FIGURE 1.9 Portion of the vegetation map for the Golden Gate National Recreation Area, Marin Co. overlaid on a standard USGS 7.5-minute topographic map series depicted at 1:10,000 scale. Acronyms are alliance labels for each polygon. CoBr = coyotebrush; CoLO = Coast Live Oak; POak = Poison oak; CaGrN = California annual grassland with Native component (a map unit aggregation of several vegetation types); PNeGr = Purple Needlegrass; MxBm = Mixed Broom (nonnative Genista and Spartium spp.); CaBay = California Bay; AnGr = Annual Grassland; DoFi = Douglas-fir; Euca = Eucalyptus sp.; MoCy = Monterey Cypress (planted); BlB = Bluebush (Ceanothus thyrsiflorus), Urb = urbanized (development).
An alternative approach is to rely on already orthorectified imagery such as USGS Digital Orthophoto Quadrangles (DOQQ) or independently developed orthorectified photos that already meet USGS specifications for spatial accuracy. These may be loaded as a base image within a computer’s GIS project. The photo interpreter simply delineates polygons using a “head’s-up” approach where on-screen digitizing is accomplished using a mouse or a digitizing tablet, while visually tracing the cursor over the boundaries of vegetation stands. The clear advantage of this approach is the reduction of time in processing and piecing together the hand delineations. However, the loss of the three-dimensional stereo-pair perspective, valuable for gleaning subtle information on vegetation structure often necessary to define habitat stage (Mayer and Landenslayer 1988) or floristic associations or alliances, is a disadvantage. Recent work on regional planning efforts such as Napa County (Thorne et al. 2004), Western Riverside County (Evens et al. 2005a), and in San Diego County (Evens et al. 2005b) has made use of this technique. These projects have maintained attribute information on height and structure of the vegetation by relying more heavily on field sampling and verification to take the place of three-dimensional stereo photo interpretation. Using the head’s-up approach a photo interpreter can attribute the individual polygons directly into a computer database, which can be linked with the GIS. The maps produced can be customized based on the many attributes stored and linked within the GIS, thus doing away with the complex polygon notation and symbolism for such earlier products as the S-V maps (see Fig. 1.4).

On some of these projects the use of both DOQQs (as the basis for on-screen delineation) and ancillary stereo pairs (set up with a stereoscope and light table immediately adjacent to the computer work-station) assists in making the fine-level distinctions whenever necessary. Recent technological advances such as split-computer-screen digital paired photography and stereo lens lenses allow for three-dimensional viewing of the digital imagery and head’s-up digitizing may make this a more fluid process making the best of both worlds.

Currently the detailed mixed mapping and classification process is being undertaken on a project-by-project basis throughout the state. The National Park Service, National Forest Service, Bureau of Land Management, Bureau of Reclamation, U.S. Geological Survey, California Department of Fish and Game, University of California, and California State Parks, have all been involved in such projects in the past 9 years. Currently approximately 20% of the state has been mapped and classified using this approach (see Fig. 1.7). The California Native Plant Society has been influential, both through its Vegetation Committee and its Vegetation Program, in instituting standards in both classification and mapping for these projects (Evens and Keeler-Wolf 2003).

Developments and Future Directions

Cooperative Mapping and Shared Standards

One of the most difficult issues traditionally for mapping and classification of vegetation has been the widely varying needs and mandates driving these projects. Colwell (1977) concluded his discussion of California vegetation mapping by stating that 50 years of different styles of mapping serving different agencies and different needs has not produced a completely compatible and uniformly applicable system for understanding the dispersion of vegetation across the state. In addition to the CNPS Vegetation committee’s efforts to standardize and refine the state’s vegetation classification, other attempts have been made in the past 30 years to coordinate efforts among the various agencies and in addition one preceding the CNPS vegetation committee in the mid-1980s where several state and federal agencies convened in meetings for several years to attempt adoption of a standard vegetation classification. The advent of the NVCS and its national acceptance over the last few years has facilitated an integrated approach to classifying and mapping through a federally mandated (FGDC 1997) acceptance of this as the standard.

Over the past few years under the direction of the State Biodiversity Council (http://ceres.ca.gov/biodiversity), the Vegetation Mapping Memorandum of Understanding was developed. A committee representing the state and federal agencies and other organizations involved in California vegetation mapping was convened. The interagency group has agreed upon the use of the NVCS as the standard classification system. This committee has developed a set of standards and guidelines (http://ceres.ca.gov/biodiversity/ vegmou.html). Important among these were a list of attributes to be used by cooperators (Table 1.10). A mapping project using these attributes could address many of the needs of the cooperating agencies including wildlife predictive modeling, identification of floristic vegetation units relating to the NVCS, and fire and fuels modeling and monitoring.

Currently the Committee is cooperating to test the efficient use of these attributes and the ability of the agencies to cooperate on statewide vegetation mapping projects. Due to different mandates and different funding sources between the various state and federal agencies cooperative mapping and classification remains to this day an elusive goal. However, there is general agreement on which agencies and organizations are involved in mapping and classification of different parts of the state and a more cooperative spirit has been engendered through the committee, which has reduced duplication of effort and increased compatibility of products. It is unlikely that fully cooperative mapping and classification will become fully developed until long-term stable funding for coordinated efforts exists.

Image segmentation and combined segmentation and delineation: Despite the recent successes of the integrated
## TABLE 1.10
Attributes Recommended by 2003 State Biodiversity Council Vegetation Mapping MOU Group

<table>
<thead>
<tr>
<th>Map Unit Attribute</th>
<th>Core at All Scales</th>
<th>Optional at All Scales</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Form (Cover Type)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecological Unit</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCV Hierarchy (derived from other fields)</td>
<td>✓</td>
<td></td>
<td>—this consists of multiple fields, one for each hierarchical level</td>
</tr>
<tr>
<td>CalVeg Hierarchy (derived from other fields)</td>
<td>✓</td>
<td></td>
<td>—this consists of multiple fields, one for each hierarchical level</td>
</tr>
<tr>
<td>Land Use/Land Cover—Anderson Level 1</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birdseye Total Cover (max value 100%)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Birdseye Total Cover by trees (canopy closure—sum of conifers and hardwoods % cover)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Birdseye Total Cover by conifers</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Birdseye Total Cover covered by hardwoods (and not covered by overstory trees)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Birdseye Total Cover covered by shrubs (and not covered by trees)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Birdseye Total Cover covered by herbaceous (and not covered by trees or shrubs)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map Unit Aggregation Type (changed name from Internal Diversity)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attribution Method (field-based, modeled, etc)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cause and Date of Record Change (fire, error correction, etc.)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant Species (visible from above, usually 1 to 3 species) by Layer</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size Class (DBH)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height class and/or Vertical Structure</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Land Use/Land Cover—Anderson Level 2</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>WHR Type (derived from other fields)—this consists of multiple fields, one for each hierarchical level</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Shrub Structural Diversity (includes live/dead fuel ratio)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Broad scale: does not apply  
Medium scale: to species for trees, to genus level for other life forms  
Fine scale: to species level  

Broad scale: optional  
Medium scale: optional; see life form  
Fine scale: core
classification and photo-interpretation-based mapping projects, the costs of these projects remain relatively high, and the number of expert aerial photo interpreters familiar with the national vegetation classification system are few. One hope for addressing these issues has come through advancements of image segmentation of more fine-scale imagery products, coupled with machine-based learning programs. Several projects are underway to test the efficiency of these approaches compared with more traditional photo-interpretation approaches. A test of image segmentation versus photo interpretation is being done under the auspices of the Biodiversity Council’s Vegetation MOU committee (http://ceres.ca.gov/biodiversity/Meetings/Special/ILCMP_06.03.pdf). The U.S. Forest Service in the Lake Tahoe Basin Management Area conducting another (Hugh Safford Personal communication February 2005). Image segmentation has also been used in vegetation mapping of Portola and Butano State Parks in the Santa Cruz Mountains of San Mateo County (Roy Woodward personal communication 2004), and is currently being investigated for the Point Reyes National Seashore as a means to update and revise the map based on aerial photography. Preliminary feedback from these projects suggests that with proper field calibration and aggregation of false reflectance and shading polygons reasonable results may be obtained. However, full accuracy assessment has not been completed on any of these projects.

### TABLE 1.10 (continued)

<table>
<thead>
<tr>
<th>Map Unit Attribute</th>
<th>Core at All Scales</th>
<th>Optional at All Scales</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbance Index (roads, exotics, erosion, other impacts)</td>
<td>✓</td>
<td></td>
<td>Broad scale: derived from other data; coarse (low) level of detail</td>
</tr>
<tr>
<td>Groundlevel Total Vegetation Cover (max value 400%—a sum of all cover values from up to four different structural layers)</td>
<td>✓</td>
<td></td>
<td>Medium scale: derived from other data or remotely sensed; medium level of detail</td>
</tr>
<tr>
<td>Groundlevel Total Conifer Cover (max value 100%)</td>
<td>✓</td>
<td></td>
<td>Fine scale: observed or derived from other data; high level of detail</td>
</tr>
<tr>
<td>Groundlevel Total Hardwood Cover (max value 100%—all hardwood cover, whether covered by overstory trees or not)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundlevel Total Shrub Cover (max value 100%—all shrub cover, whether covered by trees or not)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundlevel Total Herbaceous Cover (max value 100%—all herbaceous cover, whether covered by trees/shrubs or not)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Mortality</td>
<td>✓</td>
<td></td>
<td>Broad scale: coarse level</td>
</tr>
<tr>
<td>Special Habitat Elements (related to vegetation only-snags, downed logs, etc; not caves, cliffs, etc.—Observed)</td>
<td>✓</td>
<td></td>
<td>Medium scale: does not apply</td>
</tr>
<tr>
<td>Age Class (difficult to capture using remote sensing)</td>
<td>✓</td>
<td></td>
<td>Broad scale: does not apply</td>
</tr>
</tbody>
</table>

**NOTE**: Broad scale = range of 1:7,500,000 to 1:250,000, typical polygon size of 6,400 to 64,000 acres, and MMU of 50 acres; medium scale = range of 1:250,000 to 1:24,000, typical polygon size of 1,000 to 10,000 acres, and MMU of 10 acres; fine scale = range of 1:24,000 to 1:6,000, typical polygon size of less than 1,000 acres, and MMU of 5 acres.
Change Detection

One of the most valuable tools yet to be fully developed is the detailed assessment of change based on current and past vegetation conditions. As discussed previously, Levien et al. (1998, 1999) have developed a version of change detection using large pixel satellite imagery for wooded areas. In addition, Herwitz, Sandler, and Slye (2000) have quantified local crown change of oaks in woodlands and savannas in the central coast range using detailed measurements of repeat aerial photography, and Vaghti and Keeler-Wolf (2004) have developed change detection for fine-scale, largely herbaceous vegetation in the Suisun Marsh, Solano County. However, much remains to be clarified and for a midscale view of vegetation throughout the state. The existence of the Wieslander (1961) VTM maps provides a tempting basis for a comparison for about 40% of the state. The University of California Davis Information Center for the Environment has been experimenting with methods to efficiently scan and orthorectify the original hard copy VTM maps (Jeff Kennedy and Jim Thorne personal communication 2004). Comparison of the VTM and current mid- to fine-scale-mapping efforts seems possible, because of similar resolution and rules governing the depiction of overstory dominants (Fig. 1.10). However, using existing old maps compared to current maps always raises questions about the underlying methodological differences that could strongly skew interpretation of results. Careful interpretation and likely broadening of scales of assessment to allow for better classification matching may be necessary in some cases (e.g., fine-scale patterning of non-woody vegetation). The uncertain value of comparative studies using Wieslander (1961) plot data and relocated up-to-date samples, especially for difficult to locate stands of chaparral and other scrub, has been recently discussed by Keeley (2004).

The notion of “retrospective” mapping of vegetation has not been fully experimented with, but is a promising
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Avenue of Future Research. The concept of uniformitarianism (the present is the key to the past) could also be applied, and the photo signatures of old photos could be as easily interpreted as those of new. Existing detailed maps using the integrated approach of classification and mapping could lay the groundwork for the use of historical aerial photographs to step back in time and be photo-interpreted using the same techniques to which the current photos were subjected, assuming a detailed field-based classification for the same area is conducted and that most of the signatures are analogous and interpretable for the area using older good-quality aerial photos. Because aerial photos were flown in many parts of California well back into the 1930s, a much more quantitative assessment of change in many different parts of the state could be made.

Melding of European Phytosociology and American Approaches

Some contentious debates have developed over the years between European and North American classification schools (e.g., Rejmanek 1997). Much of this debate has to do with the notion of whether it is more useful to work from the typically American top-down or the typically European bottom-up in the classification hierarchy (Ponomarenko and Alvo 2001). However, in California much cooperation has proceeded through the association of western vegetation ecologists and European phytosociologists in recent years. This work has been particularly fruitful in certain vegetation types such as serpentine grassland (Rodriguez-Rojo et al. 2001a, 2001b) and vernal pools (e.g., Barbour et al. 2003, 2005). As the California and the national vegetation classification systems grow using the plant association as the basis of vegetation description, there will be less and less to argue about, particularly as reanalysis of an ever-growing data set of comparable relevé samples is developed.

Archiving and Analysis of Vegetation Plots

One of the most promising pathways for further refinement of the vegetation classification in the state involves the digital archiving and dissemination of vegetation data. Several efforts are underway to develop Web-based or other data-archiving and retrieval systems. A national effort is being spearheaded through VegBank (http://vegbank.org/vegbank/index.jsp). VegBank is the vegetation plot database of the Ecological Society of America’s Panel on Vegetation Classification. It currently contains over 21,000 plots nationwide including approximately 1,000 plots from California (mostly from National Park mapping projects). This system enables qualified users to download, enter, and analyze plots most of which are relevés. The California Department of Fish and Game in cooperation with the California Native Plant Society maintains a system of databases of all of their vegetation projects. Collectively called the California Vegetation Information System (CVIS), it currently houses about 13,000 samples collected within the past 10 years and includes relevés, rapid assessment, and point intercept transect data. Information about CVIS can be obtained by contacting the author at (tkwolf@dfg.ca.gov). Previously collected data including the U.S. Forest Service Ecology Plots collected by U.S. Forest Service California Regional Ecology staff include approximately 7,000 plots (contact Hugh_Safford@fs.fed.us), about 7000 Forest Inventory and Analysis plots (archived through the U.S. Forest Service’s Remote Sensing Lab archivist, Kama Kennedy; Kkennedy@fs.fed.us) and virtually all of the known 13,000 original VTM plots collected by Wieslander crews in the 1930s have been entered by the combined forces of the Wieslander data group (contact Barbara Allen-Diaz ballen@nature.berkeley.edu) to convert all existing and newly acquired vegetation plot data into digital databanks that can be accessed by any qualified ecologist for further analysis. Cooperative efforts are under way to link these various databases and provide these data for further classification analysis and other uses.

These data are beginning to be used for a number of statewide and national efforts including the LandFire (http://www.landfire.gov/index.html) analysis cooperative program with the U.S. Forest Service and NatureServe to develop national data driven fire models for all vegetation, and an effort to use vegetation data for modeling global climate change (J. Thorne personal communication, January 2005). There is significant potential for these archived vegetation samples to be used for reference conditions for restoration efforts, modeling the occurrence of rare plant and animal species (in conjunction with vegetation maps), and many other purposes.

Filling in “Holes” in the Statewide Classification

Within a few years it will be possible to display all the locations and data for the thousands of vegetation samples taken statewide. With this will come the ability to physically see which parts of the state have been adequately represented or not by samples and determine which parts of the state are more in need of further basic sampling to refine the statewide vegetation classification. At this point the largest geographic gaps in our knowledge appear to be in the largely privately held lands of the outer and middle North Coast Ranges, and the outer and middle southern Coast Ranges from Santa Barbara County north to the San Francisco Bay. For the South and central Coast Ranges, federal- and state-managed lands are now undergoing vegetation assessments, but much has yet to be learned of the vegetation of the Santa Cruz Mountains, the Diablo Range, and the non-federally managed lands of the Temblor, the Cuyama, and other mountains that make up the central and South Coast Ranges. In the North Coast Ranges west of the Mendocino National Forest and north of Point Reyes National Seashore there are large gaps in our classification knowledge until we reach Redwood

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National Park and the larger Redwood State Parks of Humboldt County.

However, because the first edition was written, there has been exceptional activity in the state, now surpassing the work done in the 1930s by Wieslander's efforts. Given the current emphasis that vegetation classification and mapping is receiving, it should take less than 10 years before a relatively complete classification and detailed map of the state's natural vegetation exist.

References


Hill, M.O. 1979. TWINSPLAN: a Fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Section of ecology and systematics, Cornell University, Ithaca, NY.


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van der Meer J. 1979). [MB58]


Western Riverside County (DFG-CNPS 2004).

