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A VEGETATON MAP OF NAPA COUNTY USING THE MANUAL OF CALIFORNIA VEGETATION CLASSIFICATION AND ITS COMPARISON TO OTHER DIGITAL VEGETATION MAPS

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ABSTRACT

In 1995, the *Manual of California Vegetation* introduced a quantitatively based method for classifying and mapping vegetation in California. We used this method to develop a classification of vegetation types for Napa County, which we then used to attribute the polygons of a new vegetation map. The new map was produced by on-screen digitizing over USGS Digital Orthophoto Quarter Quads (DOQQ's) with the aid of ancillary digital maps. We identified the distribution of 56 landcover types, 48 dominated by natural vegetation, at the alliance or aggregated alliance level, in 28,456 polygons across 2042 km^2. The effective minimum mapping unit is below one hectare. The methods used, the mapping classification system developed, and the extents of landcover types mapped are presented. In a comparison with two previous digital vegetation maps for the area, the US Forest Service's CalVeg and the Gap Analysis Program's GAP maps, the MCV map had finer spatial and floristic resolution. The MCV map has 15 more vegetation types than CalVeg and 22 more vegetation types than GAP. The MCV map contains more riparian corridors and isolated wetlands, identifying 157 km^2 of these types, compared to 7 km^2 for CalVeg and a non-spatial result for GAP.

Key Words: vegetation classification, map, GAP, CalVeg, DOQQ, riparian, serpentine.

Physical and biotic conditions, along with site history, drive the composition of plants found at any site (Major 1955; Kent and Coker 1992). Therefore, vegetation represents a unique biotic response to local environmental conditions at a site. Vegetation composition is in turn a major factor in determining what animals may be present. Because of the interactions between environment, plants, vegetation and community structure, vegetation distribution has long interested ecologists and natural resource managers. Documenting regional vegetation is useful for many purposes, including biodiversity assessment, conservation planning, resource management, and species distribution modeling (Stohlgren et al. 1997; Scott and Jennings 1998; Margules and Pressey 2000; Scott et al. 2002; Oliver et al. 2004). At watershed and broader scales, the most common way to document the vegetation is with a spatial map. The basic components of a vegetation map are: a vegetation classification, delineation of the landscape into map units (polygons), and attribution of those map units with classification labels.

This study presents the results of a recently completed vegetation mapping effort for 2042 km^2 of Napa County (map available at http://cain.nbii.gov/regional/napavegmap/). We developed a vegetation classification at the alliance, the aggregated alliance (Super Alliance) and in a few cases, the finer association level for the county using classification units described in the *Manual of California Vegetation* (MCV) (Sawyer and Keeler-Wolf 1995). Species names follow the Jepson flora (Hickman 1993). We delineated the landscape into map units (polygons) using U.S. Geological Survey (USGS) digital orthophoto quarter quads (DOQQ's), because of their low cost, ready availability, and high spatial resolution. DOQQ's have one-meter pixels and high geospatial accuracy that allowed us to map stands to a target minimum mapping unit (MMU) of one hectare (ha), with a horizontal spatial accuracy that meets USGS map accuracy standards for 1:24000-scale maps (U.S. Geological Survey 1999). Finally, we labeled the polygons using the MCV vegetation classification and an additional list of provisional or aggregated vegetation types, not yet formally defined in the MCV. Methods, results and discussion sections are broken into two parts: the first describes the methodology and the map, while the second compares it to two existing maps. Supplemental map materials not presented in

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this article are available for download at http://cain.nbii.gov/regional/napavegmap/.

The techniques presented here are a simple, low cost variant of methods currently being used to map the vegetation of California's National Park units (The Nature Conservancy and Environmental Systems Research Institute 1994a) as well as the California Mojave Desert region (Thomas et al. in press), and other conservation planning areas including western Riverside County.

The *Manual of California Vegetation* (Sawyer and Keeler-Wolf 1995), the principal authority for our map's vegetation types, is the culmination of work coordinated by the California Native Plant Society (CNPS), to develop a consensus classification and standard methodology for floristic descriptions in California. MCV types are based on dominant canopy species that define an alliance and have a correspondingly discernable signature on base map imagery.

The mapped vegetation definitions include size and cover estimates, which permit the conversion (a crosswalk) of MCV-based alliance names to the California Wildlife Habitat Relationship (CWHR) habitat types (Mayer and Laudenslayer 1988; California Department of Fish and Game 2002).

Vegetation Classification System Used

The MCV classification system was selected for the new map for four reasons. First, it is consistent with the National Vegetation Classification Standard (NVCS) hierarchy (The Nature Conservancy and Environmental Systems Research Institute 1994b; Federal Geographic Data Committee 1997) at the alliance and association level. Second, developing the MCV classification through applied mapping projects extends the evolving NVCS floristic classification standard to the montane, mediterranean-climate ecosystems of California. Third, as a quantitatively based classification system, it is objective and repeatable by different investigators, using standard techniques. Finally, it is an adaptive system. As new vegetation types are identified, they may be proposed for inclusion in the MCV. Mapping projects, like this one, play a continuing role in MCV development.

An inter-agency and academic group convened by the CNPS Vegetation Committee developed the MCV vegetation classification (Keeler-Wolf 1993, 1997; Hillyard 1999). It is designed to integrate with the hierarchical NVCS classification. The highest levels are based on dominant growth form, plant physiognomy (e.g., leaf type and seasonality), stand structure, and abiotic factors such as climate, hydrologic regime and geographic region (e.g., ''temperate'' or ''tropical''); while the lowest levels are based on the floristic composition of the vegetation (Grossman et al. 1998). The NVCS has been adopted as a federal agency standard, at the physiognomic level, by the Federal Geographic Data Committee (FGDC) (1997). The MCV classification is also hierarchical. Finer scale levels of alliance, super-alliance and association may be combined for display at coarser physiognomic levels (formation and class) to show broader vegetation patterns (Grossman et al. 1998; Maybury 1999).

The MCV is an evolving classification system, with new data still being added to the system: over 7500 California vegetation plots of field data have been collected using MCV protocols from 1994 to spring 2003 (Sawyer and Keeler-Wolf 1995; Keeler-Wolf personal observation). The plots have been used to quantitatively describe 415 alliances and over 1450 associations. Ultimately, Keeler-Wolf (personal observation) estimates that some 2000 associations occur in California. For comparison, Maybury (1999) has documented 1642 alliances and 4515 associations nationwide, and NatureServe (http://www.natureserve.org/) estimates that there will be 5000–6000 associations nationwide when all fieldwork is completed (Dennis Grossman personal communication, Science Division of NatureServe).

Previous Vegetation Maps

At least five prior maps of the natural vegetation of Napa County exist. Two early maps are the Wieslander Vegetation Type Maps (VTMs) (Wieslander 1935) and Kuchler's 1:1,000,000-scale map (1988). Two more recent digital vegetation maps exist, derived from 30-meter Landsat Thematic Mapper (TM) satellite imagery: the CalVeg map (Schwind and Gordon 2001), and the California Gap Analysis map (GAP) (Thorne 1997; Davis et al. 1998). The CalVeg and GAP maps are compared to the MCV map in this study. A fifth available map, the National Land Cover Database (NLCD), is a national map of physiognomic types, based on Landsat (TM) imagery (Vogelmann et al. 1998).

The CalVeg map was originally used for timber assessment and forest management, but it is now also used for land cover change detection, on a five-year re-mapping cycle. The CalVeg classification emphasizes single species dominance, using an automated supervised classification algorithm, applied to satellite imagery. The greatest species composition detail is provided for tree-dominated (especially conifer) types, with less detail for shrub and herb dominated types. This floristic classification is one of four separate classification components of the CalVeg mapping methodology that identify percent cover, tree size, lifeform and vegetation type (i.e., dominant species). For lifeform, CalVeg identifies 11 types: conifer, hardwoods, mixed conifer and hardwoods, shrub, wet herbaceous, dry herbaceous, barren, water, snow, agricultural and urban. The lifeform category identifies a stand as coniferous if 10% or more of the cover is in conifers. If conifer cover is $<10\%$ and hardwood cover is $>10\%$, it is a hardwood type. If there is $\leq 10\%$

tree cover, but ≥ 10% shrubs cover, it is labeled a shrub polygon. If none of these three categories apply, it is assigned to one of the other categories (Schwind and Gordon 2001).

CalVeg identifies one, two or in rare cases more than two dominant plant species per lifeform polygon. Single species are considered dominant if they occupy >50% of the dominant lifeform cover. Two species co-dominants are identified under a variety of combinations of cover class, and multiple species are identified for highly diverse types such as enriched mixed conifer forests (Schwind and Gordon 2001). The CalVeg MMU is 1 ha and the map covers most of the forested regions of the state (Schwind and Gordon 2001).

The GAP vegetation map is meant to be used in conjunction with a map representing land management classes to identify, at the ecoregional scale, vegetation types that are poorly represented on lands managed for conservation (Davis et al. 1995). The GAP map identifies up to three dominant overstory plant species in each vegetation type and records up to three vegetation types within each polygon (Holland 1986). Each vegetation class is ranked as to the percentage of the polygon it occupies. GAP converts species combinations into Holland types (Davis et al. 1998), which in turn are converted to CWHR types (Mayer and Laudenslayer 1988). Since publication of the GAP map, CDFG has replaced the Holland classification with the MCV classification and revised CWHR to facilitate a CWHR-MCV crosswalk. The GAP map's MMU is 100 ha, too coarse for most local planning uses. Unlike most other California vegetation maps, GAP covers the entire state and is part of a national program of similar state-level maps.

We used Holland types for comparison to the MCV map, as those are the closest to the vegetation types in the MCV map. To total the spatial distribution of any given Holland type, we multiplied the percentage of that type found in each polygon by that polygon's area and added the results from all the polygons. Note that while total areas can be calculated, the GAP map does not map the locations and extents of Holland types within each polygon.

Study Area

Napa County was selected as the study site because of its floristic, vegetative and environmental diversity, which provided a robust test of the mapping methodology. A biodiversity assessment of Napa County (Underwood and Russell et al. 2001) concluded that existing vegetation maps were of insufficient spatial and floristic resolution to support accurate biodiversity conservation planning. Strong local support for a new vegetation map facilitated the selection of the county, and greatly aided the investigators. Napa County is located north of San Francisco and covers approximately 2042 km^2.

The flora of Napa County consists of roughly 1520 taxa, based on a draft manuscript of the Flora of Napa County (Jake Ruygt personal communication). Of Napa's 1520 taxa, 1102 are native (present in California pre-settlement, 72.5%) and 418 are exotic (27.5%), compared to 4839 (82.5%) native and 1023 (17.5%) exotic for California's 5862 taxa (Hickman 1993). Thus, Napa County is home to 32% of the state's native flora, while comprising only 0.5% of its total area. This floristic diversity is a function of high climatic, topographic, and edaphic diversity (Ornduff et al. 2004), as well as the overlap of many species at the limit of their ranges (Jake Ruygt personal communication). It leads to a high diversity of vegetation types, many of which are not well documented. This high degree of biodiversity, rarity, and endemism is significant at both statewide and national levels (Stebbins and Major 1978; Stein 2002). The greatest biodiversity occurs in the north county, where elevation and moisture gradients are the steepest and elevations highest (Underwood-Russell et al. 2001).

Physiographically, Napa County exemplifies the California Coast Ranges, with steep, roughly parallel, northwest-trending mountain ridges separated by fertile, flat-bottomed valleys. The county's mediterranean climate has a maritime influence, with a strong, decreasing moisture gradient from west to east and from high to low elevation. Mean annual precipitation ranges from 51 to 140 cm/yr (Daly et al. 1994; Miles and Goudy 1997; Daly et al. 1998). There are 11 broad soil associations (Lambert and Kashiwagi 1978), spread over volcanic, sedimentary and ultramafic (serpentine) terraines (Norris and Webb 1990; Miles and Goudy 1997). The largest watersheds are the Napa and Suisun. The largest lake, Berryessa, is man made and covers 5.7% of the county (determined using the map presented here). Land ownership is predominantly private (Underwood-Russell et al. 2001).

Methods

Map Development

Map development had five stages: 1) landcover (vegetation) classification and minimum mapping unit (MMU) definition; 2) base map imagery and ancillary GIS data layers acquisition; 3) field reconnaissance to refine the classification and develop a photo interpretation key; 4) vegetation polygon delineation and attribution; and 5) field verification to assess polygon label accuracy and revise polygon definitions and the photo interpretation key, as needed. A five-person crew conducted photo interpretation, polygon delineation and attributing from February to June 2002. A two-person crew conducted field verification from early August through late October 2002.

Landcover classification and target MMU. We developed a list of vegetation types to be mapped by combining a literature review with input from local botanists. The list contained described vegetation types and vegetation types observed in the county, but for which no formal description (NFD) currently exists. The NFD types were designed to be consistent with the MCV classification hierarchy (Sawyer and Keeler-Wolf 1995). A vegetation type was labeled NFD if: 1) it was not currently in the MCV alliance classification, 2) it was defined in MCV, but could not be distinguished on the imagery from another type, or 3) it was an undefined association within a previously defined MCV alliance. Once a type was identified as NFD, we included it in all subsequent analyses, assuming that it will eventually be described and incorporated in the MCV.

We targeted the vegetation alliance level, rather than the finer association level for polygon labels, because associations are often defined by understory species not visible in remotely sensed imagery, and because associations are less completely defined than alliances for the region (Sawyer and Keeler-Wolf 1995). However, we used the finest hierarchical level discernable on the base imagery, which includes a few associations. Virtually all grasses and many shrub types are not identifiable to species in the imagery, and in forest types, foothill pine (*Pinus sabiniana*) was hard to discern, when its cover was $<$20%. In these cases, we used the term ''super alliance'' to indicate an aggregated-alliance, intermediate between a floristic alliance and a physiognomic formation.

Other vegetation data we recorded beyond the vegetation type were: 1) cover classes for all vegetation types, and 2) size classes for tree dominated types only. There are five cover classes, based on percent cover of the dominant stratum: 2–10%, 11–25%, 26–40%, 41–60%, and $>$60%. There are six size classes: seedlings ($<$2.5 cm diameter at breast height, DBH), saplings (3–15 cm DBH), small (16–30 cm DBH), medium (31–63 cm DBH), large ($>$63 cm DBH), and multilayered medium to large trees over smaller trees with combined cover $>$ 60%. Size and cover class for each applicable polygon were recorded to facilitate translation between MCV vegetation and CWHR habitat types (California Department of Fish and Game 2002). A crosswalk between MCV and CWHR classifications allows the MCV map to be used to estimate habitat suitability for vertebrate species and habitat management.

Given the complex, fine grained nature of the vegetation mosaic and the one-meter square size of the 1993 DOQQ imagery, we selected a target MMU of one hectare (2.5 acres), with the caveat that we would delineate smaller polygons, when feasible, for high-value vegetation types such as seeps, riparian corridors, and other wetlands.

Base map imagery and ancillary GIS data. We digitized vegetation polygons and characterized their vegetation from the most recently available DOQQ's for Napa County, flown in 1993. The following ancillary maps and air photos were used to aid polygon delineation and attributing: 1) 30-meter digital elevation models (DEMs), 2) digital raster graphics (DRGs) of the USGS 1:24,000 topographic maps, 3) the most recent fire history map from the California Department of Forestry and Fire Protection (CDF 1999), 4) the California Division of Land Resource Protection's Farmland Mapping and Monitoring Program (FMMP) maps for Napa County (produced every two years from 1984–1998, we used the 1994 map, http://www.consrv.ca.gov/DLRP/fmmp/), 5) color photocopies of ~410 color, 1:24,000 stereo pair aerial photos (WAC Corporation, http://www.waccorp.com/califcoun.shtml), 6) color photocopies of the 1931 Wieslander Vegetation Type Maps for southern Napa County, together with the associated VTM plot data and summary descriptive text (from the Dr. Allen-Diaz collection at UC Berkeley), 7) soils and geology maps depicting serpentine terrains (Lambert and Kashiwagi 1978; Wagner et al. 1982), and 8) occurrence maps of vernal pools and selected plant species of concern, provided by Napa County botanist, Jake Rugyt.

Field reconnaissance for classification refinement and photo interpretation key. Field reconnaissance consisted of a three-day, 123-stop driving tour of the county by the project ecologists and photo interpreters that documented vegetation type for 221 vegetation stands. This information was used to: 1) identify previously undocumented vegetation types and revise the vegetation classification scheme; 2) document stands of known composition, structure, and location for use in developing photo interpretation signatures; and 3) collect data on dominant species composition and environmental features at observation points to build vegetation–environment relationship models (developed from Barbour and Major 1988).

Slope, aspect, elevation, substrate, site moisture, land management and disturbance regimes and other environmental factors were recorded at each stop. The initial list of 89 possible vegetation types was distilled into a list of 53 mappable vegetation types, each linked to a vegetation-environment relationship model. Seven non-vegetated or sparsely vegetated land cover types (mudflat, open water, urban, vacant, serpentine barrens, rock outcrop and unidentified), plus agriculture, were also recorded. These observation points allowed the photo interpreters to identify image signatures for known vegetation types. The vegetation-environment relationships and the signature characteristics were then compiled in a photo interpretation key, which was used to attribute unvisited polygons (see http://cain.nbii.gov/regional/napavegmap/ for the key).

Polygon delineation and labeling. Digitizing was done on-screen, drawing vector outlines of each visible stand of vegetation. In general, the MMU is

1 ha. However, units down to ~0.25 ha were delineated around seasonally wet meadows, easily mapped pocket grasslands and farm ponds. Over 5000 polygons are less than 1 ha in size. Polygons were delineated using a larger MMU (~2 ha) for subtle divisions between very similar floristic types or to delineate within-type changes in stand size or cover class. A 5-ha MMU was used for urban features within an agricultural polygon or agriculture within urban areas.

Using the photo interpretation key, a team of five photo interpreters digitized and labeled >31,000 polygons, each encompassing a stand of vegetation (or non-vegetation cover type) of uniform structure, composition, density and size class (if applicable), as discernable on the DOQQ's. Polygon delineation was recorded on digital 7.5-minute USGS quads, each of which encompasses four 1:12,000-scale DOQQ's. These quads were then merged to create a whole-county map. Ancillary data were used, when appropriate, to facilitate polygon labeling.

Locations of known vegetation were used to start the polygon label attribution process. Photo interpreters trained on these locations, and then identified other, nearby locations of the same vegetation type using the species-environment distribution models and DOQQ image signatures. Vegetation cover and size classes were visually estimated, with the assistance of the ancillary stereo air photo pairs. Size classes were determined using canopy size-diameter at breast height (dbh) regressions available to the air photo interpretation subcontractor (Aerial Information Systems). The total number of polygons was reduced to 28,456 by merging adjacent polygons with identical label attributes.

Field verification and map unit revision. Field verification was done using a preliminary map of the labeled vegetation polygons printed on the imagery at a scale of 1:14000. Field crews drove all available public roads, and as many private roads as we could get permission to access.

When possible, the crews physically entered polygons that were verified. However, most of the field verification consisted of observing nearby slopes with binoculars from viewpoints along road rights-of-way. Verification at a distance was only feasible when the vegetation mosaic allowed extrapolation of the visual signature from nearby, readily identifiable stands to comparable stands over successively larger distances. The majority of the verification distances were <300 m, but for certain forest types with distinctive canopy characteristics, verification was possible at distances up to 600 m.

Field crews documented both correct and incorrectly labeled polygons. For incorrect polygons, an abbreviated Rapid Verification Assessment (RVA) form was used to note the amended vegetation type, attribute features and any new or unusual species. Once a pattern was documented, repeated instances of the same type of label error were recorded directly on the field maps in abbreviated form. Approximately three team months (two-person teams) were spent checking polygons.

Field verification data were used to make corrections in vegetation type descriptions and for polygon labeling. Field verification data were also collected to refine and correct the species-environment relationship models and the photo interpretation key used to label the polygons. These revisions permitted identification of nearby, unvisited polygons, which might need label corrections. Unvisited polygons requiring attribute edits were assigned a more generalized vegetation type, generally abstracting from alliance level to super-alliance.

Post-production map accuracy assessment. A formal post-production map accuracy assessment was not included in the project due to funding limitations that precluded the field work needed not only for the map accuracy assessment itself, but also for the plot data collection needed to quantitatively define the provisional NFD vegetation types. We chose to use all the verification data to develop the best map we could, given limited resources. We present results from the verification effort.

Map Comparisons

We compared the Napa MCV map to two other available digital vegetation maps: the California Gap Analysis (GAP) map and the US Forest Service CalVeg map. The comparisons are based on: 1) the vegetation classifications used; 2) the extent of different vegetation types mapped; and 3) the number and size distribution of polygons.

Comparison of vegetation classifications. We developed a crosswalk between the three maps' vegetation classification systems by comparing the vegetation classes developed for our mapping effort with the lists of vegetation types from the GAP and CalVeg maps for Napa County. We began by identifying which CalVeg species types and GAP vegetation classes (Holland types) correspond to our MCV types, and which types or classes are unique to one of the three maps. Several GAP or CalVeg classes may correspond to a single MCV class, but we did not allow a single MCV class to go to more than one class in the other systems. Extents of all vegetation classes from all maps are included as part of the mapped extents comparison.

Extent of mapped vegetation types. To compare the extent of mapped vegetation types in the county, we selected an area slightly smaller than the full extent of the county (1835 km^2), since we worked with a version of CalVeg that did not then include a small section of the southern Napa Valley. We clipped the GAP map and the MCV map to the extent of the current CalVeg coverage, then compared the extents of different vegetation types mapped by each methodology. Vegetation extents were compared for all vegetation types, and condensed into nine groups for more general comparison.

Polygon number and size distribution. We compared the size distribution and number of polygons in each of the three vegetation maps. CalVeg and GAP are regional maps that extend beyond the borders of Napa County, so they were clipped with a county outline. However, clipping the maps created many remnant polygons which had extended outside the county. These internal remnants are often small slivers that do not accurately reflect the true size of those polygons. We used a GIS procedure to exclude the full spatial extent of any polygon that touched the county line, here termed 'internal' for all three maps. This eliminates the problem of comparing partial polygons, reduced in size while clipping. Using the internal form also removed the unmapped section of Napa County from the CalVeg map mentioned above. We also include a version of GAP that includes all polygons that touch the border, named 'external', since there are so few GAP polygons in the county. We then recorded the number of polygons in each map and binned them into 19 size classes, starting with 0.25 (2^{-2}) hectares and doubling in area at each step to a top class of greater than 65,536 (2^{16}) hectares. We removed the Lake Berryessa polygon, the largest single polygon in all maps of the county, before analysis.

RESULTS

The Napa MCV Map

The Napa County MCV map covers 2042.14 km^2 (Fig. 1; for a copy go to http://cain.nbii.gov/regional/napavegmap). We identified 56 landcover types within that area (Table 1). They range widely from common to rare (Table 1, Fig. 2). Four types are human related or non-vegetative: Urban or Built up, Agriculture, Vacant, and Water. An additional three types are defined by geology or geomorphic processes rather than by vegetation: Rock Outcrop, Serpentine Barrens, and Riverine, Lacustrine and Tidal Mudflats. These rock types likely have sparse annual plants that cannot be mapped to the alliance level using DOQQ's or remotely sensed imagery.

Of the 48 vegetation-dominated cover types, 28 were previously defined MCV types, at the following hierarchical levels: three formations, one super alliance, 23 alliances and one restoration type. The remaining 20 vegetation types were not formally defined (NFD): ten NFD super alliances, two NFD alliances and eight NFD associations.

The three most extensive vegetation types are: Blue Oak (*Quercus douglasii*) alliance, California Annual Grasslands alliance, and Chamise (*Adenostoma fasciculatum*) Chaparral alliance. The three types with the least mapped extent are the California Juniper (*Juniperus californica*) alliance, Sugar Pine—Canyon Live Oak (*Pinus lambertiana*—*Quercus chrysolepis*) super alliance, and the Coyote Bush—California Sagebrush—Lupine spp. (*Baccharis pilularis*—*Artemesia californica*—*Lupinus* spp.) super alliance. Three vegetation types largely represent non-native plants: Eucalyptus alliance, Upland Annual Grasslands and Forbs and California Annual Grasslands. Forty-five types are dominated by native vegetation.

Agriculture occupies 12.5% of the county, water and urban total 5.7% and 5.2%, respectively. In aggregate, the five cover types that represent the human-mediated removal of natural vegetation cover encompass 24.1% of the county, exclusive of San Pablo Bay, leaving 75.9% with natural or semi-natural vegetative cover. Fifty percent of the vegetation types occupy in aggregate five percent of the land (Table 1). Note that water is almost exclusively a human-dominated cover type, because all mapped bodies of open water are either artificial reservoirs, agricultural irrigation ponds, or inundated, diked bay flats.

Vegetation classification and field verification. During field verification, 3108 polygons were observed, representing ~11% of total polygons. Of the 3108, 1001 (32.5%) required some degree of correction, 200 polygons (6.2%) initially labeled 'unknown' were assigned to a cover type (not considered an error), and 1907 were judged to be entirely correct (61.3%). In most cases, editing changes were minor (e.g., correcting one of two oak species in a mixed oak alliance). An additional 1243 polygons flagged as 'unknown' types by the photo interpreters, were not field visited, due to limited access. The changes recorded in polygon labels were then applied in a GIS environment to make changes to nearby, similar, but unvisited polygon labels. Finally, a small number of polygons (203, totaling 0.3% of the county's area, 0.7% of all polygons) were unidentifiable on the base imagery and remain unclassified.

Analysis of the field verification data resulted in a reduction of the initial, pre-reconnaissance natural and semi-natural vegetation classification from 53 to 48 types.

This reduction reflected the inability of the photo interpreters to reliably distinguish foothill pine in

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FIG. 1. Vegetation map of Napa County using the Manual of California Vegetation Classification. This map represents the results of the MCV mapping effort in Napa County and depicts 56 land cover types in 28,456 polygons across 2,042 km^2. The legend lists the cover types in the same order as in Table 1. Landcover types found on serpentine are indicated in hues of purple and pink.

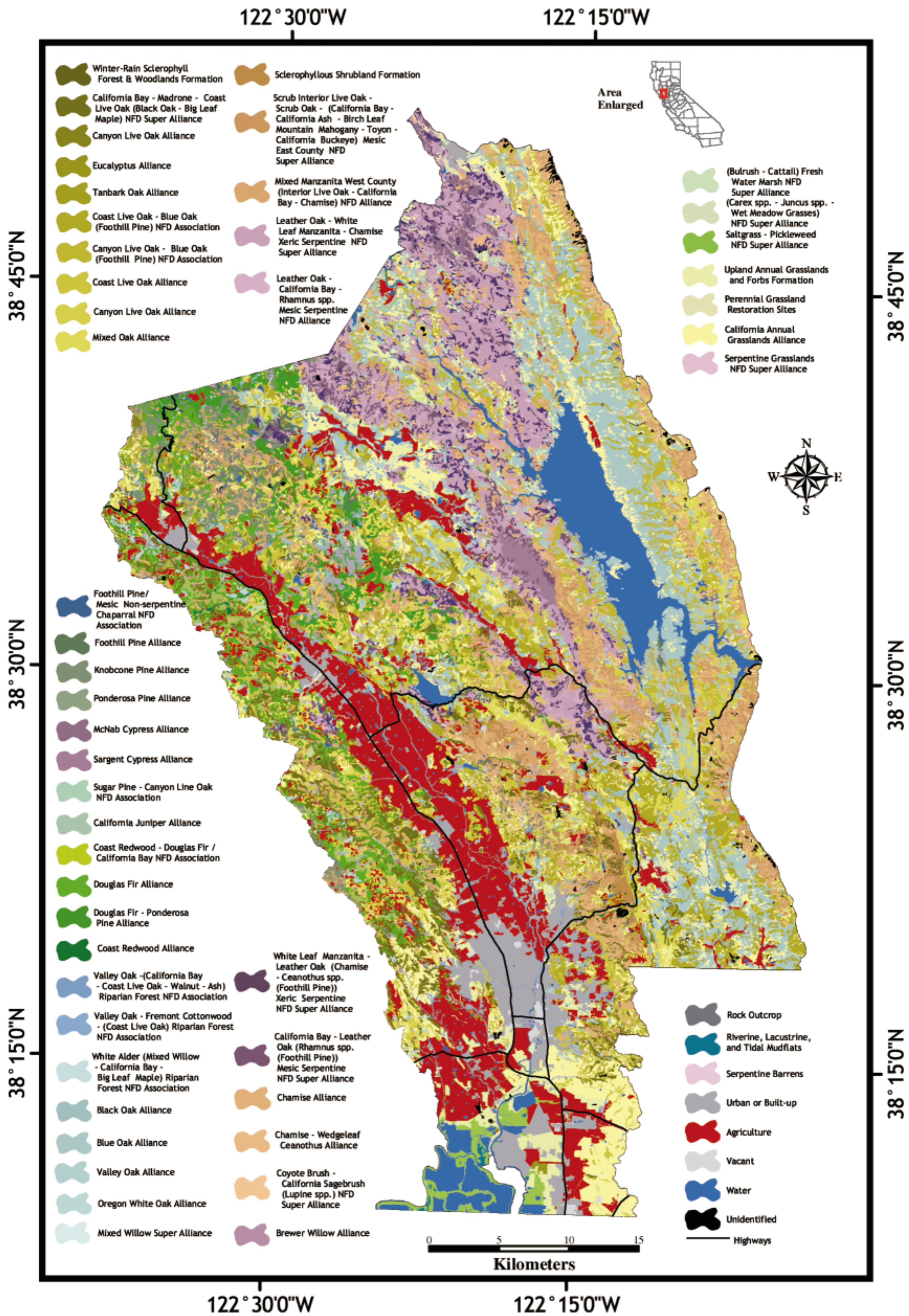
122°30'0"W
122°15'0"W
38°45'0"N
38°30'0"N
38°15'0"N
Winter-Rain Sclerophyll Forest & Woodlands Formation
California Bay - Madrone - Coast Live Oak (Black Oak - Big Leaf Maple) NFD Super Alliance
Canyon Live Oak Alliance
Eucalyptus Alliance
Tanbark Oak Alliance
Coast Live Oak - Blue Oak (Foothill Pine) NFD Association
Canyon Live Oak - Blue Oak (Foothill Pine) NFD Association
Coast Live Oak Alliance
Canyon Live Oak Alliance
Mixed Oak Alliance
Sclerophyllous Shrubland Formation
Scrub Interior Live Oak - Scrub Oak - (California Bay - California Ash - Birch Leaf Mountain Mahogany - Toyon - California Buckeye) Mesic East County NFD Super Alliance
Mixed Manzanita West County (Interior Live Oak - California Bay - Chamise) NFD Alliance
Leather Oak - White Leaf Manzanita - Chamise Xeric Serpentine NFD Super Alliance
Leather Oak - California Bay - Rhamnus spp. Mesic Serpentine NFD Alliance
Area Enlarged
(Bulrush - Cattail) Fresh Water Marsh NFD Super Alliance
(Carex spp. - Juncus spp. - Wet Meadow Grasses) NFD Super Alliance
Saltgrass - Pickleweed NFD Super Alliance
Upland Annual Grasslands and Forbs Formation
Perennial Grassland Restoration Sites
California Annual Grasslands Alliance
Serpentine Grasslands NFD Super Alliance
N
W
E
S
Foothill Pine/ Mesic Non-serpentine Chaparral NFD Association
Foothill Pine Alliance
Knobcone Pine Alliance
Ponderosa Pine Alliance
McNab Cypress Alliance
Sargent Cypress Alliance
Sugar Pine - Canyon Line Oak NFD Association
California Juniper Alliance
Coast Redwood - Douglas Fir / California Bay NFD Association
Douglas Fir Alliance
Douglas Fir - Ponderosa Pine Alliance
Coast Redwood Alliance
Valley Oak -(California Bay - Coast Live Oak - Walnut - Ash) Riparian Forest NFD Association
Valley Oak - Fremont Cottonwood - (Coast Live Oak) Riparian Forest NFD Association
White Alder (Mixed Willow - California Bay - Big Leaf Maple) Riparian Forest NFD Association
Black Oak Alliance
Blue Oak Alliance
Valley Oak Alliance
Oregon White Oak Alliance
Mixed Willow Super Alliance
White Leaf Manzanita - Leather Oak (Chamise - Ceanothus spp. (Foothill Pine)) Xeric Serpentine NFD Super Alliance
California Bay - Leather Oak (Rhamnus spp. (Foothill Pine)) Mesic Serpentine NFD Super Alliance
Chamise Alliance
Chamise - Wedgeleaf Ceanothus Alliance
Coyote Brush - California Sagebrush (Lupine spp.) NFD Super Alliance
Brewer Willow Alliance
Rock Outcrop
Riverine, Lacustrine, and Tidal Mudflats
Serpentine Barrens
Urban or Built-up
Agriculture
Vacant
Water
Unidentified
Highways
0 5 10 15
Kilometers

TABLE 1. SPATIAL EXTENT OF MANUAL OF CALIFORNIA VEGETATION TYPES IN NAPA COUNTY. Area measurements for each landcover type are shown. The table shows the percent of the county occupied by each landcover type; the rank order by area in descending order; and the number of polygons in each type. The code represents the numbers assigned in the GIS version of the map and is included for reference along with species names according to the Jepson Flora (Hickman 1993).

Code	Cover type	Area (ha)	% Total area	Area rank order	Number of polygons
1100	Winter-Rain Sclerophyll Forests and Woodlands Formation	250.6	0.1	40	60
1101	California Bay–Madrone–Coast Live Oak–(Black Oak–Big Leaf Maple) NFD Super Alliance (*Umbellularia californica–Arbutus menziesii–Quercus agrifolia* (*Quercus kellogii–Acer macrophyllum*)	7423.6	3.6	10	849
1122	Canyon Live Oak Alliance (*Quercus chrysolepis*)	229.2	0.1	41	22
1123	Eucalyptus Alliance (*Eucalyptus* spp.)	165	0.08	46	52
1124	Tanbark Oak Alliance (*Lithocarpus densiflorus*)	99.3	0.05	51	9
1201	Coast Live Oak–Blue Oak–(Foothill Pine) NFD Association (*Quercus agrifolia–Quercus douglasii* (*Pinus sabiniana*))	10,734.8	5.26	8	1840
1202	Canyon Live Oak–Blue Oak–(Foothill Pine) NFD Association (*Quercus chrysolepis–Quercus douglasii* (*Pinus sabiniana*))	7315.5	3.58	11	1243
1221	Coast Live Oak Alliance (*Quercus agrifolia*)	5332.9	2.6	13	1597
1222	Interior Live Oak Alliance (*Quercus wislizenii*)	2161.7	1.06	23	374
1223	Mixed Oak Alliance (*Quercus* spp.)	11,659.4	5.7	5	1814
2104	Foothill Pine/Mesic non-serpentine chaparral NFD Association (*Pinus sabiniana*)	382.1	0.2	39	84
2121	Foothill Pine Alliance (*Pinus sabiniana*)	717.2	0.35	34	144
2122	Knobcone Pine Alliance (*Pinus attenuate*)	2401.1	1.18	21	374
2123	Ponderosa Pine Alliance (*Pinus ponderosa*)	68.1	0.03	52	5
2124	McNab Cypress Alliance (*Cupressus macnabiana*)	981	0.5	29	131
2125	Sargent Cypress Alliance (*Cupressus sargentii*)	742.8	0.36	32	31
2126	Sugar Pine–Canyon Oak NFD Association (*Pinus lambertiana–Quercus chrysolepis*)	1.4	0.001	55	1
2127	California Juniper Alliance (*Juniperus californica*)	1	0.00	56	1
2201	Coast Redwood–Douglas Fir/California Bay NFD Association (*Sequoia sempervierens–Pseudotsuga menziesii/ Umbellularia californica*)	1164.7	0.57	28	92
2222	Douglas Fir Alliance (*Pseudotsuga menziesii*)	7032.5	3.44	12	781
2224	Douglas Fir–Ponderosa Pine Alliance (*Pseudotsuga menziesii–Pinus ponderosa*)	3794.4	1.9	16	305
2230	Coast Redwood Alliance (*Sequoia sempervierens*)	131	0.06	47	8
3101	Valley Oak–(California Bay–Coast Live Oak–Walnut–Ash) Riparian Forest NFD Association (*Quercus lobata–(Umbellularia californica–Quercus agrifolia–Juglans californica–Fraxinus dipetala*)	2313.6	1.13	22	206
3102	Valley Oak–Fremont Cottonwood (Coast Live Oak) Riparian Forest NFD Association (*Quercus lobata–Populus fremontii* (*Quercus agrifolia*)	210.3	0.1	43	31
3121	Black Oak Alliance (*Quercus kellogii*)	898.4	0.4	30	91
3122	Blue Oak Alliance (*Quercus douglasii*)	17,883.8	8.76	2	2992
3123	Valley Oak Alliance (*Quercus lobata*)	1310	0.64	27	333
3124	Oregon White Oak Alliance (*Quercus garryana*)	459.4	0.23	37	83
3201	White Alder (Mixed Willow–California Bay–Big Leaf Maple) Riparian Forest NFD Association (*Alnus rhombifolia* (Salix spp.–*Umbellularia californica–Acer macrophyllum*)	391.1	0.19	38	46
3202	Brewer Willow Alliance (*Salix breweri*)	112.2	0.06	48	29
3221	Mixed Willow Super Alliance (*Salix* spp.)	218.3	0.1	42	85
4300	Sclerophyllous Shrubland Formation	1325.4	0.7	26	283
4301	Scrub Interior Live Oak–Scrub Oak–(California Bay–California Ash–Birch Leaf Mountain Mahogany–Toyon–California Buckeye) Mesic East Count NFD Super Alliance (*Quercus wislizenii* var. *frutenscens–Quercus berberidifolia*–(*Umbellularia californica–Fraxinus dipetala–Cercocarpus betuloidies–Heteromeles arbutifolia–Aesculus californica*)	4471.9	2.2	15	985

TABLE 1. CONTINUED.

Code	Cover type	Area (ha)	% Total area	Area rank order	Number of polygons
4302	Mixed Manzanita–(Interior Live Oak–California Bay–Chamise) West County NFD Alliance (*Quercus wislizenii–Umbellularia californica–Adenostoma fasciculatom*)	3570.7	1.8	17	810
4303	Leather Oak–White Leaf Manzanita–Chamise Xeric Serpentine NFD Super Alliance (*Quercus durata–Arctostaphylos viscida–Adenostoma*)	10,915.2	5.4	7	1352
4304	Leather Oak–California Bay–Rhamnus spp. Mesic Serpentine NFD Super Alliance (*Quercus durata–Umbellularia californica*)	1797	0.9	24	397
4305	Whiteleaf Manzanita–Leather Oak–(Chamise–Ceanothus spp. (Foothill Pine)) Xeric Serpentine NFD Super Alliance (*Arctostaphylos viscida*–Quercus durata (*Adenostoma–ceanothus* (*Pinus sabiniana*)))	3225	1.6	18	624
4306	California Bay–Leather Oak–(Rhamnus spp. (Foothill Pine)) Mesic Serpentine NFD Super Alliance (*Umbellularia californica–Quercus durata* (*Pinus sabiniana*))	2951.5	1.5	19	463
4321	Chamise Alliance (*Adenostoma fasciculatum*)	12,443.4	6.1	4	2656
4322	Chamise–Wedgeleaf Ceanothus Alliance (*Adenostoma fasciculatum–Ceanothus cuneatus*)	2814	1.4	20	439
4501	Coyote Brush–California Sagebrush (Lupine spp.) NFD–Super Alliance (*Baccharis pilularis–Artemisia californica*)	17.1	0.008	54	8
6402	(Bulrush–Cattail) Fresh Water Marsh NFD Super Alliance (*Scirpus* spp–*Typha* spp)	109.7	0.05	49	50
6403	(Carex spp.–Juncus spp.–Wet Meadow Grasses) NFD Super Alliance	168.4	0.08	45	82
6501	Saltgrass–Pickleweed NFD Super Alliance (*Distichlis* sp–*Salicornia* sp)	1444.6	0.71	25	45
7100	Upland Annual Grasslands and Forbs Formation	4921.7	2.4	14	408
7101	Native Grassland Restoration Sites	103.6	0.05	50	3
7120	California Annual Grasslands Alliance	15,903	7.8	3	2528
7130	Serpentine Grassland NFD–Super Alliance	843.9	0.4	31	591
9001	Rock Outcrop	703.4	0.34	35	331
9002	Riverine, Lacustrine and Tidal Mudflats	174.5	0.09	44	22
9003	Serpentine Barrens	18	0.009	53	17
9100	Urban or Built-up	10,702.6	5.24	9	716
9200	Agriculture	25,991.5	12.8	1	769
9300	Vacant	722.8	0.4	33	193
9400	Water	11,653.5	5.7	6	768
9999	Unidentified	635.3	0.3	36	203
	Total:	204,213.5	100		28,456

several of the preliminary vegetation classes where that species was frequently observed to be a sparse dominant in the upper tree canopy. As a consequence, these vegetation types were redefined on the basis of their remaining co-dominants, and Foothill Pine was listed as a parenthetical species or was eliminated from the name, but mentioned in the cover type description (see http://cain.nbii.gov/regional/napavegmap for a description of all Napa MCV vegetation types). The Serpentine Barrens category was added, because it is habitat for a variety of rare or endemic annual species and was used to re-label all Rock Outcrops that overlap serpentine on the geology or soils maps.

Map Comparisons

Number and size of polygons. The number of polygons in the MCV map totaled 28,456, compared to 28,918 for CalVeg and 69 for GAP. For the internal versions, there were 27,456 MCV polygons, versus 27,435 for CalVeg and 29 for GAP. Mean and median (internal) polygon sizes are within one hectare for the MCV and CalVeg maps, while the GAP polygon mean and median are three orders of magnitude larger. The MCV map has the smallest standard deviation in polygon size, followed by CalVeg and GAP (Table 2).

MCV has 5415 polygons (19.7% of all MCV

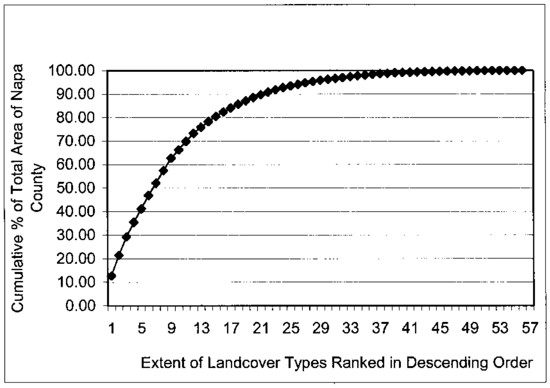

FIG. 2. Area cumulative percent chart. This chart shows the increasing area of Napa County covered as landcover types are added to the map in rank order.

polygons) that are smaller than the smallest polygon in either the CalVeg (1 ha) or the GAP (100 ha) maps (Table 2). While the MCV has polygons smaller than CalVeg, the numbers of polygons in the larger size classes of the two maps are comparable. GAP polygons are much larger; the smallest GAP polygon is larger than 99.1% of the MCV polygons and 99.5% of the CalVeg polygons.

The shape and spatial configuration of polygons differ for each map (Fig. 3a, b, c). CalVeg polygons have a stair-stepped edge appearance, resulting from the 30 m pixels of the Landsat TM base map imagery. MCV and GAP maps have smooth curvilinear outlines but are at very different scales. We did not attempt to quantify edge differences.

Classification crosswalks and vegetation type extents. For clarity, we only allowed each MCV vegetation type to correspond to a single CalVeg or GAP type. However, we allowed CalVeg and GAP types to link to one or more MCV types. The comparisons listed here were done on the 1835 km^2 sub-region of the county, the area covered by the CalVeg map (~90% of the county).

The Napa GAP map has 36 cover types, 10 of which cover human land use types, open water, barren land and eucalyptus, leaving 26 vegetative types. The CalVeg map has 46 cover types, nine of which cover human land use types, eucalyptus, open water and barren sites. We compared all possible types, focusing on the 48 MCV, 26 GAP, and 37 CalVeg natural vegetation types (Table 3).

Only the MCV map identifies 'Rock Outcrops' as a cover type. The closest type for CalVeg and GAP is 'Barren'. 'Rock outcrop' contains some vegetative potential, as many plant species grow sparsely in rocky areas. The same applies for the MCV 'Serpentine Barrens' type, which had no direct match in the other classification systems. MCV has a term for a potential aquatic plant habitat,

TABLE 2. POLYGON SIZE DISTRIBUTION COMPARISON FOR THREE DIGITAL VEGETATION MAPS OF NAPA COUNTY. Polygons touching the border of Napa county, and Lake Berryessa have been excluded in the 'internal' versions. Border polygons are completely included in the GAP 'external' column.

Polygon size distribution by hectare size class	Number of MCV polygons, internal	Number of CalVeg polygons, internal	Number of GAP polygons, internal	Number of GAP polygons, external
0–0.25	327	0	0	0
0.5	1237	0	0	0
1	3851	0	0	0
2	6244	8927	0	0
4	6412	10,113	0	0
8	4798	5452	0	0
16	2685	1890	0	0
32	1199	623	0	0
64	449	258	0	0
128	144	91	1	2
256	67	30	3	3
512	30	17	1	2
1024	4	7	3	7
2048	8	4	7	11
4096	0	1	8	15
8192	0	0	5	14
16,384	0	1	0	11
32,768	0	0	1	2
65,536	0	0	0	1
Total # polygons	27,455	27,434	28	68
Average size polygon (ha)	6.7	5.8	3072.3	5290.4
Median size polygon (ha)	2.5	2.7	1923.7	3063.5
Standard deviation (ha)	33.4	59.1	3953.2	6079.0
Polygon size range hectares (ha)	0.001–1964.0	1.01–8307.5	120.8–20,390.2	110.8–33,680.8

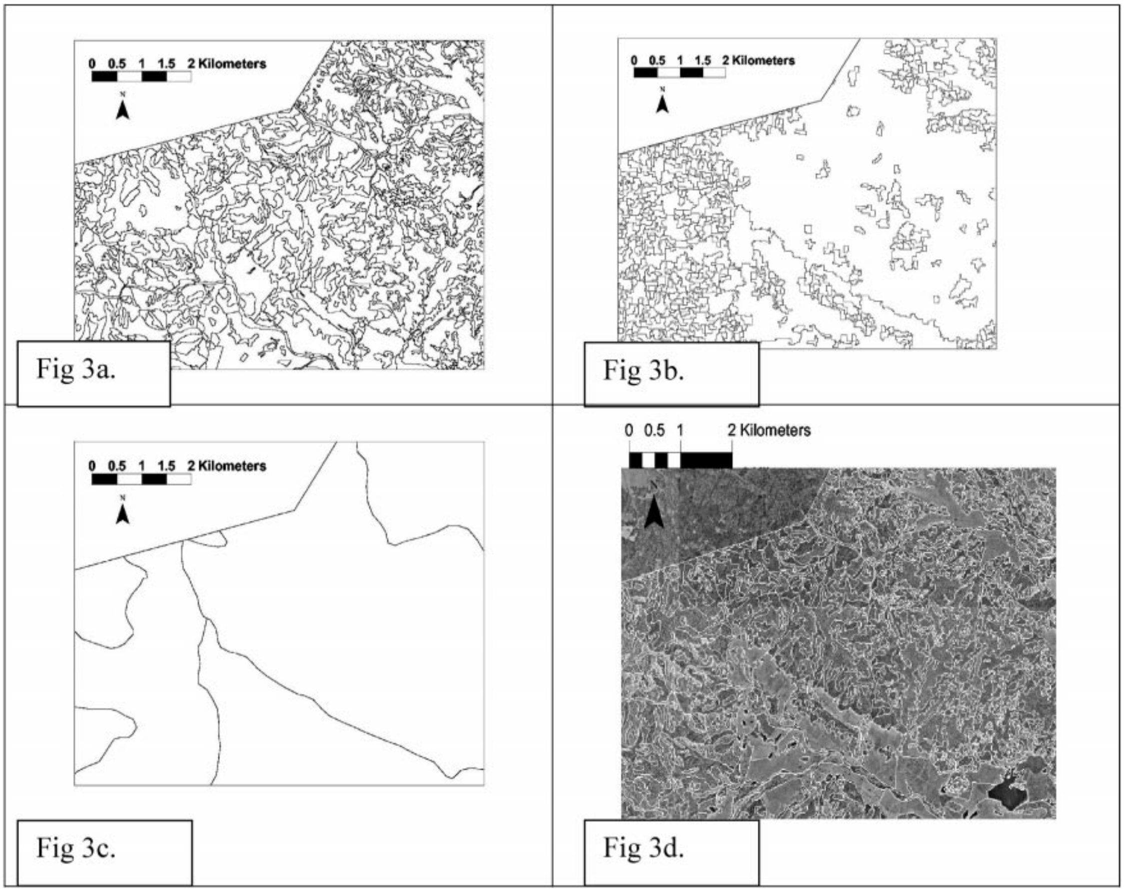

FIG. 3. Polygon shape differences. Figures 3a–c illustrate the differences in polygons between a section of the three maps compared in this study. Figure 3a shows the MCV map, 3b the CalVeg map, and 3c the GAP map. Figure 3d shows the MCV map underlain by the Digital Ortho Photo Quad imagery used as the basis for polygon delineation.

'Riverine, Lacustrine and Tidal Mudflats'. GAP has two similar terms, 'Bays and Estuaries' and 'Streams and Canals'. MCV has six specifically named serpentine types, CalVeg has one and GAP two.

MCV compared to GAP. Of the 26 vegetation types in GAP, ten correspond to a single MCV type. Two MCV types, Douglas-fir (*Pseudotsuga menziesii*) alliance (2222) and Foothill Pine (*Pinus sabiniana*) alliance (2121) have three GAP types associated with them. Six MCV types have two GAP types in them (Table 3). GAP has a method of identifying cover density in the class name, with some hardwoods listed separately as both woodland and forest. This naming convention accounts for three of the doubled crosswalk links, which would go to individual MCV types if we used the MCV cover attribute (not presented here). The GAP map does not explicitly map riparian vegetation types because they generally fall below GAP's target MMU of 100 ha. However, GAP lists 921 ha of Valley Oaks (*Quercus lobata*), which may include a riparian phase (Table 3), and 21 of the 69 GAP polygons list riparian species as present.

MCV compared to CalVeg. Of the 37 CalVeg types, 23 correspond to a single MCV type. CalVeg maps one type, California Buckeye (*Aesculus californica*) (QI, 15.8 ha), that is not currently in the Napa MCV map. Buckeye is a listed alliance in the MCV (Sawyer and Keeler-Wolf 1995), but its typically small stands were not mapped.

Seven CalVeg types describe 19 MCV types: two CalVeg types, Productive Hardwoods (NX) and Foothill Pine (PD), correspond to four MCV types each; one CalVeg type, Barren (BA), corresponds to three MCV types; and, four CalVeg types, Valley Oak (QL), Willow (QO), Lower Montane Mixed Chaparral (CQ), and Ultramafic Mixed Shrub (C1) correspond to two MCV types each. Three MCV types have two CalVeg types associated with them: Coyote Bush (4501), California Bay—Madrone—Coast Live Oak (Black Oak—Big Leaf Maple) (*Umbellularia californica*—*Arbutus menziesii*—*Quercus agrifolia* (*Quercus kellogii*—*Acer macro-*

TABLE 3. VEGETATION CLASS EXTENTS FROM THE MCV, CALVEG AND GAP VEGETATION MAPS OF NAPA COUNTY. MCV vegetation classes listed, with corresponding CalVeg and GAP vegetation classes on the same row and subsequent rows. CalVeg and GAP types that apply to more than one MCV class are listed at each MCV class they correspond to, the second and subsequent times in hard brackets []: the spatial extents are listed only after the first record. Categories not comparable with MCV types are listed at the bottom of each subsection. CalVeg and GAP types that correspond to MCV types but were not mapped in Napa are included for cross-reference purposes, receiving zeros for their area extents.

MCV vegetation type classes	CalVeg alliance type	GAP/CNDDB type classes	MCV mapped hectares	CalVeg mapped hectares	GAP mapped hectares	MCV type codes	CalVeg type codes	GAP CNDDB codes
Hardwood Types								
Winter-Rain Sclerophyll Forests and Woodlands Formation			235.3			1100		
California Bay–Madrone–Coast Live Oak–(Black Oak–Big Leaf Maple) NFD Super Alliance	California Bay		7317.8	18.9		1101	QB	
	Mixed Hardwood			32,310.0			NX	
Coast Live Oak Alliance	Coast Live Oak	Coast Live Oak Forest	4939.9	1845.3	14,588.5	1221	QA	81310
		Coast Live Oak Woodland			1972			71160
Coast Live Oak–Blue Oak–(Foothill Pine) NFD Association	[Mixed Hardwoods]		10,664.2			1201	[NX]	
Interior Live Oak Alliance	Interior Live Oak	Interior Live Oak Forest	2150.8	2006.1	4715.7	1222	QW	81330
		Interior Live Oak Woodland			1207.6			71150
Interior Live Oak–Blue Oak–(Foothill Pine) NFD Association	[Mixed Hardwoods]		7371.3			1202	[NX]	
Black Oak Alliance	Black Oak	Black Oak Forest	885.1	434.3	1530.4	3121	QK	81340
		Black Oak Woodland			1563.3			71120
Blue Oak Alliance	Blue Oak	Blue Oak Woodland	17,965.0	22,645.6	19,539.2	3122	QD	71140
Oregon White Oak Alliance	Oregon White Oak	Oregon Oak Woodland	447.1	528.1	2913	3124	QG	71110
		Mixed North Slope Cismontane Woodland (in part)			10,300.5			71420
Valley Oak Alliance	Valley Oak	Valley Oak Woodland	1023.0	452.9	920.5	3123	QL	71130
Tanbark Oak Alliance	Tanoak (Madrone)		101.6	4.7		1124	QT	
Canyon Live Oak Alliance	Canyon Live Oak	Canyon Live Oak Forest	225.9	329.3	1870.6	1122	QC	81320
Mixed Oak Alliance	Productive Mixed Hardwoods		11,424.4	1795.0		1223	TX	
	[Mixed Hardwoods]						[NX]	
	California Buckeye			15.8			QI	
Coniferous Types								
Foot Pine Alliance	Gray Pine	Open Foot hill Pine Woodland	710.2	5877.3	1864.3	2121	PD	71310
		Foothill Pine-Oak Woodland			29,689			71410
Foothill Pine/Mesic non-serpentine chaparral NFD Association	[Gray Pine]	Non-Serpentine Foothill Pine Woodland	373.8		9302.7	2104	[PD]	71322

TABLE 3. CONTINUED.

MCV vegetation type classes	CalVeg alliance type	GAP/CNDDB type classes	MCV mapped hectares	CalVeg mapped hectares	GAP mapped hectares	MCV type codes	CalVeg type codes	GAP CNDDB codes
Douglas Fir Alliance	Pacific Douglas Fir	Upland Douglas Fir Forest	7090.6	5474.2	1251.2	2222	DF	82420
		Mixed Evergreen Forest (in part)			3984			81100
		Coast Range Mixed coniferous Forest			8013.6			84110
Douglas Fir–Ponderosa Pine Alliance	Douglas Fir/Pine		3819.2	2931.0		2224	DP	
	Mixed Conifer–Pine			107.3			MP	
Ponderosa Pine Alliance	Ponderosa Pine		68.9	491.6		2123	PP	
California Juniper Alliance			1.0			2127		
Coast Redwood Alliance	Redwood		124.7	0.0		2230	RW	
Coast Redwood–Douglas Fir/California Bay NFD Association	Redwood–Douglas Fir		1178.8	1334.9		2201	RD	
Knobcone Pine Alliance	Knobcone Pine	Knobcone Pine Forest	2382.1	1015.5	3244.5	2122	KP	83210
McNab Cypress Alliance	McNab Cypress		978.1	1566.1		2124	MN	
Sargent Cypress Alliance	Sargent Cypress		820.6	781.0		2125	MS	
Sugar Pine–Canyon Oak NFD Association			1.3			2126		
Riparian Types								
Valley Oak–(California Bay–Coast Live Oak–Walnut–Ash) Riparian Forest NFD Association	[Valley Oak]		1670.2			3101	[QL]	
Valley Oak–Fremont Cottonwood (Coast Live Oak) Riparian Forest NFD Association	Fremont Cottonwood		64.9	0.0		3102	QF	
White Alder (Mixed Willow–California Bay–Big Leaf Maple) Riparian Forest NFD Association	Mixed Riparian Hardwood		234	337.6		3201	NR	
Mixed Willow Super Alliance	Willow		119.2	19.3		3221	QO	
Brewer Willow Alliance	[Willow]		60.3			5222	[QO]	
Hard Chaparral Types								
Sclerophyllous Shrubland Formation	Lower Montane Mixed Chaparral	Buck Brush Chaparral	1323.3	37,695.0	4807.8	4300	CQ	37810
Scrub Interior Live Oak–Scrub Oak–(Cal. Bay–Cal. Ash–Birch Leaf Mountain Mahogany–Toyon–Cal. Buckeye) Mesic East County NFD Super Alliance	Scrub Oak		4303.6	2479.1		4301	CS	
Mixed Manzanita–(Interior Live Oak–California Bay–Chamise) West County NFD Alliance	[Lower Montane Mixed Chaparral]	Northern Mixed Chaparral	3470.1		8156*	4302	[CQ]	

TABLE 3. CONTINUED.

MCV vegetation type classes	CalVeg alliance type	GAP/CNDDB type classes	MCV mapped hectares	CalVeg mapped hectares	GAP mapped hectares	MCV type codes	CalVeg type codes	GAP CNDDB codes
Leather Oak–White Leaf Manzanita–Chamise Xeric Serpentine NFD Super Alliance	Ultramafic Mixed Shrub Alliance		11,035.4	0.0		4303	C1	
Leather Oak–California Bay–Rhamnus spp. Mesic serpentine NFD Super Alliance	[Ultramafic Mixed Shrub Alliance]		1766.9			4304	[C1]	
Whiteleaf Manzanita–Leather Oak–(Chamise–Ceanothus spp. (Foothill Pine)) Xeric Serpentine NFD Super Alliance	[Gray Pine]	Serpentine Foothill Pine–Chaparral Woodland	3221.7		2177.5	4305	[PD]	71321
California Bay–Leather Oak–(Rhamnus spp. (Foothill Pine)) Mesic Serpentine NFD Super Alliance	[Gray Pine]		2905.5			4306	[PD]	
Chamise Alliance	Chamise	Chamise Chaparral	12,390.0	6723.8	3798.4	4321	CA	37200
Chamise–Wedgeleaf Ceanothus Alliance	Ceanothus Chaparral	Mixed Serpentine Chaparral	2820.0	50.4	297.7	4322	CC	37610
	Wedgeleaf Ceanothus			15.1			CL	
Soft Chaparral Types								
Coyote Brush–California Sagebrush (Lupine spp.) NFD Super Alliance	Coyote Bush		12.2	8.6		4501	CK	
	Mixed Soft Scrub Chaparral			20.4			SQ	
Grassland Types								
Upland Annual Grasslands and Forbs Formation	Annual Grass–Forb		3001.0	22,749.4		7100	HG	
Native Grassland Restoration Sites	[Annual Grass–Forb]		105.2			7101	[HG]	
California Annual Grasslands Alliance	[Annual Grass–Forb]	Non-Native Grassland Coastal Prairie	15,175.8		10,314.4* 2819.3	7120	[HG]	42200 41000
Serpentine Grassland NFD Super Alliance	[Annual Grass–Forb]		732.7			7130	[HG]	
Wetland Types								
(Bulrush–Cattail) Fresh Water Marsh NFD Super Alliance	Tule–Cattail		71.6	0.0		6402	HT	
(Carex spp.–Juncus spp.–Wet Meadow Grasses) NFD Super Alliance	Wet Meadow		64.7	2.7		6403	HJ	
Saltgrass–Pickleweed NFD Super Alliance	Pickleweed–Cordgrass	Northern Coastal Salt Marsh	0.3	0.0	0	6501	HC	52110
Miscellaneous Types								
Rock Outcrop	Barren	Mixed Barren Land	665.3	376.0	1539.9	9001	BA	11770

TABLE 3. CONTINUED.

MCV vegetation type classes	CalVeg alliance type	GAP/CNDDB type classes	MCV mapped hectares	CalVeg mapped hectares	GAP mapped hectares	MCV type codes	CalVeg type codes	GAP CNDDB codes
Riverine, Lacustrine and Tidal Mudflats	[Barren]	Bays and Estuaries	82.9		0	9002	[BA]	11540
		Streams and Canals			0			11510
Serpentine Barrens	[Barren]		17.9			9003	[BA]	
Human-Non-native								
Urban or Built-up	Urban or developed	Urban or Built-Up Land	4854.8	1642.9	752.8	9100	UB	11100
Eucalyptus Alliance	Eucalyptus	Eucalyptus Groves (exotic)	30.4	0.0	0	1123	QZ	11300
	Non-native/Ornamental Grass Conifer/Hardwood			7.3			IM	
	Non-native/Ornamental grass			171.6			IG	
	Non-native/Ornamental Hardwood			11.2			IH	
	Non-native/Ornamental Shrub			2.0			IS	
Agriculture	Agriculture	Agricultural types	21,180.4	20,657.0	1297.7	9200	AG	11200
		Agricultural types			769.5			11201
		Agricultural types			4818			11210
Vacant	[Barren]		385.0			9300	[BA]	
Water	Water	Permanently-flooded Lacustrine Habitat	8867.5	8571.8	5250.4	9400	WA	11520
		Strip Mines, Quarries and Gravel Pits			10			11750
Unidentified			576		18,225.6	9999		

TABLE 4. SUMMARY OF VEGETATION EXTENTS. The mapped extents of MCV, CalVeg and Gap Analysis vegetation maps for a subsection of Napa county are shown here. The full list of types has been reduced to nine categories for easier comparison.

	MCV mapped hectares	CalVeg mapped hectares	Gap mapped hectares
Hardwood types	64,751	62,386	61,122
Coniferous types	17,549	19,579	57,350
Riparian types	2149	357	0
Hard Chaparral types	43,236	46,963	19,238
Soft chaparral types	12	29	0
Grassland types	19,015	22,749	13,134
Wetland types	137	3	0
Miscellaneous	766	376	1540
Human/Non-native	35,894	31,064	31,124

phyllum)) (1100), and Douglas-fir—Ponderosa Pine (*P. menziesii—Pinus ponderosa*) (2224), see Table 3 for corresponding CalVeg types.

Regional summary of three vegetation maps. MCV, GAP and CalVeg map similar hardwood extents (Table 4). Note that we adjusted the GAP extent from 713 km^2 to 611 km^2 due to a known error in the GAP map (David Stoms personal communication). The GAP map has 398 km^2 and 377 km^2 more coniferous vegetation than MCV or CalVeg. The MCV map of hard chaparral types is similar to CalVeg and about double the extent found in GAP. MCV soft chaparral types span half those in the CalVeg map, while none are identified in the GAP map. The MCV map identifies ~37 km^2 less grasslands than CalVeg and 60 km^2 more than GAP (Table 4).

The most significant differences between the three maps involve riparian vegetation and wetlands, which are important for wildlife habitat and landscape connectivity. Riparian types are much more widely represented in the MCV map than in CalVeg or GAP (where they are noted, but not spatially recorded). Wetlands are also better represented in the MCV map than in CalVeg or GAP (Table 4). Human land use and non-native types (excluding eucalyptus) were relatively similar (Table 4). For the small miscellaneous category, combining rock outcrops, open flowing water and serpentine barrens, GAP has twice the area of MCV or CalVeg.

DISCUSSION

Human photo interpretation produced a realistic looking, and accurate, spatial delineation at a modest increase in cost over automatic classification. Nevertheless, the new MCV map is only a first step in what will necessarily be an iterative process of plot data collection, vegetation type description and mapping using higher resolution color imagery.

MCV Map

Strengths. The MCV map's strengths include: high spatial and floristic resolution, relatively low cost, speed of production, scalability to different levels of floristic classification, hierarchical conformance with national (NVCS) standards, and the ease with which it can be crosswalked with CWHR and other widely used classification systems. The method relies on GIS data available throughout California, and much of the West, and should be easy to implement elsewhere, though local vegetation identification keys will be needed for each new region. The map is simple to relate to other digital maps since it matches the mapping scale of standard USGS maps.

The spatial resolution of any vegetation map increases as the classification proceeds from coarse physiognomic to finer floristic levels. The fine spatial resolution of the MCV map is a consequence of the 1-m pixels of the base DOQQ imagery, the relatively small MMU (<1 ha for vegetation types of conservation or management interest) and the large number of floristic types mapped. The MCV map also maintains fine spatial resolution when it is aggregated to higher physiognomic levels (12 vegetation types at the Group-Formation level; six at the Class-Subclass level).

Updates to the MCV map should be relatively easy as new imagery becomes available, since detailed re-interpretation will be needed only on polygons that have changed. Ancillary data layers such as CDF wildfire maps that identify most fire-disturbed areas, and biannual farmland monitoring maps that show conversion of natural vegetation to agriculture, will speed the interpretation and re-labeling process of a map update.

Limitations. We mention three types of limitations to the MCV map: 1) undocumented vegetation types; 2) the date of the imagery used; and 3) the capacity of the imagery to resolve some species. First, there are a large number of previously undocumented vegetation types used in the vegetation classification. California is ecologically complex, with the nation's highest diversity of plant communities (Stein et al. 2000). Broad-scale efforts to quantitatively define California's vegetation only began in earnest in the early 1990s (Sawyer and Keeler-Wolf 1995), and the MCV classification is a work in progress. The number of defined alliances has more than doubled since the first edition of the MCV was published (Keeler-Wolf personal observation). Moreover, many parts of California have not had systematic plot-based vegetation surveys. Consequently, only 44% of the MCV landcover types for Napa County are previously defined alliances, which necessitated pre-mapping field reconnaissance to identify local vegetation types and classification rules. Mapping projects can play a central role in identifying previously undefined vegetation types for inclusion. Inclusion of vegetation plot data collection is necessary to produce an accurate map, and to advance the classification of California's vegetation. No funds were available to support the vegetation plot data collection for our project, but we recommend such data be collected in the future.

The second limitation of the MCV map is the 1993 date of the base imagery, which makes the ''new'' map effectively ten years old. However, this affords the opportunity to use newer imagery to record land use changes that have occurred over the past decade.

The third limitation is the inability to identify certain dominant canopy species in the black and white DOQQ imagery. For example, it was difficult to identify the presence of Foothill Pine in the imagery when pine cover was less than 20%, due to its sparse canopy, light needles and near absence of a cast shadow. In addition, the relationship between Foothill Pine and various environmental factors including substrate, moisture and temperature relationships, is not quantitatively documented, so it was not possible to model the distribution of this species.

Similarly, many oak assemblages observed in the field were lumped into a single Mixed Oak cover type, as they were neither distinguishable in the imagery, nor easy to model without plot data. California bay and madrone were difficult to differentiate, and dominant shrub species co-occurred in such a way that that it was difficult to reliably divide the shrub communities into the pre-determined classes found in the MCV. Species richness is quite high in these shrub communities. Within-stand species distribution patterns are often complex, and boundaries between shrub communities and adjacent types vary from sharp and distinct to broad and gradational. As a consequence, shrub-type labels and delineation, particularly between adjacent shrub types, was not as accurate as for forest and woodland types.

Riparian vegetation heterogeneity also posed some labeling problems. Riparian communities exhibited notable changes in dominant species composition from stream reach to stream reach, but this turnover usually occurred at scales below the target MMU and was hard to detect on the imagery. The riparian polygons in the MCV map are long, linear and seemingly homogeneous, when, in fact, many have observable changes in structure and composition along their length. Ground-based field mapping will be required to more finely map riparian cover types. Nevertheless, the photointerpretation process used in the MCV maps was clearly better able to identify riparian features than the automated procedures used to generate the CalVeg coverage.

Finally, most herb-dominated types were aggregated into coarser physiognomic classes, due to their similar appearance in the imagery. For any vegetation map, fieldwork will be necessary to map herb-dominated communities reliably at the floristic levels of alliance or association. Despite these limitations, the MCV map was able to record the spatial distribution of 48 vegetation types.

Prospects for MCV map revision. Many of the image interpretation and classification problems could be overcome by the use of imagery with greater spectral resolution. Color imagery or hyperspectral data would likely permit many of the species ambiguities to be resolved, and would enable mappers to delineate exposed geology of floristic interest (Roberts et al. 1998). Radar and Lidar data can yield more information on stand structure (Riano et al. 2003). Satellites with higher spatial and spectral resolution should improve change-detection and our ability to estimate vegetation predictors such as soil moisture and evapotranspiration. MCV mapping methodologies can be readily applied to better imagery as it becomes available.

A more detailed geology map (than 1:250,000) and a more current farmlands data layer would help the next iteration of the map. All other data used were available at scales of 1:24,000 or 1:12,000, including a soils map (U.S. Dept Agriculture 2000), which showed serpentine specific soils at the resolution of the DOQQ's. The MCV map could also be modified to provide an Anderson level II subdivision (Anderson et al. 1998) of agricultural types using the California Division of Land Resource Protection FMMP maps, which would permit use of the revised CWHR classification.

Spatial extent, commonness, rarity and conservation application. Patterns of spatial extent (Table 1, Fig. 2) provide insights into the utility of the MCV map for various planning and conservation purposes. In Napa County, the 10–15 vegetation types of greatest spatial extent cover 70–80% of the natural landscape and form the matrix of the observed landscape. The rarest 50% of the vegetation classes comprise, in aggregate, only 5% of the county's total area. These results can be used in conservation planning, whether for biodiversity, scenic open space or working landscapes. Given the map scale, analyses are possible on a watershed or finer basis.

Map Comparisons

Number and size of polygons. Comparing polygon size distribution allows for an estimation of landscape complexity captured by the maps. Where equal vegetation type extents were measured between GAP and MCV, MCV provides more information about the distribution. MCV and CalVeg have an equal number of polygons, but the smaller polygons in the MCV permit capture of ecological information below the resolution of the CalVeg map.

Classification comparison. The MCV map had greater floristic detail, particularly for riparian and grassland types, with five and four categories compared with three and one for CalVeg and zero and two for GAP. CalVeg identified one type that was not detected in the current MCV map.

Each of the classification systems has vegetation types used to aggregate difficult species combinations into coarser units within the classification hierarchy. These types represent vegetation combinations that have not been separated out, or are beyond the resolution of the imagery to differentiate. MCV has Winter-Rain Sclerophyll Forests and Woodlands and Mixed Oak. CalVeg aggregates multiple species into Mixed Hardwood, Productive Mixed Hardwoods, Gray Pine, and Mixed Conifer Pine. GAP's aggregated types include Coast Range Mixed Coniferous Forest (which does not crosswalk to MCV), Mixed Evergreen Forest, and Mixed North Slope Cismontane Woodland. One of the differences between the classification systems is that those vegetation types still under development are clearly identified in the MCV classification through the use of the term 'Not Formally Defined' (NFD) to identify types that still need additional fieldwork. In that sense, the MCV is explicit about the iterative process that all vegetation classification systems go through as additional data are added.

The CalVeg classification scheme generally identifies fewer species in a given polygon than the MCV map does. Both MCV and CalVeg classifications have many species identified as possible alliance components (Sawyer and Keeler-Wolf 1995; Schwind and Gordon 2001). Generally, the MCV map provides more information about sub-dominants and low cover percentage co-dominants than does CalVeg. GAP compares favorably to the other two in terms of identifying up to three dominant species in any given vegetation type, but there is little information on associated sub-dominants.

Minimum mapping units and polygon size. The variable lower limit on polygon size in the MCV map allows vegetation analysts and conservation planners a method of selectively delineating features of particular conservation interest, such as seeps, without an impossible increase in mapping costs on common vegetation types.

Imagery. In CalVeg, vegetation is classified for each 30-m pixel (900 m^2), then aggregated to 1 ha, versus 1 m^2 resolution and a 0.25 ha MMU for MCV. Both CalVeg's line work and its classification are driven by multiple automated, rule-based algorithms, which account for its pixilated appearance (Fig. 3b). The MCV line work more closely resembles the sinuous nature of natural vegetation breaks (Fig. 3a), because the polygons are delineated by hand over high-resolution imagery (Fig. 3d). MCV polygons may not be as repeatable because of being hand-drawn. However, the detail in the MCV map is comparable to CalVeg, and its variable MMU permits the registration of many stands not delineated by to CalVeg.

The interaction between spatial accuracy and floristic labeling accuracy is a factor that we did not measure in this project. At issue is the question of whether very small polygons are well enough spatially positioned so that their attributes actually refer to the intended vegetation. The level of registration accuracy in the CalVeg and MCV maps is an open question, one that we feel warrants further study. GAP polygons, being generalized, would not be considered potentially inaccurate in this way.

The GAP map (Fig. 3c) is the most spatially general map, with a mean polygon size of approximately 3072 ha in Napa County. The GAP polygons were hand-delineated using TM imagery as the backdrop; so GAP map linework more naturally reflects breaks in vegetation than the CalVeg map. However, since the CalVeg map has finer spatial resolution, but uses the same TM imagery, it better identifies dominant vegetation on a pixel-by-pixel basis.

Note that the CalVeg, GAP and MCV classifications all contain stand structure information not analyzed here, and that adjacent polygons may contain the same vegetation, differing only on the basis of plant size or cover attributes.

Vegetation extent comparisons. By combining vegetation types into more abstracted hierarchical classes, we identified some of the overall differences between the three maps (Table 4). Hardwoods are fairly evenly mapped between the three maps. MCV and CalVeg identified similar levels of conifers (~200 km^2), but the GAP map had nearly three times as much conifer area. The GAP map under-reports chaparral in the region by about 200 km^2, compared to the other maps. This suggests that the GAP classification bins chaparral types into conifer types. Conifers in the MCV map are about 20% percent lower than CalVeg, which may represent the mis-classing of low density foothill pine into chaparral types.

Grassland types were roughly equivalent in extent between MCV and CalVeg at about 200 km^2 in the county. GAP reports this class at about 130 km^2. The difference is likely due to low cover stands of hardwood and conifer- that might be classed as grasslands by MCV and CalVeg- being classed as Woodland types in GAP. At the scale GAP is working, this type of classification is justifiable, since it is more conservative to register a low-cover stand as woodland than as grassland from a resource management perspective. In the California Coast Range, many grasslands are openings in a woodland matrix, and thus are appropriately lumped into woodland at GAP's scale of spatial aggregation. Another possible explanation is that in the approximately 10 years between the imagery used for GAP (1990 Landsat TM) or MCV (1993 DOQQ's) and CalVeg (recent Landsat TM), many of the low density woodlands of Napa may have been converted to grassland.

The MCV map identified considerably more riparian and wetland areas than either of the other maps. Considering the high ecological value of these types, this marks one of the most valuable contributions the MCV map can make to the management of lands in Napa County. Valley oak, both as a member of riparian areas and as its own alliance, is better mapped by MCV than the other maps. MCV identifies about three times as much valley oak as GAP, and four times the amount mapped in CalVeg. MCV also identifies rock outcrops, not classed in the other systems. Rock outcrops are habitat for many rare species that may not occur frequently enough to form an alliance.

All three maps identified similar extents for human and non-native cover types. This is unusual, since it is known that there has been extensive vineyard conversion between the dates the maps were made. MCV identifies about 40 km^2 more than the other two, despite its older base map imagery compared to CalVeg. The difference may be due to the finer scale of mapping, which could identify human altered landscapes on smaller areas than the other maps.

Future research and applications. Conservation planning on a species by species basis can be complicated by the large numbers imperiled species. Conservation for groups of species (Grossman et al. 1998) and preservation of natural vegetation types in an ecoregional context is increasingly important. When protected, natural vegetation types help to conserve their component species, both rare and common (e.g., GAP logic, Davis et al. 1998). The MCV map vegetation types can be used in developing a comprehensive conservation design for the county. The authors recommend that the map be used in conjunction with ancillary data sources for conservation planning (Noss et al. 1997; Thorne et al. 2002; Thorne 2003).

The MCV map is useful for a wide array of natural resource management purposes, including forest and range inventory and assessment, watershed characterization in support of hydrologic modeling and erosion control, wildfire risk and behavior modeling, urban-wildland interface issues, and disease risk and spread modeling. This latter use is of particular importance, since the majority of species susceptible to Sudden Oak Death Syndrome (SODS) caused by the fungus, *Phytophthora ramorum*, are canopy dominant species that form the basis for defining many MCV alliances and map units. Therefore, the new map is especially suitable for SODS risk assessment and spread analysis.

Other applications include land use planning and policy assessment and pre-project impact scoping. Finally, the map can be used to identify and target areas for more detailed ground-based vegetation inventory and mapping work.

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