CHAPTER 6

DRYLAND HABITATS

September 17…After breakfast I walked with Dr. Marsh to the summit of a conical hill, about a mile distant from his house, from which the view of the plain on the north, south, and east, and the more broken and mountainous country on the west, is very extensive and highly picturesque. The hills and the plain are ornamented with the evergreen oak, sometimes in clumps or groves, at others standing solitary. On the summits, and in the gorges of the mountains, the cedar, pine, and fir, display their tall, symmetrical shapes.

-Edwin Bryant 1848

DRYLAND HABITATS

Woodland, savanna, chaparral, dune, and grassland communities together comprise the dryland vegetation of East Contra Costa County (ECCC; fig. 6.1). These communities provide a wide array of ecological functions and support many species of special concern. Among these, the San Joaquin kit fox (*Vulpes macrotus mutica*) and the Western burrowing owl (*Athene cunicularia hypugea*) are particularly associated with open grassland or savanna communities. Chaparral provides essential habitat for HCP species such as the Alameda whipsnake (*Masticophis lateralis euryxanthus*) and numerous rare plants such as Mount Diablo manzanita (*Arctostaphylos auriculata*). The Silvery legless lizard (*Anniella pulchra pulchra*) is supported by chaparral, savanna, dune habitats, and woodland communities with suitably sandy soils. While these communities may not be the primary habitat for wetland-associated species, many such species—including the Western pond turtle (*Clemmys marmorata*), the California tiger salamander (*Ambystome californiense*), and the California red-legged frog (*Rana aurora draytonii*)—depend on the dryland communities for movement or foraging.

During the development of the HCP, questions arose concerning historical changes in the dryland habitats supporting these species. These changes include the potential expansion of woody vegetation during historical times, which could have affected kit fox through reduced extent and changes in patch size of open grassland. Conversely, reduction of dune habitats may have negatively affected the silvery legless lizard. Loss of habitat connectivity due to development may negatively impact a host of native species. Understanding these changes and their implications can provide a stronger basis for effective management strategies.

Vegetation patterns in ECCC generally reflect physical controls such as slope, aspect, soil depth (Bowerman 1944 , Holstein 2000), moisture gradients (Griffin 1973), and disturbance regimes (Matsuda 1986; fig. 6.2). Many such physical factors interact to produce a landscape that is both spatially complex at the local level and

Figure 6.1. Views of dryland habitats: montane, foothill, and plain. A) North Peak, taken from the summit of Mount Diablo. B) Russell aerial photo, "one mile north of Brentwood," looking west across former grasslands and savanna, converted to agriculture by the 1920s. C) Clayton Valley , ca. 1913, with oaks (likely blue or valley oak) still standing in cultivated grain fields. (A: Storer 1912, courtesy of MVZ; B: Russell ca. 1925, courtesy State Lands Commission; C: Unknown ca. 1913, courtesy of the Clayton Historical Society)

generally presents discernable patterns at the larger scale. As ECCC lies within the rain shadow of Mount Diablo, much of the native vegetation reflects that of semiarid regions (Carpenter and Cosby 1939). Mount Diablo and ECCC comprise a unique region where ecological zones overlap and some species are found at the very northern-most limit of their range while other species occur at their southern-most limit (Bowerman 1944).

Many of the blue oak and valley oak woodland and savanna systems existing in California today are degraded and continue to degrade due to a variety of factors including persistently low oak recruitment (of particular concern with blue oaks) and declining tree densities, disease, mammalian consumption, invasive exotic species, and altered fire regimes (Bolsinger 1988, Kelly et al. 2005, Plieninger 2006, Tyler et al. 2006, Acacio et al. 2007, Zavaleta et al. 2007, Davis et al. 2011). These trends have raised concerns about the resiliency of these ecosystems to stressors such as climate change and further habitat fragmentation (Brown and Davis 1991, Davis et al. 2000, Sork et al. 2002, Mahall et al. 2005).

Due to the ecological and cultural significance of dryland habitats, conservation and restoration efforts are underway in many locations. A historical perspective can help ground these efforts to make restoration effective and sustainable. Historical ecology can provide a broader landscape perspective of the relative distribution and abundance of target habitats, and an understanding of variability under locally specific conditions. As with riverine and wetland systems, substantial research on terrestrial ecosystems in recent years has shown that conservation efforts can be misguided without accurate historical information, resulting in unsustainable or unprecedented restoration targets (e.g., Hamilton 1997, Foster and Motzkin 2003).

In this chapter, we discuss our understanding of the distribution, stand density, species composition, and other characteristics of the woodlands, savannas, chaparral, dune habitats, and grasslands in ECCC prior to significant Euro-American modification. We also address possible explanations for regional and local changes in these habitats during historical times. We describe methods and results, and discuss our findings within the context of regional studies on vegetation change. Specifically, we discuss the relative abundance of woodlands, savannas, chaparral, dune habitats, and grassland in relation to landscape position and other physical factors.

METHODS

Our understanding of native dryland habitats relies on a broad but heterogeneous set of historical data sources, each with their own social context and level of accuracy and uncertainty. Sources used to map dryland habitats include Wieslander Vegetation Type Maps (VTM; Wieslander 1935a), historical aerial photography (USDA 1939), mid-1800s General Land Office (GLO) survey data, explorer and traveler accounts, Mexican land grant maps and associated text, other early cartographic sources, and landscape photography (table 6.1).

Figure 6.2. Blue oak at Chaparral Spring. A mosaic of chaparral, grassland, and oaks along a trail in the newly acquired Chaparral Spring property east of Clayton, illustrating the rich habitat complexity in the upper elevations of East Contra Costa County. (photo August 19, 2006 by Scott Hein, www.heinphoto.com)

Table 6.1. Key data sources used to map dryland habitats. General data sources are listed with their associated uses in the mapping process, the era from which the source originates, its spatial coverage, and its accuracy. All sources also contributed to the assignment of habitat types.

Data Sources	Use of data	Era	Spatial coverage	Spatial accuracy
Narrative accounts	Corroborate relative density and location	1770s	Limited areas	Usually general
Maps	Refine habitat boundaries	1830s-1910s	Individual maps cover many parts of study area	Depends on source
GLO bearing tree data	Estimate point stand density, refine habitat boundaries	1850s-1870s	Distributed point data	High
GLO field notes	Corroborate relative density, refine habitat boundaries	1850s-1870s	Point data distributed across study area	High
Landscape photography	Corroborate relative density	1880s	Limited areas	Depends on source
Soil surveys	Establish correlation with soil type and tree presence	1900s	Continuous for study area	High
Aerial photography	Refine habitat boundaries, estimate oak population, establish correlation with soil type and tree presence	1930s	Continuous for study area	High

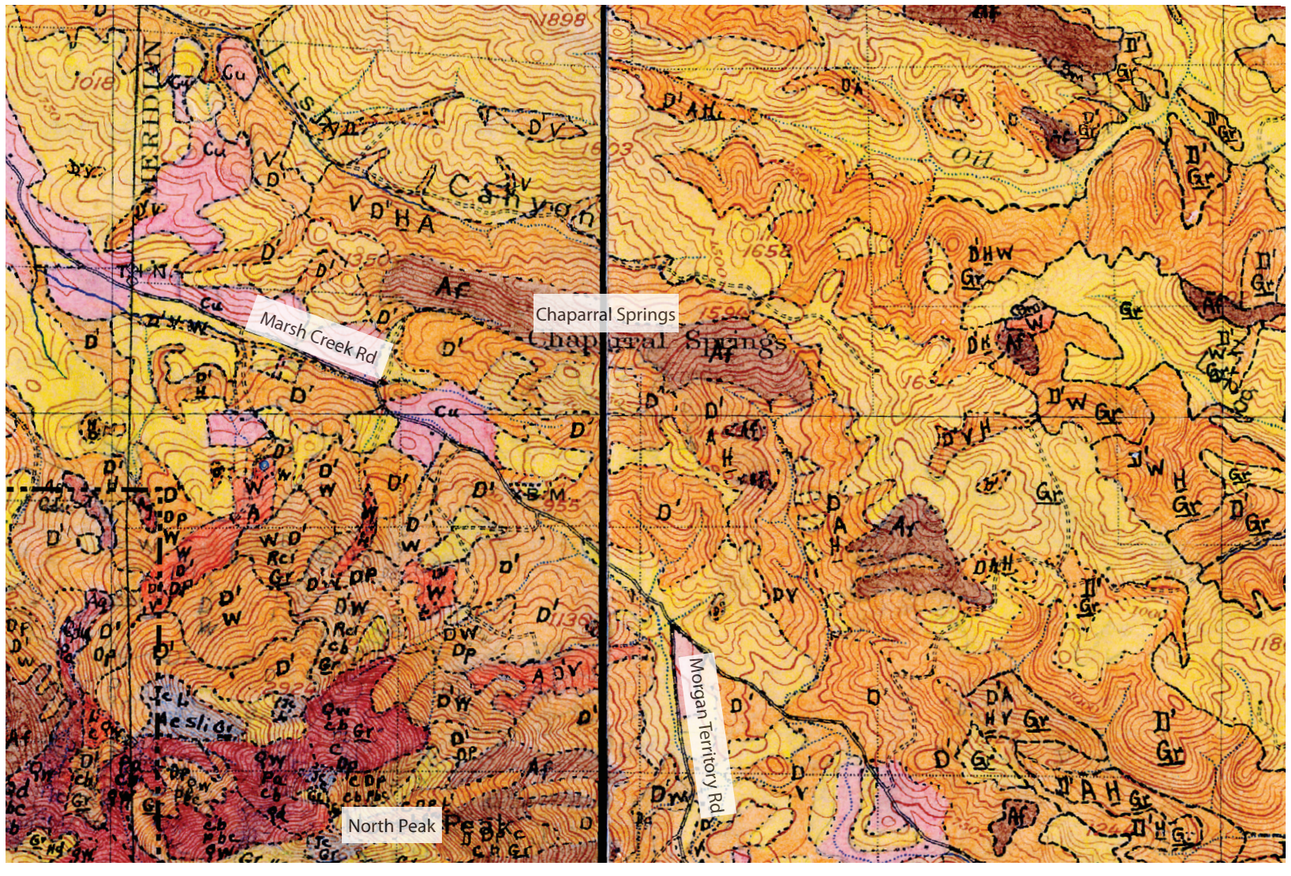


Figure 6.3. VTM map. This example area from a map produced on 15-minute USGS quads by Wieslander's Vegetation Type Mapping project shows the vegetation distribution in the vicinity of Chaparral Spring, just east of Clayton. The colors indicate vegetation types; the codes indicating dominant species, as determined by field work are listed for each vegetation polygon. Vegetation codes visible here include D' (*Quercus douglasii* - blue oak), Af (*Adenostoma fasciculatum* - chamise), and Cu (cultivated). (Wieslander et al. 1933, courtesy of ICE, UC Davis)

In general, historical data fell into two distinct groups, divided by geomorphic units (see fig. 2.4). In the montane geomorphic unit (or region; >900 ft elevation) and most of the foothills (200-900 ft elevation), VTM data and historical aerial photography were available, but few pre-1930s sources were available. Conversely, in the plains region (<200 ft elevation), extensive 19th-century data were found, but VTM and early aerials were less useful because of the extent of modification by the 1930s. As a result, historical mapping of the upper elevations is more systematic but derived largely from later sources, while plains region data sources are more heterogeneous but earlier.

While most of our detailed mapping in the upper elevations relied upon 1930s data, some early sources, land use history, and contemporary literature discussing vegetation trends did allow us to refine our mapping and build confidence that the mapping generally represents overall extent and relative composition of ECCC vegetation prior to significant Euro-American modification, though substantial uncertainties exist at the local scale and in terms of vegetation density. Dominant anthropogenic drivers of change vary depending on location, and they include changes to fire frequency and grazing practices in the montane region, and urban and agricultural development in the lower plain. For most analysis, we used the geomorphic units derived from the HCP (Jones & Stokes 2006): montane, foothills, and plains. We maintained a minimum mapping unit of 5 acres to provide consistency when mapping from sources of different scales and to avoid overmapping.

Reconciling Wieslander Vegetation Type Mapping with Historical Aerial Photography

The earliest comprehensive effort to map California vegetation began in the 1930s, when Alfred Wieslander led the Vegetation Type Mapping (VTM) project for the U.S. Forest Service (Wieslander 1935a). The effort produced a set of vegetation maps, as well as plot data and maps, species inventories, and landscape photography, the protocols for which were documented in a carefully developed field manual (Wieslander et al. 1933). The vegetation type mapping was conducted in the field directly on 15-minute (1:62,500 scale) U.S. Geological Survey (USGS) quadrangles without the benefit of aerial photography. Vegetation was classified as either complex vegetation mosaics or as pure or mixed stands, with the dominant as well as subdominant species listed (fig. 6.3).

These data have proven to be a valuable resource for researchers attempting to understand vegetation patterns and change over the past century. Recently, researchers at UC Berkeley and UC Davis have digitized many of these records (Kelly and Allen-Diaz 2005, Thorne 2006). The information has been used in a number of studies including the statewide California Gap Analysis project (Davis et al. 1998) and a regional analysis examining vegetation change (Thorne 2006). However, few, if any, studies have compared the mapping to early aerial photography, which followed the VTM efforts by just a few years. As a result, there has been little assessment of their local-scale spatial accuracy and applicability to local ecological planning.

We acquired digital versions of the vegetation maps through Dr. Jim Thorne and the Information Center for the Environment (ICE) at UC Davis. These digital maps were created by georeferencing and then digitizing the original VTM maps (Morgan et al. 2007). Each polygon was attributed by the ICE group with Wildlife Habitat Relationships (WHR; Mayer and Laudenslayer 1988) and Manual of California Vegetation (MCV; Sawyer and Keeler-Wolf 1995) vegetation classifications, based on the dominant species listed by the VTM cartographers. Visual comparison to the contemporaneous aerial photography dataset made it clear that the VTM mapping scale was far coarser (e.g., generalized topography creating generalized vegetation polygons) than the mapping scale possible using aerial photography. This scale difference is expected given that VTM mapping

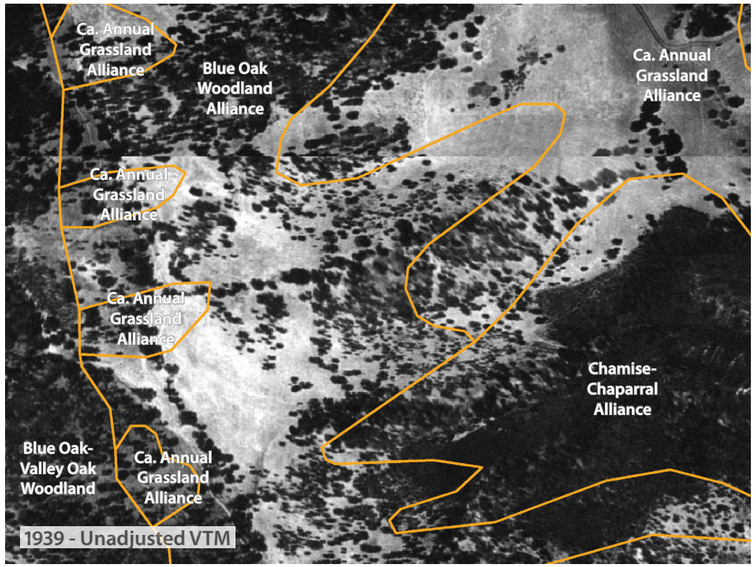


Figure 6.4. Adjusting VTM polygons. Original Wieslander VTM polygon boundaries (shown as orange lines with MCV alliance labels in the upper image) follow the general pattern of vegetation type visible in aerial photography, but are clearly distorted in part due to the more general USGS topographic quads and field methods used by the VTM. The blue oak woodland and chaparral boundaries in particular do not follow those clearly visible and mappable in the historical aerial photography. Shown below are adjusted polygons, classified by the general habitat type used in our mapping. These polygons also include attribution of the more detailed species community information offered by the VTM mapping. For example, the lower right chaparral polygon in the bottom image contains the VTM attribute of Chamise-Chaparral Alliance, based on the VTM polygon it is coincident with Both versions are shown against 1939 photography. (USDA 1939, courtesy Contra Costa County and Earth Sciences & Map Library, UC Berkeley)

was performed by hand on USGS maps at a scale of 1:62,500. We concluded that the potential for improving the mapped vegetation boundaries using the historical aerial photography was high and would enhance detection of areas of change (fig. 6.4).

We therefore developed methods to create a more spatially detailed habitat map, while retaining the information of the attribute-rich field-based VTM maps. Through initial overlay comparisons with the HCP vegetation mapping (Jones & Stokes 2006) we noted significant similarity in vegetation patterns. To avoid redundant work and overestimates of change, we used the HCP mapping as the starting point. In the parts of the study area that were not extensively developed by the 1930s (primarily in the foothills and montane region), we developed the historical habitat map by adjusting polygon boundaries where appropriate and filling in the attributes using VTM data.

Four primary habitat classes were defined to correspond with the Jones & Stokes (2006) classification: chaparral, woodland (>10% tree cover), savanna (5-10% tree cover), and grassland (<5% tree cover; Barbour et al. 2007, California Fish and Game Code §1361). For the generation of comparable datasets, we matched the patterns mapped by Jones & Stokes (2006), particularly in the distinction between savanna and woodland. For both datasets, the 10% cutoff is soft. We usually found boundaries between denser (woodlands) and sparser (savannas) areas relatively easy to detect as most woodlands were quite dense. Rock outcrops mapped by Jones & Stokes (2006) were left unchanged. The chaparral class encompasses both chaparral and sage scrub communities due to the difficulty distinguishing between these types in the historical aerial photography. Similarly, the woodland class includes both oak woodland and upper montane forest types. Although these types were not distinguished at the primary habitat type level due to limitations in detecting vegetation differences from historical aerial photography (Jones & Stokes 2006), the VTM attributes provide some information to make such distinctions.

We used habitat boundaries visible in the historical aerial photography to adjust polygon boundaries and assign habitat types that largely reflect 1939 conditions. Mapping was performed at a scale of 1:5,000 with a 5 acre minimum mapping unit. Polygon boundaries were adjusted if the distance of change exceeded 150 ft (a distance greater than the uncertainty associated with digitizing sources).

Some boundaries were difficult to adjust due to challenges in detecting texture differences in black and white photography (e.g., chaparral boundaries, fig. 6.5). To determine native habitat type assignment for the upland areas with clear human alteration, such as farming or clear-cutting, we extrapolated from available data to assign a native habitat type. This included using textual descriptions of the area or, where no additional data existed, basing attribution on adjacent vegetation type.

To take advantage of the rich species data included in the VTM maps, we attributed the mapped polygons with VTM species composition information using a spatial join. We also divided habitat polygons (e.g., woodland) based on species composition boundaries indicated on the VTM map. That is, the habitat type boundaries (e.g., woodland) were digitized based on vegetation boundaries evident in the aerial photography, but subsequent refining within those classes included the use of less accurate VTM polygon boundaries, which often followed topographic boundaries. This process resulted in a one-to-one relationship between the VTM attributes and the 1939 historical habitat polygons. The purpose was to create a historical map generated at a scale that would facilitate change detection using the contemporary dataset, while also providing additional detail on the habitat species composition available from the VTM dataset.

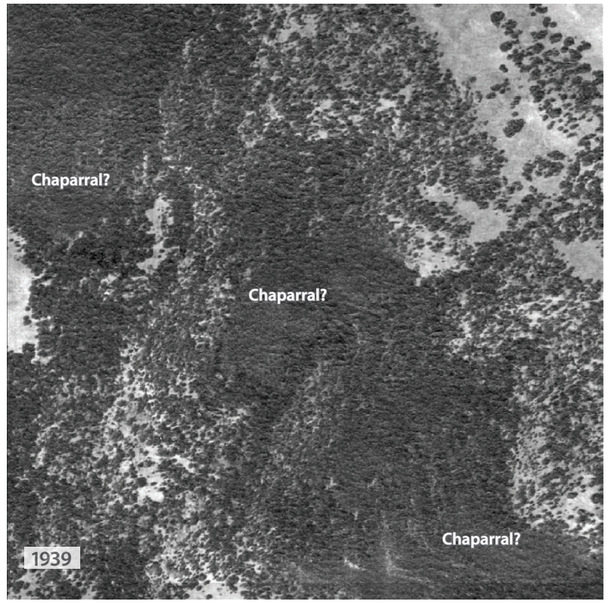


Figure 6.5. The challenge of detecting chaparral boundary in historical aerials for mapping purposes. These two aerial photos, taken in 1939 (top) and 2005 (bottom), illustrate the difficulty in determining whether any change in vegetation type boundaries is visible between these two time periods represented. In such cases as these where no clear boundary shifts are visible or where texture differences are inconclusive, no change was mapped. (Top: USDA 1939, courtesy of Contra Costa County and Earth Sciences & Map Library, UC Berkeley; Bottom: USDA 2005, courtesy of NAIP)

Summarizing General Land Office Survey Data

The General Land Office (GLO) Public Land Survey (PLS) field notes provide detailed descriptions of landscape and vegetation prior many of the extensive environmental changes that followed Euro-American contact (Buordo 1956). The GLO survey data have provided researchers throughout the U.S. with ecological data at a level of accuracy, consistency, and spatial extent rarely available from other sources of this era. The GLO survey progressed from Ohio to the West Coast after being initiated in 1785 by the Land Ordinance. The survey reached Contra Costa County in 1851 and continued surveying the area until 1875. The survey established townships of 36 mi^2 divided into square mile sections. The section and township corners ideally form a square grid across the landscape at a resolution as fine as the quarter-section. However, many areas in California, including parts of the study area, lack a complete network of inner township section lines as a result of private Mexican land grant holdings, as well as, in the case of this study, the Delta tidal marshes and some areas of exceptionally steep terrain on Mount Diablo (White 1991, Whipple et al. 2011).

The GLO field notes contain a wealth of information about local ecology and hydrology. This includes descriptions of overstory and understory composition, creek seasonality and channel geometry, and ponds and marshes. In addition, to establish section corners and quarter-section points (at the mile and one-half mile points), surveyors recorded the species, diameter, azimuth, and distance from the survey points for up to four "bearing" trees, ideally one tree per quadrant. If no trees were available within "convenient and suitable distances," surveyors were instructed to establish a mound and trench (White 1991). In addition to bearing trees, surveyors recorded the species and diameter of trees encountered in the path of survey lines ("line" trees).

We adapted methods developed by the Forest Landscape Ecology Lab at the University of Wisconsin-Madison to store, display, and analyze the GLO data within a GIS environment (Manies 1997, Radeloff et al. 1998, Sickley et al. 2000). One of the primary benefits of the ArcMap (Esri) form developed by the Wisconsin group is the ability to place the survey points efficiently and accurately within a contemporary spatial coordinate system. The resulting database can be easily manipulated for subsequent analyses. These data have been used most often in reconstructions of historical forest structure and composition in the Midwest and Northwest but relatively rarely in California systems (Radeloff et al. 1999, Collins and Montgomery 2001, Bloom and Bahre 2005, Brown 2005, Whipple et al. 2011).

We performed quantitative analysis of the GLO bearing tree dataset to estimate tree density by calculating point density estimates. This information was used to compare across different regions of the study area and to estimate average tree densities. Various different methods have been used to estimate density based on GLO bearing tree data (Bouldin 2008). We used both the point-centered quarter method developed by Cottam and Curtis (1956) and the more robust Morisita (1957) formula (see appendix for details). We also evaluated the GLO tree dataset for diameter at breast height (dbh) distribution and species composition, which were summarized by geomorphic unit.

While these surveys were systematic and spatially comprehensive, researchers have noted the importance in understanding potential bias, such as preferences for tree species with easily marked bark, trees of particular size classes, or trees within particular angle quadrants (White 1983, Radeloff et al. 1999, Collins and Montgomery 2001, Kronenfeld and Wang 2007). Inconsistencies also exist depending on individual surveyors, and it should be kept in mind that although the surveys recorded valuable ecological data, their intended purpose was to sell land to settlers and timber, railroad, and mining interests. As an example of possible effects, an underestimation of tree density would result if some surveyors tended to select trees other than the closest trees. Although it was not possible to quantify the bias of this dataset, examination of the range of species and the size-class distribution suggests that one can draw meaningful comparisons from the dataset.

In addition, it is important to note that each survey represents conditions present at one particular point in time. However, while extreme events (such as flooding in 1862) may impact descriptions of temporally dynamic characteristics such as stream flow, the distribution of long-lived features such as oaks is unlikely to be affected by most short-term weather events.

Integrating Additional Data Sources

While VTM data and early aerial photography provided extensive information in the uplands, earlier historical sources were of paramount importance, particularly when mapping dryland features on the alluvial lowlands. The plains were already developed and under cultivation by the time of the Wieslander VTM project and the historical aerial photography, so these sources could be used only rarely for mapping historical vegetation in this part of the study area. Instead, we used primary historical sources that included GLO, narrative accounts, soils, and other historical maps. Most were earlier, though less spatially-detailed and comprehensive, than the VTM and historical aerials. We used a variety of methods to incorporate these additional data sources.

Qualitative use of GLO contributed to our mapping efforts as part of the GIS synthesis process. For example, where surveyors noted entering timber or brush or little tree cover, we used this to provide 19th century calibration of 1930s-era habitat boundaries. These data were especially useful in areas such as the plains region which were already heavily modified by the time of the VTM maps. The field notes also provided valuable, mid-19th century narrative accounts of the landscape, such as whether slopes were densely covered in brush or sparse timber.

To better understand soils as a factor contributing to tree location in the plains region, we used GIS and chi-square analysis to correlate canopy sized trees (> 15 m) digitized from the 1939 historical aerial photography with soil types (Neu et al. 1974, Mahall et al. 2005). Trees were digitized based upon their distinctive size, shape, and groupings (Brown 2002, Sork et al. 2002, Mahall et al. 2005). Our preliminary evaluation using digitized trees from historical aerials to determine soils associated with savannas or woodlands was fairly inconclusive. However, we did find that soils tending to have higher oak density matched areas supported by other sources. Other soil types with pronounced characteristics, such as the Oakley sands, do appear, through qualitative evaluation, to reflect different habitat types. Soil descriptions were useful as well: the 1939 soil survey identifies an area of Cayucos adobe clay southeast of Antioch as a type that supports "a few oak trees," where "intervening spaces are carpeted with grasses" (Carpenter and Cosby 1939). Such soil type distinctions were found to be especially useful in the plains region where topographic effects were not as significant in determining vegetation patterns. Although we were not able to establish oak-bearing soils with a certainty high enough to map oaks directly from the soils in the absence of other evidence, we were able to use these soils to refine oak polygon boundaries when other sources indicated oak presence.

In addition to soils and GLO survey notes, we found that historical maps, early photographs, and narrative accounts all provided valuable data. Usually several lines of corroborating evidence contributed to our understanding of historical dryland conditions. For example, to map the large stretch of oak savanna along the eastern edge of East Contra Costa, we relied heavily on GLO surveys, soils, and the 1853 Whitcher map (see p.7). We sketched the initial polygon directly from Whitcher's map and then compared this shape with the locations of GLO bearing trees, narrative data, and lithographs of the area. We found that this shape matched well with both these sources and the 1933 soil survey (Carpenter and Cosby 1933). Towards the mouth of Marsh Creek, Whitcher shows a gap in the oak cover that corresponds with a large patch of Sorrento clay. This clay soil would have been too wet to support oaks and suggests that Whitcher purposefully did not place oaks here. In this way, we were able to use the soils map to refine the oak savanna polygon. By using many sources as corroborating or conflicting evidence, we were able to map historical habitats with a much higher degree of confidence than would have been possible by using the individual sources in isolation. Each mapped polygon was assigned certainty levels of either high, medium, or low for three different characteristics: habitat type interpretation, feature size, and feature location (see p. 10). In general, features mapped from earlier and more spatially accurate sources tended to be assigned higher certainty levels.

To explore within-habitat class density shifts over the past 70 years and the nature of that change, we also developed a preliminary method of raster image analysis that would, for a given area, show the location as well as trajectory of change between woody vegetation cover (chaparral or trees) and no cover (grassland). This was done with binary classification of the images' pixel values as woody vegetation cover (dark) or no cover (light), the areas and locations of which could then be compared between the two years of aerial photography (Mast et al. 1997). For full discussion of this method, see appendix. Although visually many places appeared to have become denser through either tree growth or filling in of chaparral, this preliminary analysis produces relatively inconclusive results given uncertainties associated with determining appropriate pixel value breaks for comparison between the time periods and complications such as shading. A true analysis to test vegetation change hypotheses using remote sensing techniques was beyond the scope of the project. In addition, ideally an analysis such as this would be accompanied by on-the-ground field measurements of tree age classes to better understand apparent trends in tree density and tree size.

RESULTS

The historical landscape of ECCC included a wide range of plant communities (fig. 6.6). Some maintain significant expression in the contemporary landscape, while others do not. Dryland vegetation patterns reflected the topographic, elevational, and edaphic controls of the region. As it does today, chaparral generally dominated shallower soils, while grasslands or savannas occupied deeper soils on south slopes and woodlands occupied deeper soils on north-facing slopes (Holstein 2000, Ertter and Bowerman 2002). Oak savanna and grassland historically occupied large areas of the valley floor, merging into smaller, but more numerous patches of woodland and savanna that followed topographic boundaries in the foothills, with grassland occupying the more "exposed slopes" (Carpenter and Cosby 1939). These habitats transitioned into oak woodland and montane forest interspersed with patches of chaparral, savanna, and grassland in the upper elevations of Mount Diablo. Within the highest elevations of Mount Diablo, pine, juniper, scrub oaks and other chaparral species dominated, with relatively few areas of grass (Hilgard 1881), similar to today. (fig. 6.7, table 6.2)

Habitat complexity and relative patch size reflect the complexity of the physical characteristics. These relationships were noted by early observers, as in this description relating the distribution of vegetation on Mount Diablo to topography: "the hills and lower slopes of the mountains being dotted over with picturesque oaks; standing alone or gathered in clumps; while the ravines that furrowed their sides were filled with chaparral and innumerable flowering shrubs" (Degroot 1875). Another writer characterized the pattern in the upper elevations of Mount Diablo as follows: "to the very summit, wild oats and chaparral alternate. In the canons are oak and pine trees from fifty to one hundred feet in height; and on the more exposed portions there are low trees from twenty to thirty feet in height" (Olmstead 1962; fig. 6.8).

Loss of native habitats within the lower elevation regions of ECCC has been significant. Direct effects due to agricultural and urban development have had the most dramatic impact on the relative distribution and abundance of dryland habitats. These modifications have transformed the plains, making pre-modification patterns unrecognizable.

Changes are less pronounced, though potentially not insignificant, in the upper elevations. Some localized change is quite evident due to direct effects of clearing, while other changes are more subtle and may be attributed to multiple interacting long and short term indirect drivers of change (fig. 6.9). While some apparent changes as detected when comparing the historical and modern habitat mapping may be attributable to imagery interpretation and classification errors, overall distribution and extent of habitat types are apparently still largely controlled by topography and other physical factors. Available evidence suggests that the proportion and distribution of dryland habitats within the montane (>900 ft elevation) and foothill (200-900 ft elevation) regions of ECCC have remained largely consistent over the last 70 years and likely the last 150 years, at least within the resolution of available historical information and between the defined habitat types. It should be noted, however, that our mapped distribution may not include some woodland or savanna areas that were cleared or thinned prior to 1939, given the dependence upon 1930s-era data sources. For instance, historical and qualitative data do suggest several drivers of change that would have led to cutting of blue oaks in the foothill region early on. Some evidence suggests that the 1930s may have been a low point for woodland and savanna cover (Adams pers. comm.). Also important to consider is that changes within habitat types may be significant, such as the introduction of native grasses or the gradual loss of individual trees due to mortality and low recruitment. Overall, the effects of changing grazing and fire regimes appear to have caused few large-scale vegetation type changes, and shifts in vegetation boundaries are not large, though density shifts in both blue oak woodland and chaparral are detectable in some areas. Although a thorough evaluation of possible changes from the mid-1800s distribution in these regions due to more these more indirect factors is not possible at this time, we explore these likely losses qualitatively.

Table 6.2. Estimated total acres of natural dryland habitats. Total acreage includes some areas that were mapped outside of the HCP (dune habitats, in particular) and are not reflected in the contemporary numbers. The difference between historical and contemporary acreages reflects conversion to agriculture and urban land use. (Contemporary numbers from Jones & Stokes 2006)

Class	Habitat	Historical Acreage	Contemporary Acreage
Dryland	Grassland	97,000	58,409
	Woodland	25,300	24,198
	Oak savanna	17,000	5,894
	Chaparral	3,300	3,016
	Rock outcrops	120	142
	Interior dune habitats	8,500	
	Total	**151,230**	**91,659**

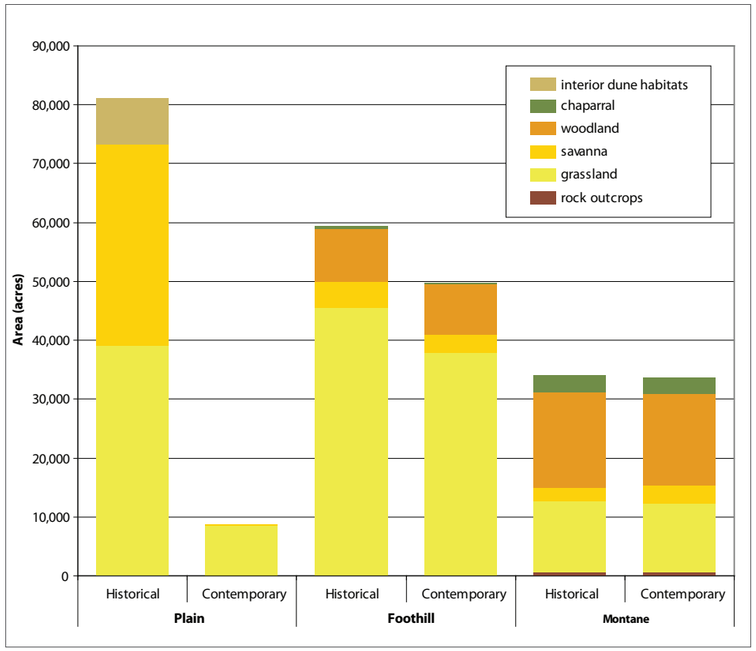


Figure 6.7 Historical and contemporary dryland habitats by geomorphic unit. (above) The greatest change in dryland habitat extent has occurred in the plains geomorphic unit. Virtually all plains region interior dune and savanna habitat has been developed or cultivated. The foothill region has also lost a significant amount of native dryland habitat cover, mostly attributable to loss of grassland to development and agriculture. The montane region has changed relatively little, though a noticable increase in savanna is likely due to a related decrease in woodland as a result of localized clearing. The plains region difference can be expected to be largely reflective of change since the mid-1800s, while the foothill and montane regions are more reflective of change since 1939. It should be noted, however, that due to uncertainties some apparent changes may be a result differences in mapping methods and aerial photo interpretation. This graph shows acreages for the six natural vegetation types (the two dune habitat types have been combined) and not the urban and other human-influenced land cover types, which explains the dramatic loss of total acres in the plains. Loss (or gain) in acreage for any particular habitat type may be due to a number of different factors.

Figure 6.6. Dryland habitats. Dryland habitats include fields of poppies, buckeye and oak trees near Vasco Caves, a patchwork of woodlands , grassland, and chaparral on the hillsides, and grazed grassland. (Left and middle right photos by Scott Hein, www.heinphoto.com; Middle left photo by Ruth Askevold; Right photo by Abigail Fateman, CCC)

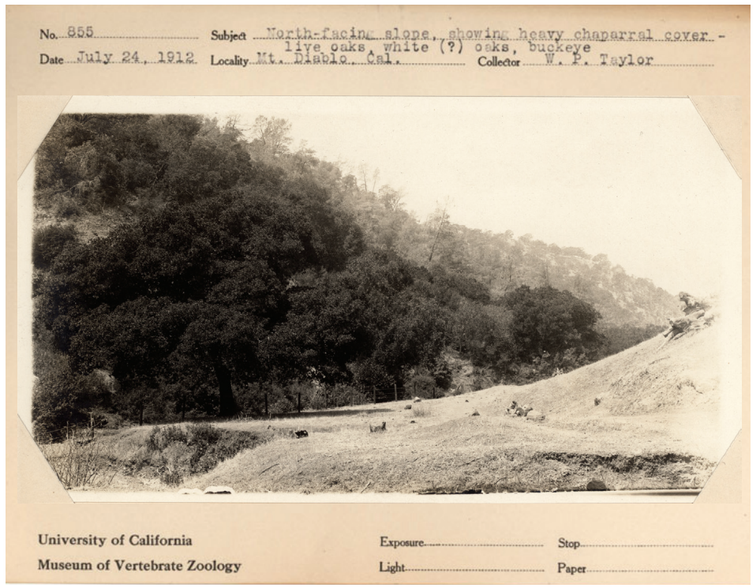


Figure 6.8. Differences in north and south-facing slopes. Note the contrast between the north-facing slope covered with live oaks and chaparral (top), and the relatively open and grassy south-facing slope (bottom). Exact location within the Mount Diablo foothills is unknown. (Taylor 1912b,c, courtesy of Museum of Vertebrate Zoology)

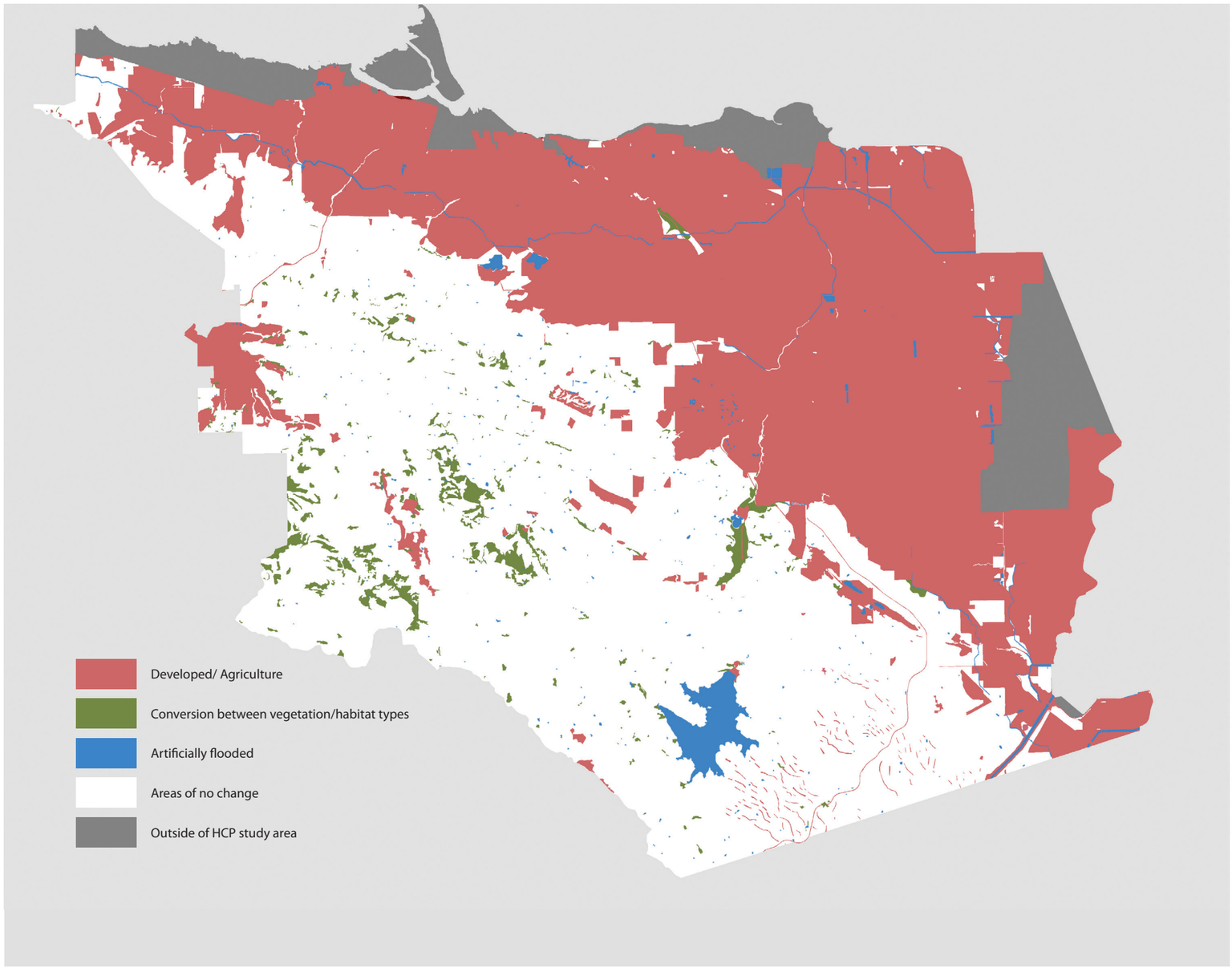
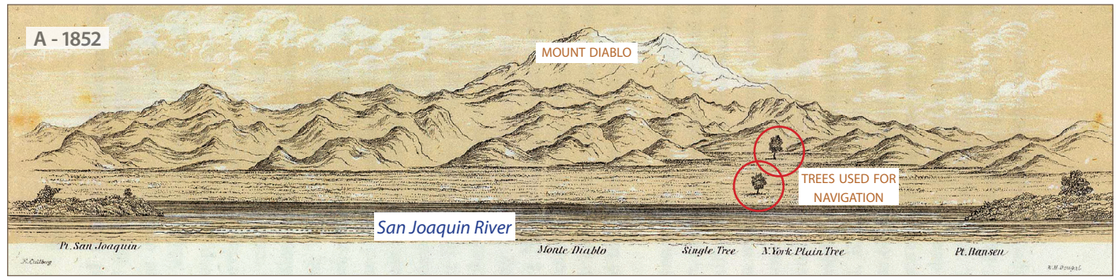
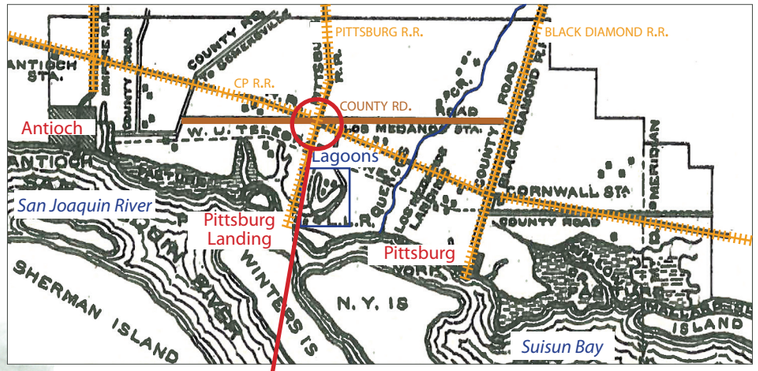


Figure 6.9. Selected areas of change within study area. A spatial comparison of historical and contemporary habitat mapping reveals particular areas that have undergone change. The reddish areas on the map show all historical habitats developed since historical times (e.g. urban and agricultural development). The green areas represent shifts between vegetation/habitat types (e.g., conversion of chaparral to grassland types) rather than alliance or association-level shifts (e.g., between types of oak woodland). This includes, for example, patches of woodland in 1937 that were thinned to savanna densities by 2005. This appears to have been the most common trend. However, this conversion also includes less extensive type conversions, such as expanding boundaries of chapparal into grassland. Some apparent conversion may also be a result of differing aerial imagery interpretation and classification methods between our and Jones & Stokes (2006) efforts. The blue areas have been largely artificially flooded (e.g., reservoirs, aqueducts). Many small features cannot be seen at this scale – this image captures change over areas larger than a few acres in size.





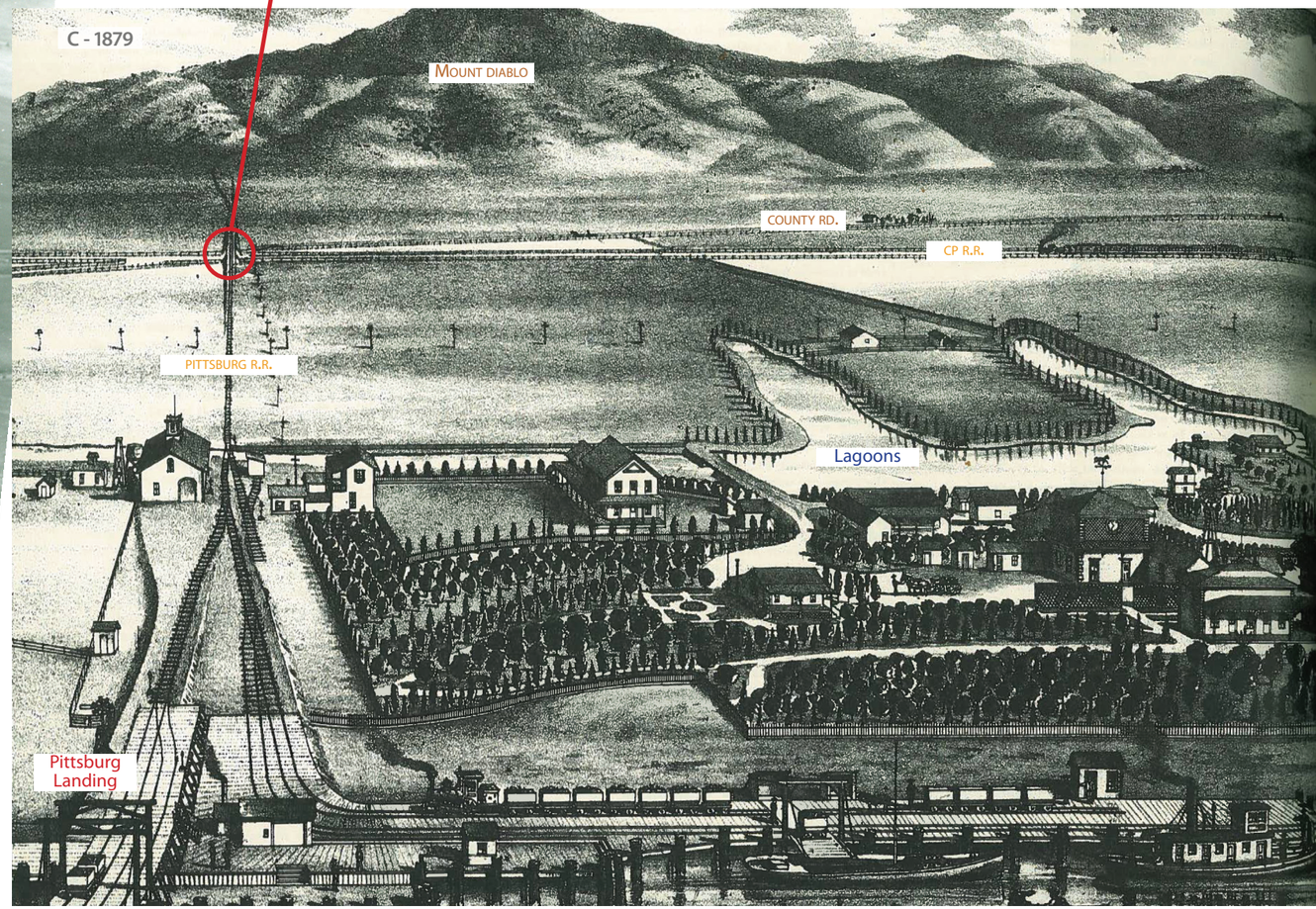


Figure 6.10. Three views of the treeless plain looking south from Pittsburg toward Mount Diablo. A) This image from Ringgold's 1852 charts of the San Francisco Bay shows distinctive and solitary trees, used for navigational purposes. Ringgold likely omitted foothill trees that were not relevant to navigation. B) Grasslands of the plain east of Pittsburg, shown in this image ca. 1925, lie directly to the east of Robinson's Landing, shown in image C). Some clearing may have occurred by this time. Note that the only visible trees occur along the railroad tracks in a planted formation and in the foothills. C) Robinson's Landing (near Pittsburg) and the planted grounds of Robinson's farm contrast with the treeless plain and scattered foothill trees. Note the intersecting county road and railroad lines shown on both images B and C. Although the drawings were intended for a specific purpose and may not have shown each individual tree, and the photograph was taken relatively late, after some clearing had certainly taken place, these images do give a sense for the generally treeless plain. (A: Culberg and Dougal 1852, courtesy of the David Rumsey Collection; B: Russell ca. 1925, courtesy of the State Lands Commission; C: Smith and Elliott 1879)

Grassland

Grassland and annual forbland (hereafter, grassland) dominated much of the historical landscape of ECCC (fig. 6.10). Four native perennial grasses are relavitely common today, *Nassella pulchra, Elymus multisetus, Poa secunda,* and *Melica californica,* which Ertter and Bowerman (2002) presume to be remnants of the original cover. Frequent comments about "timberless land" (Kip [1850]1946), "grassy plain" (Matthewson and Allardt 1862) and "treeless hills" (*Byron Times* Fifth Booster Edition 1916a) suggest a natural vegetation distribution of the northern part of ECCC that contrasts against the wooded East Bay hills (a difference some commented on). Relatively treeless foothill lands were noted by Spanish explorer Fages in 1772 – "the soil appeared good and rather grassy but scare in wood" (Stanger and Brown 1969) – and four years later Anza recorded traveling "over a very sterile and dry plain" as he traveled east towards Antioch (Brown 1998). Brewer in 1861 bemoaned the treelessness: "through the Kirker Pass, then among rounded hills, almost bare of grass or herbage, in places entirely so – no trees to cheer the eye, no water in the many canyons and ravines" (Brewer 1974).

Our historical mapping shows that grassland covered 97,000 acres, or 52% of the study area, compared to 58,800 acres, or 34% today (see fig. 6.6, table 6.2). Grassland occurred in about 37% of the montane region, in contrast to 75% in the foothill region. The coverage today remains at 36% in the montane region, but has decreased to 62% in the foothills. The lower elevation plains were composed of about 42% grassland historically, compared to 27% today. Grassland has been disproportionately affected by urban development as residential subdivisions have largely occurred within the plains and foothill regions of the study area.

Grassland tends to largely dominate clay-rich, deep soils (Holstein 2000). The 1939 soil survey describes the Altamont clay, which extends through the majority of the foothill region, as "covered with grass, together with a few oaks and patches of chamiso *[sic]* or other brush" (Carpenter and Cosby 1939). The grass in this region was also described as supporting "a luxuriant growth of alfilaria and wild oats" ca. 1853 (Hulaniski 1917). This account notes in particular that "on the wash of Sand Creek, where the soil had been flooded, the oats were so tall that the antelope and cattle made trails through and underneath them, and it was possible for a horseman to lap the heads of the oats together over his shoulders while sitting on his horse" (Hulaniski 1917). While non-native species are described here, these accounts suggest that the richer soils of the alluvial plains, with presumably higher moisture content, provided a more vigorous growth of herbaceous vegetation. Moving toward the upper elevations, grassland intermixed with woodlands and savannas at a small scale (smaller patch size), and occurred predominantly on south slopes due to topographic (greater solar insolation) and edaphic effects (Holstein 2000). Grass appears to have been less robust in these upper elevations with "only a scanty growth of grasses fit for sheep pasture," as GLO surveyor Wackenreuder reported in 1875(a).

Both perennial bunchgrasses and annual forbs were likely a part of the historical grassland (fig. 6.11). Holstein (2000) identifies this region as a "potential forbland corridor" due to a climate with insufficient rainfall to support extensive perennial grasses. Elk and other megafauna browsed on these grassland species, which likely had a profound effect on plant species distribution and abundance (Benyo 1972, Edwards 1992, Hamilton 1997, D'Antonio et al. 2000, Shiffman 2007, Barry et al. 2006). Bidwell observed a "large herd of elk and wild Horses, grazing upon the plain" when he passed through en route to Marsh's adobe in 1841 (Bidwell [1842]1937). And GLO surveyor Leander Ransom remarked on "herds of elk, antelope and deer that abound here" during his survey of Mount Diablo (1851). Changes in grassland species composition occurred shortly after Spanish contact in ECCC as elsewhere in California (Mensing and Byrne 1999). Non-native wild oats, mustard and other invasive grasses were commonly found by the early 1800s. GLO surveyors frequently report of plains covered by wild oats and Wilkes, during his 1845 exploring expedition, found the hills "thickly covered with wild oats" (Wilkes 1845).

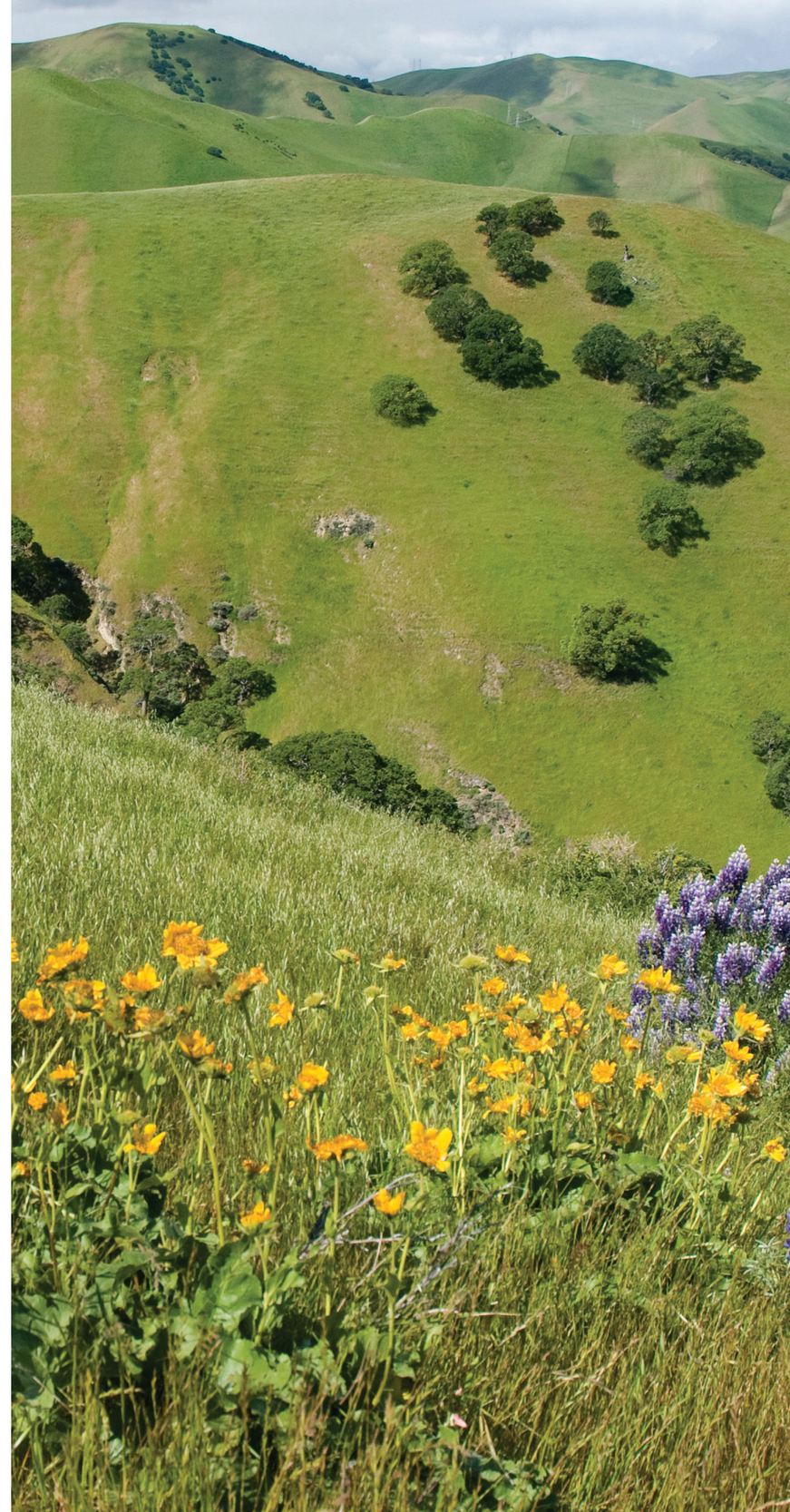


Figure 6.11. Grasses and forbs. Many native forbs are still present. This photo from the Black Diamond Mines regional park shows a mix of grasses and forbs with rangelands and scattered oaks in the background. (Photo April 6, 2008, by Scott Hein, www.heinphoto.com)

Woodland and Savanna

Regional Spatial Patterns

Overall, we mapped 25,300 acres of woodland and 17,000 acres of savanna, compared to 24,200 acres of woodland and 5,900 acres of savanna in the recent HCP mapping of the area (Jones & Stokes 2006; see fig. 6.7, table 6.2). This mapping was based largely on 1930s data. Our mapping shows that woodland and savanna covered the majority of the montane region, with 47% of the area (16,200 acres) as woodland and 6% (2,200 acres) as savanna. This is compared to 45% (15,500 acres) and 9% (3,000 acres) today, respectively. In the foothills, we mapped 15% of the area (9,000 acres) as woodland and 7% (4,500 acres) as savanna. HCP mapping shows 14% (8,600 acres) as woodland and 5% (3,100 acres) as savanna for this region. Estimates for the plains region, which were generally based on mid- to late 1800s sources, suggest that savanna covered 11% of the region (10,300 acres) historically. Only 0.1% of the plains (80 acres) is mapped as savanna today.

Summarizing the data using the Manual of California Vegetation (MCV; Sawyer et al. 2009) alliance classification that had been assigned to the VTM species assemblages by the UC Davis ICE group, we found that montane region Manual of California Vegetation (MCV) alliance woodland and savanna types that covered more than 2% of the area were Blue Oak Woodland (22%), Coast Live Oak Woodland (7%), Mixed Oak Forest (3%), and Interior Live Oak Woodland (3%). In the foothills, Blue Oak Woodland covered 11% of the area. Areas without VTM information make up about 16% of the montane and 13% of the foothill region, caused by areas of no data in the VTM and relicts of the VTM adjustment process (fig. 6.12).

Some conversion of savannas and woodlands to less dense habitat types occurred in all regions. In the plains, 430 acres (0.6% of the region) of savanna were converted to grassland. Our mapping shows 390 acres (0.6% of the region) of foothill savanna shifted to grassland, while only 66 acres shifted to woodland. For woodland, 160 acres (0.3% of the region) shifted to savanna. In the montane region, conversion of savanna to grassland and to woodland was similar (100 acres and 140 acres respectively). Woodland conversion to savanna was much greater (850 acres or 3% of the region). Significant clearing and thinning of oak woodlands has occurred in the upper watershed of Marsh Creek, particularly in Morgan Territory. Some clearing is also evident in the 1939 historical aerial photography. One large area, in particular, is between Sand and Deer creeks (fig. 6.13). Elsewhere, changes in tree cover can be seen following parcel boundary lines and around mining towns (Adams pers. comm.).

This trend of thinning tree cover, with coversion of woodlands to savannas and savannas to grassland, likely persisted throughout the late 1800s and early 1900s as a result of mining and settlement (Adams pers. comm.). Therefore, the mapped extent of woodlands and savannas, primarily mapped using the 1939 aerial photography, likely underrepresents the presence of these habitat types in the mid-1800s landscape. Based on calibration against narrative descriptions and examination of the historical aerials for obvious areas of cutting, we expect these changes to be fairly localized, although the historical record is not definitive. As might be expected, the greatest areal loss of woodlands and savannas was to urban and agricultural uses, especially in the lower elevations.

Using the bearing tree dataset as a calibration against the habitat mapping, we found that only 33 out of 318 bearing trees with azimuth and distance information were more than 500 ft outside of mapped savanna or woodland polygons, which lends solid early support for our mapping. Most of those 33 trees fell within the foothills and plains region, particularly within the Marsh Creek and Kellogg Creek watersheds (fig. 6.14). This could suggest that these areas may have had more trees historically than were apparent in the 1939 historical aerial photography. However, it is perhaps more likely that these GLO trees are the widely spaced trees evident in the 1939 aerials that were not mapped as savanna due to the extremely low density.

Alluvial plain oak savannas are currently a rare habitat, but historically occurred in many parts of the study area. Savannas were documented along the small alluvial valleys as well as in a broad swath along the eastern margin of ECCC. The southern tip of this region of oaks reached almost to Byron and was known as 'Point of Timber' both due to its shape and the fact that it was the first significant stand of timber encountered when coming from the south. A number of sources confirm the presence of large oaks in this area. GLO Surveyor Norris (1851) described the eastern portion of these trees as "thin but very large" and noted

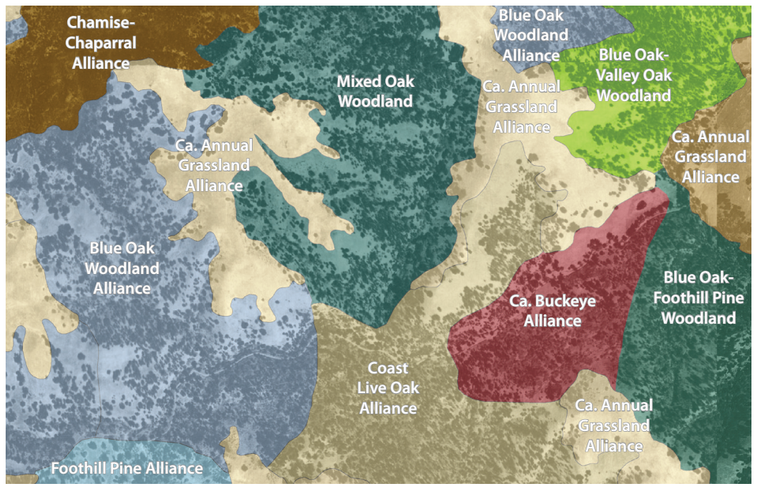


Figure 6.12. Historical habitats attributed by VTM classification. This area in the upper elevations of Mount Diablo shows the detail available from the 1930s VTM mapping (MCV classification shown here) in combination with the mapping accuracy possible using historical aerial photography.

Figure 6.13. Area of change prior to 1939. In the center of the image, extensive areas of stumps and/or small trees are seen around the chaparral. Large trees cover these areas today. (USDA 1939, courtesy courtesy Contra Costa County and Earth Sciences & Map Library, UC Berkeley

Figure 6.14. GLO bearing trees shown in mapped grassland. This area in the foothills near Marsh Creek shows that GLO surveyors did find some bearing trees in areas mapped as grassland, possibly indicating a higher density of trees in the mid-1800s in comparison to the 1939 aerial photography.

two bearing tree white (likely valley) oaks with six foot diameters 210 feet apart. Continuing north in the vicinity of Point of Timber, Surveyor Dyer (1862a) described "scattering oaks." He also noted of this township (T1N, R2E) as a whole that "it was at one time covered with a heavy growth of oak timber." Near Oakley, explorer Font (1776) recorded "we turned to the east-southeast and traveled this way some three leagues [1.5 miles], having on our right a grove of oaks which runs for about six leagues [3 miles] along the foot of the sierra to the south" (Font and Bolton 1933). Almost a century later, General Land Office surveyors note a transition from chaparral to an "oak orchard" as they "leave chemisal *[sic]* and enter scattering oak timber" near present-day Lake Alhambra (Ransom 1851, Wackenreuder 1875b), an area that is also described by explorers and in land grant testimony (Whitcher 1853b, Smith 1866, Font and Bolton 1933). These trees appear to have been mostly cleared in the space of a few decades, as agriculture, particularly wheat and orchards, spread east.

Another distinct alluvial oak savanna occurred along Marsh Creek, extending above and below present-day Marsh Creek Reservoir (fig. 6.15). Geologist William Brewer in 1862 described emerging "into a flat of perhaps two or three hundred acres surrounded by low rolling hills and covered with oaks scattered here and there, like a park. And such oaks! How I wish you could see them – nearly worthless for timber, but surely the most magnificent trees one could desire to see" (1974) The *Contra Costa Gazette* (1887) described "great oaks which crowd the entrance to the valley and wander out on to the plains;" these trees are also depicted in George Russell's ca. 1925 oblique photos of this region and on historical maps (Brown 1912, Whitcher 1853a). An 1881 confirmation map depicts scattering trees over an area of 500-600 acres in this valley and extending into the Marsh alluvial fan, supporting our mapping of low-density oak savanna (Von Schmidt 1881).

In addition to these areas, one of the more prominent oak savannas (320 acres mapped) was located within the valley now occupied by the Los Vaqueros reservoir. Within this area, the Wieslander VTM mapping identified both blue and valley oaks.

Early accounts of the general distribution and character of ECCC provide complementary perspectives on vegetation patterns. These sources tend to paint the landscape in extreme terms, both glowing and critical. Most of those discussing the majesty of large, grand oaks or "fields that look like an old park" (Smith and Elliott 1879) focus on the lower elevations, regions that, today, are mostly developed. For instance, an 1879 history of the county declares that "there are no heavily timbered tracts in the county," but then notes that "nearly every valley is dotted over with majestic oaks of several varieties" (Smith and Elliott 1879). To another, the landscape evoked a similar image; "a broad and well-watered plain, covered with many groves of magnificent oaks" (Buffum 1933).

Written sources tend to support the mapping and the overall vegetation patterns that exist today in the undeveloped areas of the foothills: they are generally unimpressed with the tree cover and often discuss scattering oaks and areas of little or no timber (6.16). Landscapes often described as containing groves of grand trees on the plain

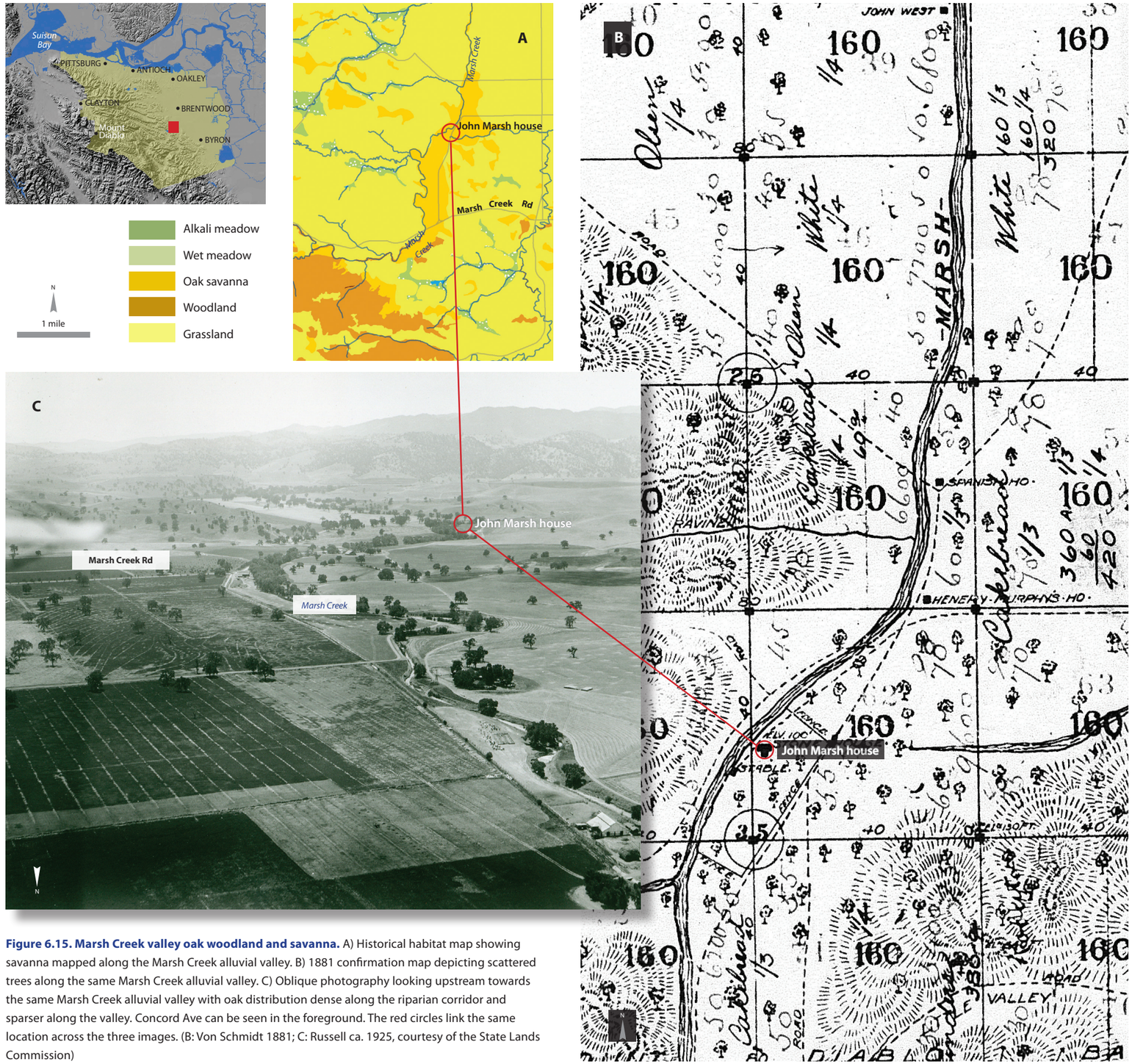


Figure 6.15. Marsh Creek valley oak woodland and savanna. A) Historical habitat map showing savanna mapped along the Marsh Creek alluvial valley. B) 1881 confirmation map depicting scattered trees along the same Marsh Creek alluvial valley. C) Oblique photography looking upstream towards the same Marsh Creek alluvial valley with oak distribution dense along the riparian corridor and sparser along the valley. Concord Ave can be seen in the foreground. The red circles link the same location across the three images. (B: Von Schmidt 1881; C: Russell ca. 1925, courtesy of the State Lands Commission)

contrast with the frequently described ECCC foothill landscape of "few scattered oaks" (Bidwell 1937) or "scattered oaks with a ground cover of alfileria, bur-clover, and wild oats" (Carpenter and Cosby 1939).

One of the more unfavorable accounts with regards to timber quality in the foothill and montane regions is that of Leander Ransom, whose 1851 GLO survey established the Mount Diablo meridian (see p. 11). He found that "the want of suitable timber for posts proved another serious difficulty, and even where it was found, you seldom met with a limb or branch more than 2 feet in length which was even tolerably straight" (Ransom 1851). He further stated that Mount Diablo "has but a small amount of timber of any kind growing either upon the mountain ranges or in the valleys" (Ransom 1851). The scarcity of timber is important to Ransom because it meant that "seldom did we meet with trees near enough to our line for bearing trees" and "our line was run for miles without meeting a tree that it was necessary to mark as coming within the scope of our work" (Ransom 1851). This scarcity of trees is supported overall by the GLO survey dataset, where only 18 line trees were recorded for the whole of ECCC. However, in the same description he does use grander terms for denser areas: "where the timber is most dense it resembles in heights and general appearance the old irregular orchards in New York, planted by the French before the Revolution" (Ransom 1851).

Species Composition and Size Class

The GLO tree dataset of the mid- to late 1800s includes 352 trees and 10 recorded species: white oak (interpreted as blue or valley oak), red oak (interpreted as blue or valley oak), live oak, black oak, pine, maple, laurel, cedar, buckeye, and sycamore (fig. 6.17). Of these trees, 65% were recorded as white oak. Most of white oaks are from the foothills and montane regions, so presumably the majority of these trees are blue oaks. The next largest group is live oak, which comprised 19% of the dataset. Pines and buckeyes each comprise 2% of the dataset. The plains region GLO trees were almost exclusively oaks, with about 20% each of red oak and live oak recorded. Trees recorded within the foothill region were about 75% white (presumably blue) oak, 10% live oak, with some sycamore and buckeye. As would be expected, the montane region has the most diverse range of trees, with nine species represented, though over half were identified as white oaks (fig. 6.18).

The VTM dataset contains more detailed information about species, which has been translated into MCV alliance types. Each mapped polygon was labeled with the dominant species, which we retained in our effort to refine mapping using historical aerial photography. For example, in an area where the GLO survey recorded several pine trees and a live oak as bearing trees, the VTM dataset identified blue oak, live oak, and pine as the dominant tree cover. Summarizing vegetation type at the VTM MCV alliance level supports that the Blue Oak Woodland Alliance dominates both the foothill and montane wooded areas (80% and 48%, respectively, for those areas attributed

Figure 6.16. Scattered oaks. Winter rains tranform the yellow grasslands of ECCC to bright green. These images show grassland (with patches of wetlands) and scattered oak savanna transitioning into woodland and chaparral. (Top: March 4, 2010, by David Ogden, Save Mount Diablo; Bottom: March 24, 2002, by Scott Hein, www.heinphoto.com)

Table 6.3. Acreage summarized by MCV alliance type. Summed acreages are included for the foothill and montane region.

Class (Sawyer et al. 2009)	Acres in Foothill	Acres in Montane
Barren	135	24
Bigberry manzanita chaparral	2	17
Birch leaf mountain mahogany chaparral		86
Black sage scrub	3	20
Blue oak woodland	7,199	7,405
California bay forest	0	11
California buckeye groves	209	603
California juniper woodland		87
California sagebrush scrub	14	32
California sagebrush-black sage scrub	21	5
Canyon live oak forest		76
Chamise chaparral	260	1987
Coast live oak woodland	98	2419
Arctostaphylos manzanita Provisional Shrubland		18
Coulter pine woodland		33
Ghost pine woodland	52	254
Interior live oak chaparral		199
Interior live oak woodland	585	847
Mixed oak forest	72	1070
Toyon chaparral		28
Valley oak woodland	388	356
Fremont cottonwood forest, Red willow thickets, or Sandbar willow thickets	8	

with VTM info). Other alliances comprising greater than 5% of the montane region include the Chamise Chaparral, the Coast Live Oak, the Interior Live Oak Woodland, and the Mixed Oak Forest (Sawyer et al. 2009; table 6.3). In the foothills, only Interior Live Oak Woodland and Blue Oak Woodland are over 5%. Further analysis of these datasets, including VTM plot data, could be carried out and would allow for a more comprehensive synthesis. More detailed descriptions of species composition can also be found in the ECCC HCP/NCCP (Jones & Stokes 2006) as well as Ertter and Bowerman's book, *The Flowering Plants and Ferns of Mount Diablo, California* (2002).

The GLO bearing tree dataset also allows for examination of diameter at breast height (dbh) distribution. We examined just oak species, and found that the 315 oaks with diameter data had an average dbh of 21 inches. The size distribution differs between geomorphic units, with 20-30 inches being the most common size class in the plains region, and 10–20 inches the most common class in the foothills and montane regions. Also, no oaks larger than 40 inches were recorded in the montane region while one oak with an 8 ft dbh was found in the foothills and several up to 6 ft dbh were found in the plains (fig. 6.19). Some areas were characterized by particularly large trees. For example, of the 12 GLO bearing trees in the area of the Point of Timber, all were found to be 20 inches in diameter or greater, with an average of 46 inches.

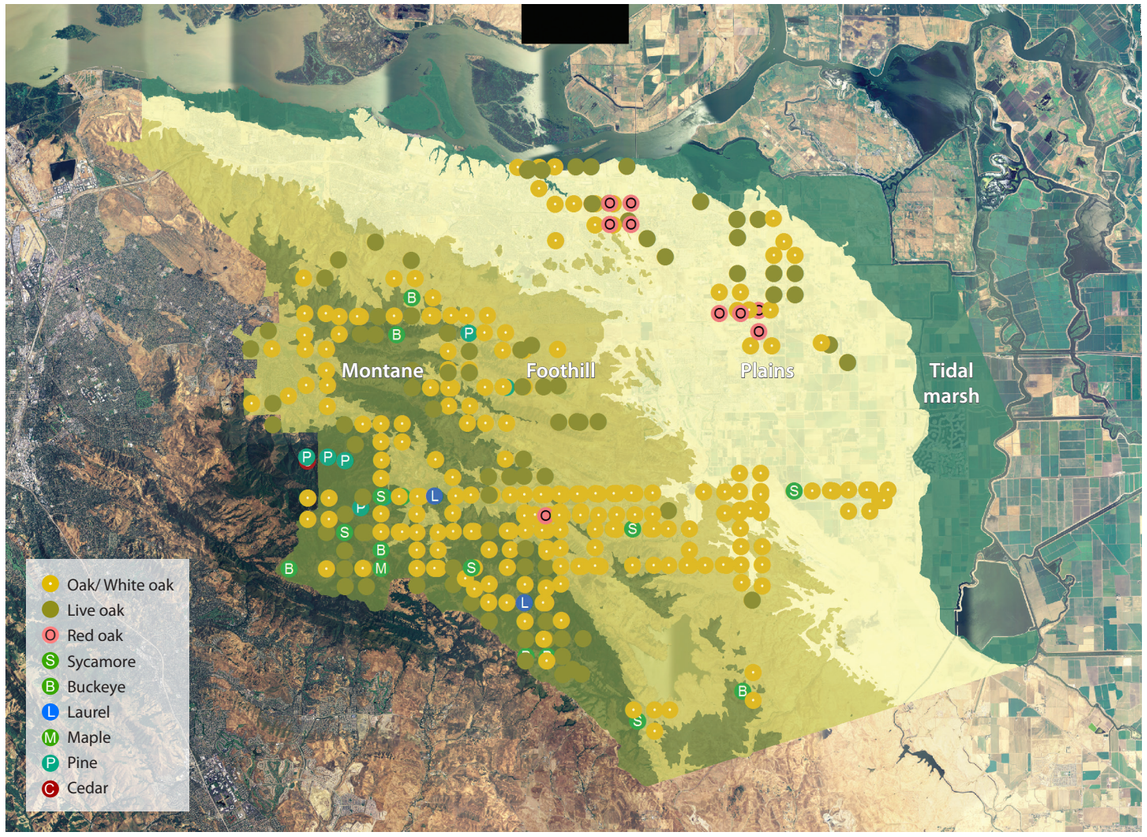
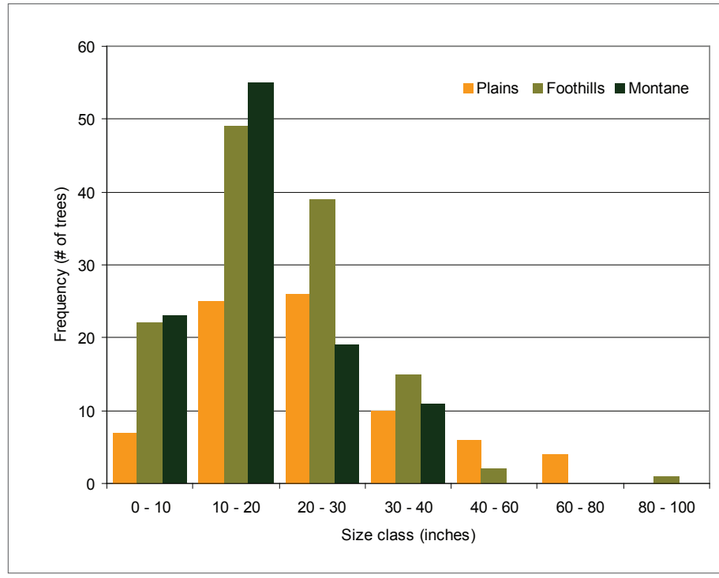
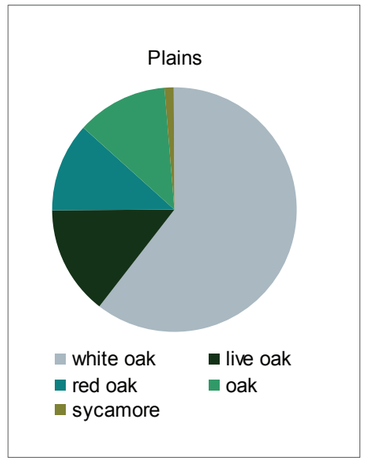


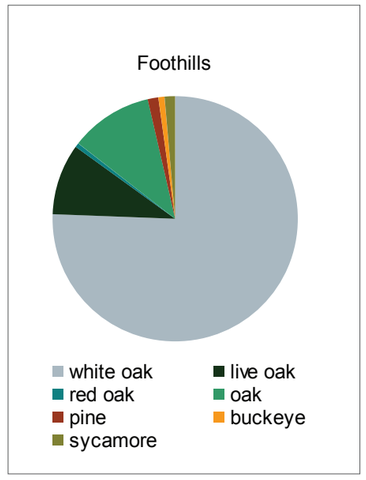
Figure 6.17. Distribution of GLO trees. (above) The GLO survey tree dataset displayed over geomorphic region showing basic distribution and species. The greatest number and diversity of species are found in montane (dark green) and foothill (light green) region. White oak (valley oak), red oak (valley or blue oak), and oak (undifferentiated) reflect the GLO naming conventions, based on East Coast trees. (overlaid on USDA 2005, courtesy of NAIP)

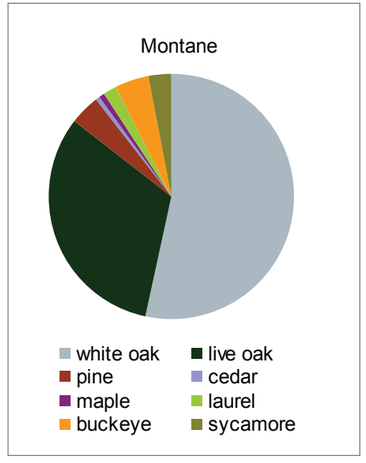
Figure 6.18. GLO tree species by geomorphic unit. (far right) Pie charts show the composition of GLO tree species, broken down by geomorphic unit. Size is not relative to the total number of recorded trees. White oak (valley or blue oak), red oak (valley or blue oak), and oak (undifferentiated) reflect GLO naming conventions..

Figure 6.19. Tree sizes. (right) Size distribution of trees by geomorphic units. The largest trees were found in the plains region.









Density Estimations

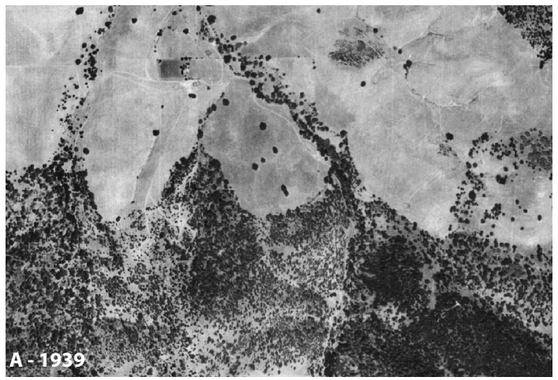
Early descriptions of density patterns identified groves as important features in the landscape, suggesting patterns of greater and lesser tree density. Some of the savanna descriptions suggest areas of denser groves with woodland characteristics; it should be assumed that smaller patches of woodlands occurred within the large region of mapped savanna. Along the alluvial plains, the arrangement of trees is described as "a park" where "they are disposed about the plains in most lovely groups, masses or single ones" (Smith and Elliott 1879; an identical description was used in Napa Valley, which suggests the authors may be describing a Bay Area-wide pattern; Smith and Elliott 1878). One of these groups, in the vicinity of Point of Timber, was composed of at least "twenty-five of those grand old oak trees, whose boughs gracefully sweep down and reach the ground"(Smith and Elliott 1879). This description is characteristic of other valley settings of the Bay Area: widely spaced, large valley oaks in a savanna setting. Another account from the Daily Alta California states that "the plain is interspersed with clumps of evergreen oaks, which look at a little distance like our apple orchards in the Atlantic States" (*Daily Alta California* 1860). (While this account emphasizes live oaks, the GLO data show that deciduous, i.e., valley/blue oaks were more prevalent.) Groves apparently became quite dense in some areas, such as the Byron area, described as "so dense it is said their tops seemed to grow together" (Hill 1990).

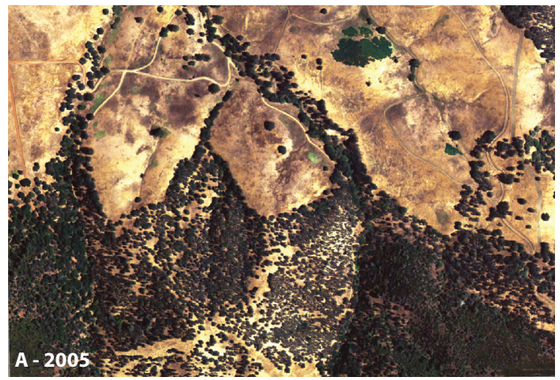
Table 6.4. Average density estimates from GLO dataset. Data are averaged by region to show relative differences in density across geomorphic units. Estimates from both the Morisita (1957) and Cottam and Curtis (1956) methods are shown for comparison.

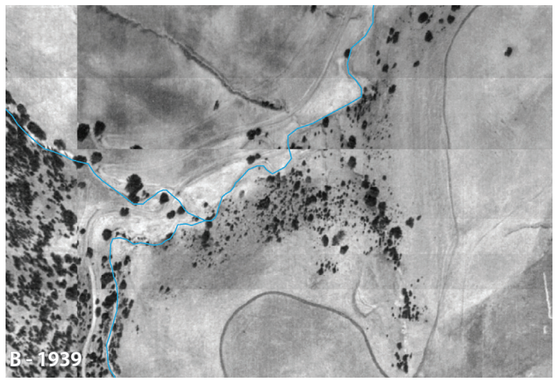
	DENSITY (Morisita method)			DENSITY (Cottam and Curtis method)		
	No. of survey points	Density (trees/ac)	Error in density	No. of survey points	Density (trees/ac)	Error in density
Plain	21	2.6	0.9	39	6.6	2.1
Foothill	39	9.3	2.2	70	12.4	4.2
Montane	29	9.2	4.1	76	21.1	4.8

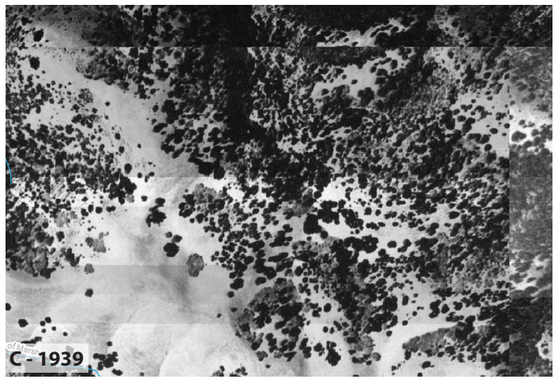
Table 6.5. Density of individual patches. We estimated tree density in small stands of live oaks found on patches of isolated interior dune sand (see p. 90). The numbers below reflect the number of trees at each of four nearby locations. Area was approximated by drawing a small polygon around the group of trees.

Location	Area (acres)	Source	# of trees	Density (trees/acre)
West of Antioch - large oak patch	43.4	Davidson USCGS 1887	22	0.5
West of Antioch - large oak patch	43.4	San Pablo-Tulare Railroad n.d.	15	0.3
West of Antioch - smaller oak patch	3.5	San Pablo-Tulare Railroad n.d.	5	1.4
Antioch Dunes	86.9	Davidson USCGS 1887	76	0.9









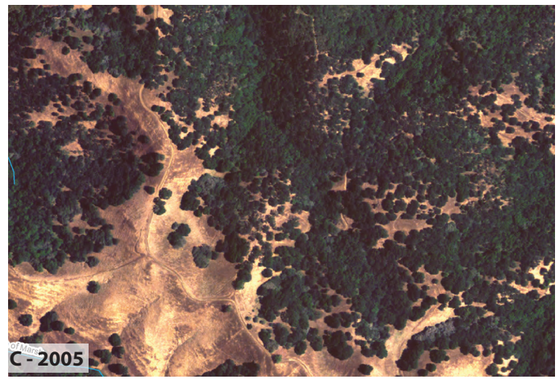


Figure 6.20. Examples of possible shifts in oak woodland density. (above) Visible differences between the 1939 and 2005 imagery suggest that canopy sizes are increasing, as opposed to increased stand density. However, such apparent changes are difficult to interpret given differences in the imagery. Additional research through remote sensing techniques and on-the-ground field work to determine age structure would be necessary to address these perceived trends. A) Upper Mount Diablo Creek watershed appears to show less space between tree canopies in contemporary imagery. B) A small stand of apparently smaller trees in the historical imagery seems to have grown in by 2005. C) A relatively dense woodland in the upper Marsh Cr watershed becomes even more dense as open spaces visible in the historical imagery are filled in. (Left: USDA 1939, courtesy of CCC and Earth Sciences & Map Library, UC Berkeley; Right: USDA 2005, courtesy of NAIP)

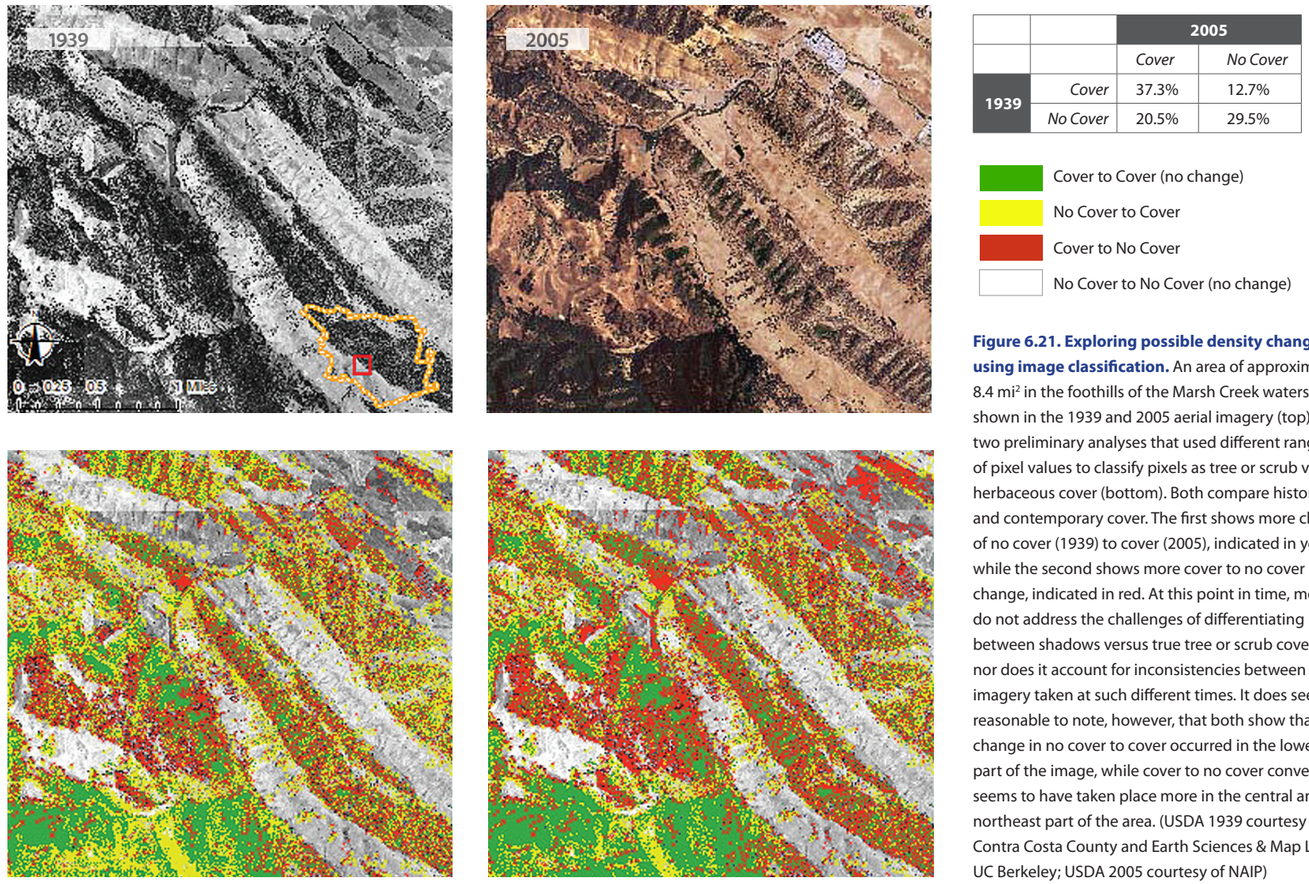
Density estimations using the GLO survey bearing tree dataset (using all species) and two different calculation methods demonstrate that density was lower in the plains than the other geomorphic units, supporting the mapping of savanna along the plains (table 6.4). However, an expected higher density in the montane region in comparison to the foothills is evident only with the Cottam and Curtis method. Part of the explanation is that density variation likely occurs at smaller scales. To explore this, we noted a few visually identifiable "populations," or clusters of points, that had distinctly different density characteristics. For instance, the Point of Timber region contained five survey points with bearing trees, which were associated with the extremely low average density of approximately 1 tree/acre. This, combined with the information that these were significantly larger trees than the average oak in the study area, suggests that the Point of Timber oaks were a unique population of trees along the plains.

We used additional sources to estimate stand densities for other habitat types for which data were available. In three locations along the northern edge of Contra Costa, within the interior dune habitats, historical maps provided information showing individual trees. To estimate density, we divided the number of trees depicted by an individual source by the area of the surrounding polygon. Two independent sources mapped live oaks in the larger polygon west of Antioch, so we calculated a separate density estimate for each source (table 6.5). The distribution of roughly 0.3-1.4 tree per acre fits within our classification of savanna, but is at the lower end of estimates from the GLO dataset. USCGS maps of this era can accurately show individual trees (Westdahl 1897); however it is possible that not all trees were shown in some of these maps and our estimates are low.

Upon examination of historical aerials and comparison to modern imagery, certain density shifts are evident. In some cases, this appears to be a result of changes in tree canopy size as opposed to changes in stand density. In places, gaps between trees that were evident in the 1939 aerial photography were filled in by the time of the contemporary imagery (fig. 6.20). We were unable to assess the entire area quantitatively, and thus must caution that we are unable to state whether the majority of wooded areas have become more or less dense over the past 80 years. Follow up research including tree dating and more comprehensive spatial analysis would help establish the pattern.

Examining density changes through raster analysis can illustrate how spatially complex these changes may be. In a 8.4 mi² example to test methods from the Marsh Creek watershed, about 26% of the area was shown to have undergone a change from chaparral or tree cover to grassland or vice versa (fig. 6.21). While it cannot be determined with this level of analysis whether the overall trend was toward denser or less dense cover, particular areas do appear to have changed more than others (e.g., the southwestern corner appears to have proportionately more change from grassland to trees and chaparral, while just above that the trend is the opposite). Another preliminary raster analysis to detect small changes of density within particular habitat types supports the observation that some woodland areas within the uplands have become denser, not necessarily through an increase in the number of trees, but rather through a canopy size increase (fig. 6.22). The coarse assessment for this area suggests that tree cover may have increased by 10% (see fig. 6.21).

Blue oaks at a very low density (mapped as grassland) are found along much of the ECCC foothills. In some of these areas, it was possible to observe the slow loss of individual trees which had occurred between the times of the two sets of aerial photography (fig. 6.23). Such losses suggest natural mortality and the lack of seedling recruitment.



		2005	
		Cover	*No Cover*
1939	*Cover*	37.3%	12.7%
	No Cover	20.5%	29.5%

Figure 6.21. Exploring possible density change using image classification. An area of approximately 8.4 mi² in the foothills of the Marsh Creek watershed is shown in the 1939 and 2005 aerial imagery (top) with two preliminary analyses that used different ranges of pixel values to classify pixels as tree or scrub versus herbaceous cover (bottom). Both compare historical and contemporary cover. The first shows more change of no cover (1939) to cover (2005), indicated in yellow, while the second shows more cover to no cover change, indicated in red. At this point in time, methods do not address the challenges of differentiating between shadows versus true tree or scrub cover nor does it account for inconsistencies between the imagery taken at such different times. It does seem reasonable to note, however, that both show that more change in no cover to cover occurred in the lower left part of the image, while cover to no cover conversion seems to have taken place more in the central and northeast part of the area. (USDA 1939 courtesy of Contra Costa County and Earth Sciences & Map Library, UC Berkeley; USDA 2005 courtesy of NAIP)

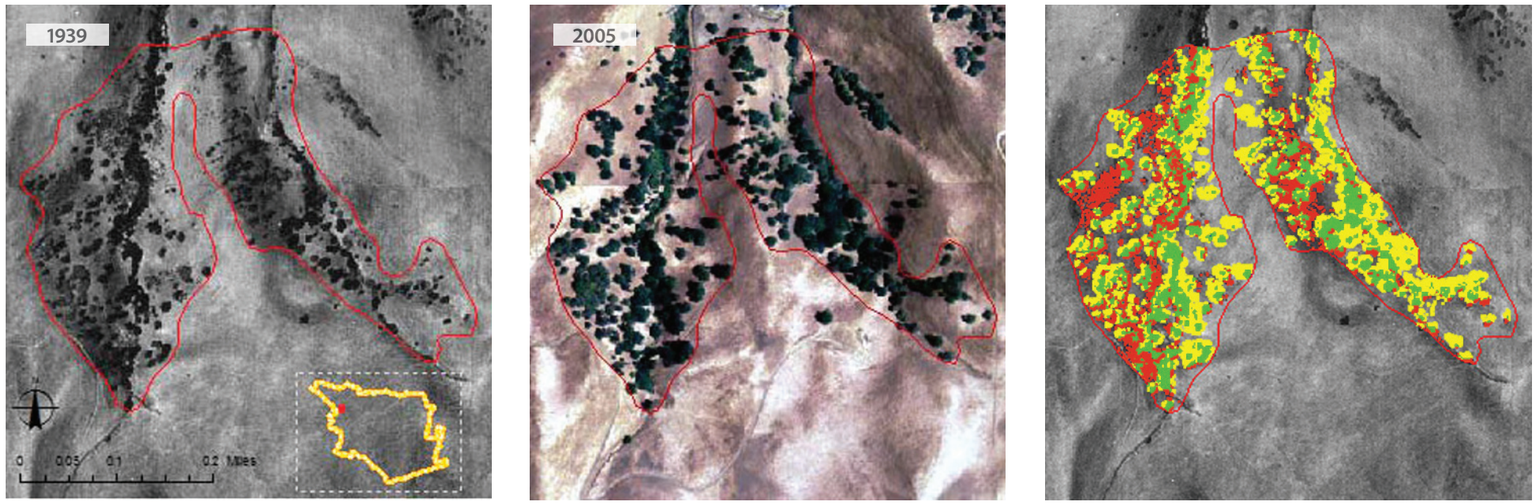


Figure 6.22. Effects of changes in tree size on image classification. (above) Similar classification techniques as shown figure 6.21 were used for a single mapped woodland polygon to explore possible change as a result of larger canopy sizes. Individual tree canopies are mostly shown as no cover to cover in the image, indicating larger tree sizes in the contemporary imagery. Some error can be detected to orthorectification errors. Future analysis could assess if these are real trends through more sophisticated imagery analysis and on-the-ground field assessments to analyze tree age. It may also be valuable to explore trends by geomorphic unit or by other physical factors such as slope and aspect. (USDA 1939, courtesy of CCC and Earth Sciences & Map Library, UC Berkeley; USDA 2005, courtesy of NAIP)

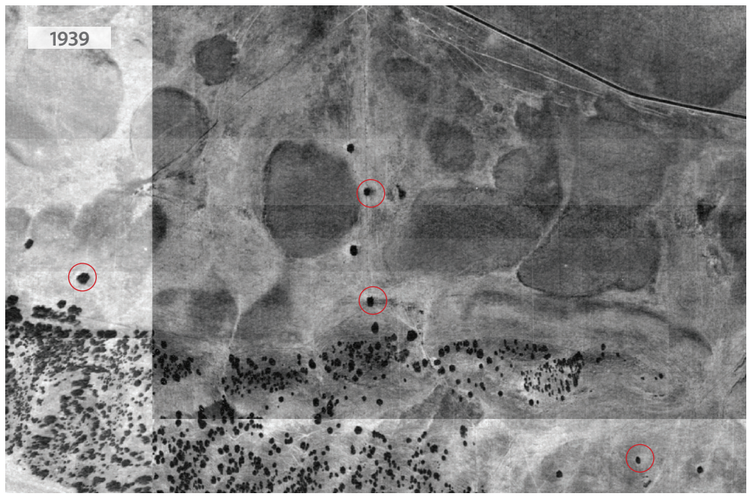
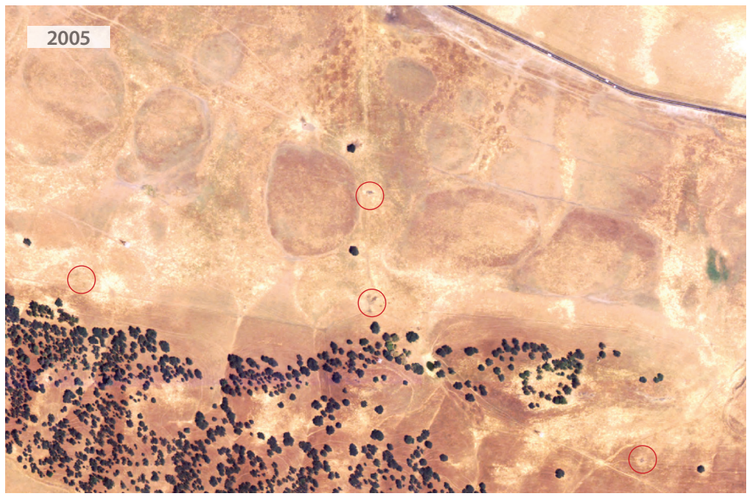


Figure 6.23. Area of individual tree loss. Although this area is mapped as grassland in both the historical and contemporary mapping, several individual trees within this grassland visible in the historical aerials are gone by the time of the 2005 imagery (trees in circled in red in historical imagery are missing in 2005).



In "sparse savanna" settings such as these, tree density - while initially quite low - may have decreased substantially. (Left: USDA 1939, courtesy CCC and Earth Sciences & Map Library, UC Berkeley; Right: USDA 2005, courtesy of NAIP)

Figure 6.24. Images of chaparral. Chaparral and scattered oaks on facing hillsides illustrate the patchwork of vegetation types in the foothills of ECCC. The inset historical photo, ca. 1920, shows the view looking towards the Black Hills from the Los Vaqueros reservoir area. (Contemporary image: February 9, 2003, by Scott Hein, www.heinphoto.com; Historical image: courtesy of the California Historical Society)

Chaparral/Scrub

At the regional scale, the distribution of chaparral and coastal scrub vegetation types appears to have remained largely unchanged since the mid-1800s. Historically, chaparral covered a total of 2% of the study area, or 3,400 acres. The general distribution of chaparral/scrub is consistent with that of today. Within the foothill geomorphic unit, chaparral was a relatively minor component, yet has decreased by over 25%: we mapped 0.6% (360 acres) as chaparral, compared to 0.4% (270 acres) mapped today. About 0.1% of the foothill region converted from chaparral to grassland and 0.1% to woodland. Mapped chaparral/scrub in the montane region historically covered about 8.7% of the area or 2,950 acres, slightly more than is mapped today (8.1% or 2,750 acres). Our mapping reveals that about 0.6% of the montane region, or 200 acres, converted from chaparral to woodland. Conversion also included 0.1% to ruderal, while 0.1% of the region shifted from savanna to chaparral and 0.1% of the region from woodland to chaparral (see figs. 6.7, 6.9, table 6.2).

Chaparral and scrub vegetation is characteristically found in the upper elevation, steep southerly-facing slopes of Mount Diablo (fig. 6.24, 6.25). There are few distinct correlations between chaparral and geology (Bowerman 1944). However, the vegetation boundary is often quite clearly related to topography; as one GLO field note states: "Summit of hill… leave chamisal, enter oak timber" (Partridge 1873). GLO surveyor Ingalls (1868) specifies that his line south of Mount Diablo is a "very steep southern slope covered with chaparral." In addition, "chamisal ridge" is often-used phrase to describe the setting. Along some of the foothills, the southwest-facing slopes are replaced by grasses, while chaparral and woodland occupy the northeast-facing slopes. Chaparral does not occur exclusively in those areas, however. GLO surveyor Sherman Day (1853) describes his path south along the ranges southeast of Mount Diablo as "very precipitous on the W. side, and covered on that side with chamisal... avoiding entirely the high chamisal mountain." The rough and steep character of the land covered with brush was noted by GLO surveyors, who used phrases such as "broken and rocky with chemisal paths" to describe their lines (Dyer 1861). "Thick bushes" (Day 1853), "brushy ravines" (Thompson 1867), or "dense thicket" (Day 1853) and species such as Manzanita are recorded in some upland ravines, hollows, or drainages.

Thick and dense chaparral on ECCC hillsides posed an obstacle to GLO surveyors in the mid 1800s. Chaparral on steep slopes was not the landscape GLO surveyors enjoyed traversing and, in some places, was deemed "impassable." Field notes often contained phrases such as "North Boundary of the Section was not run on account of the thick chemisal brush which rendered it impracticable" (Thompson 1867) or "avoid thick 'chaparral' angle" (Ransom 1851). A touch of exasperation is detected in Tallyrand's 1872 survey: "I find it utterly impossible to run this first ½ mile of this line." One area in particular, the southeast part of Township 1N1E, was simply not surveyed and its general description was that the "hills become higher and are covered with brush" (Thompson 1865). GLO surveyor Wackenreuder (1875a) described the proportion of chaparral in the northern foothills: "half of it is overgrown with dense Chaparral, with scattering Oak and Pine trees; the other half yielding only scanty growth of grasses fit for sheep pasture." Not all the chaparral was dense; steep rocky slopes often only supported a sparse cover of brush (Cain and Walkling 2006). Hilgard (1881), in a general statement about the vegetation, comments that the "slopes and higher portion [of Mount Diablo] are mainly treeless and afford fine pasturage." As many surveyors appear to have surveyed through the brush as those who avoided it.

Based on the MCV alliance classifications from VTM attributes, mapped chaparral consists of 83.5% Chamise Chaparral, 7.4% Interior Live Oak Chaparral, and 3.2% Birchleaf Mountain-Mahogany (Sawyer et al. 2009). Bigberry Manzanita, Black Sage Scrub, California Sagebrush, California Sagebrush-Black Sage Scrub, and Toyon Alliances also occurred, each comprising 2% or less (table 6.3; 619 acres of the total 3,310 acres were mapped as chaparral from aerial photography, but not mapped by VTM, and were thus not included in this summary). The earlier mid 1800s data from GLO surveyors were less specific about brush species. Most surveyors appear to have used the terms chaparral and chamisal interchangeably, save for the detail-oriented Sherman Day, who included both chaparral and "chemisal" independently in his description of a line in the upper Kellogg Creek watershed. He also noted Manzanita bushes along some of his lines. Descriptions sometimes also mention scrubby oaks or oak brush.

In comparing historical chaparral boundaries mapped largely from 1930s data to 19th century GLO points noting brush, we found no consistent trend of expansion or contraction. Differences were observed among the datasets, but appeared related to error rather than directional change. For example, of 47 1930s-era chaparral polygons lying along survey lines, 24 were not noted by the GLO survey. On the other hand, of 69 GLO survey field notes concerning the presence of chaparral, 25 were not mapped in the 1930s.

A few of these comparisons did suggest change, where either a GLO point was showing the placement of a chaparral boundary that may have since receded, or

Figure 6.25. Chaparral on the slopes of Mount Diablo. Large swaths of chaparral mixing with woodlands are visible across the southern slopes of Mount Diablo (Photo October 24, 2009, by Scott Hein, www.heinphoto.com)

a mapped polygon was showing an area that was not chaparral at the time the surveyors went through. However, most of these inconsistencies are a reflection of the differences in how the vegetation was detected and interpreted as opposed to actual change. For instance, some of the polygons that were not included in the GLO data and vice versa were in the upper elevations, where GLO described "scrubby oaks" (Dyer 1861) and where tree and chaparral cover was likely mixed; these were areas that were difficult to classify using the aerial imagery. Another complicating factor is that many of the polygons not noted by GLO have boundaries that just barely cross over the line of the survey, which may not have been significant enough for the surveyors to note them.

Upon visually comparing the historical and contemporary aerial photography, we did not find extensive areas where the boundary of chaparral patches had changed dramatically between the two periods (1939 and 2005). A few chaparral boundary changes were detectable, but no distinguishable trend was found; suggestive evidence of both receding and expanding boundaries could be found for a few areas. It is unknown whether these areas faced different pressures (e.g. fire, grazing) or whether they reflect natural fluctuations in vegetation that occur at greater frequencies than the time elapsed between the two imagery dates. It is also unknown if any such shifts can be extrapolated back to the mid-1800s conditions. Two of the more distinguishable local shifts occurred along the south facing foothills in the Briones and Deer Creek valleys and are shown as examples in figure 6.26.

One of the more extensive areas of apparent change in the montane region is shown around the peak of Mount Diablo (fig. 6.27). While Jones & Stokes (2006) mapped the area as woodland and savanna, VTM data for the same area was assigned MCV classification of Mixed Chaparral and Grassland (Thorne pers. comm.), based on dominant cover recorded as chamise, Wedgeleaf Ceanothus, Black Sage, Interior Live Oak shrub and Mountain mahogany on the VTM maps. We therefore mapped this area as chaparral, although it is difficult to detect significant vegetation change in a visual comparison between the historical and contemporary imagery. Given that this may not be a true habitat type conversion, a modern classification of chaparral may be more appropriate here. Several GLO field notes from this area describe, "timber scattering oak, undergrowth chaparral" (Ingalls 1868), which supports the idea that the discrepancy is perhaps more a product of vegetation interpretation than actual vegetation change.

Visual comparison of historical and contemporary aerial imagery suggests that some chaparral areas have shifted in density as opposed to expanded or contracted (fig. 6.28). These changes were often slight, however, and hampered by challenging image interpretation due to factors affecting the comparability of the two datasets. In addition, it is unknown whether these perceived changes are simply due to natural local variability over time. Depending on location, we found some evidence for trends toward denser as well as sparser chaparral. Further analysis, using more quantitative imagery analysis methods and perhaps additional imagery from interim dates, is necessary to investigate whether there have been true shifts in chaparral density over the past 70 years and could begin to link these trends to factors such as grazing and fire.

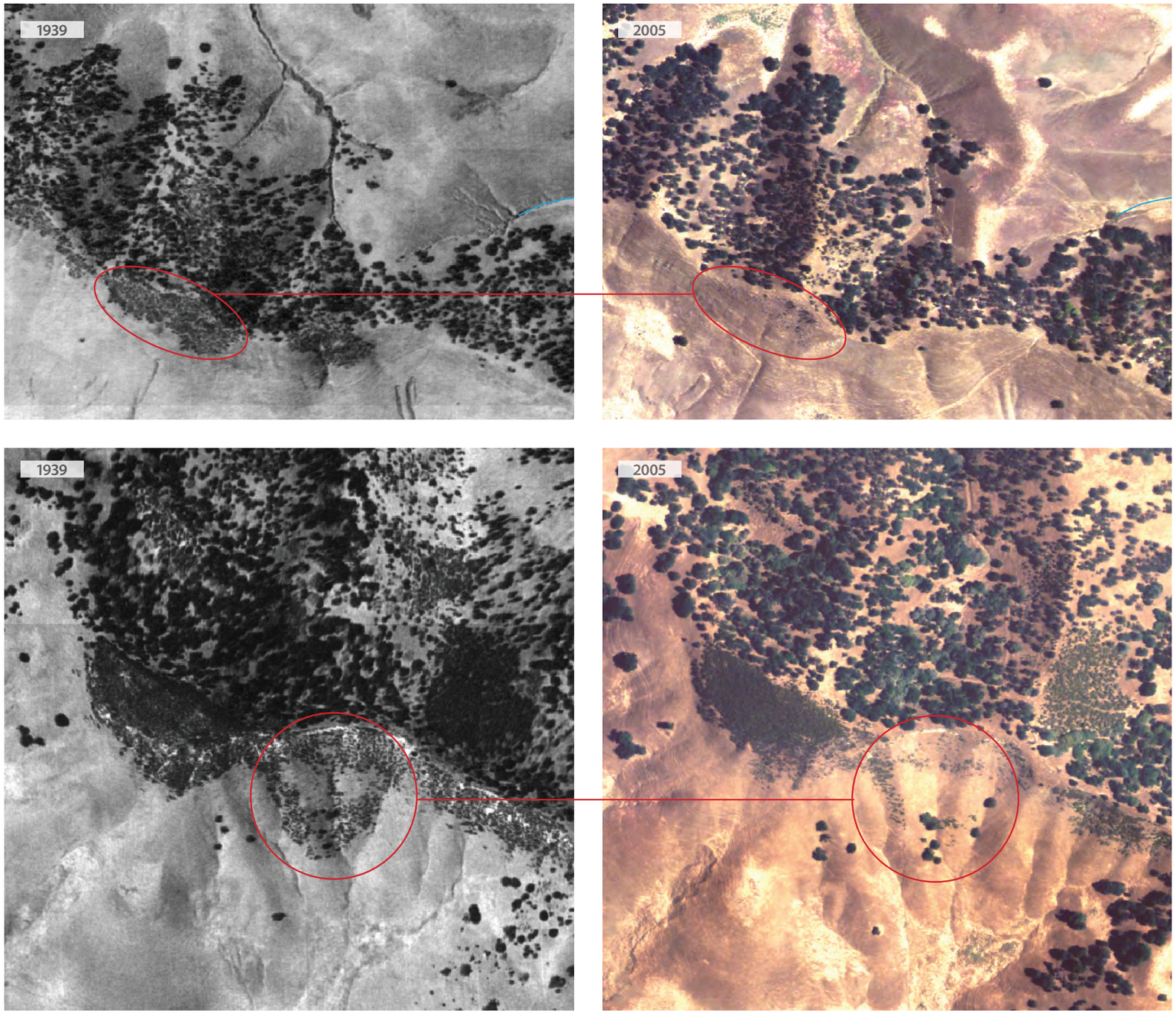
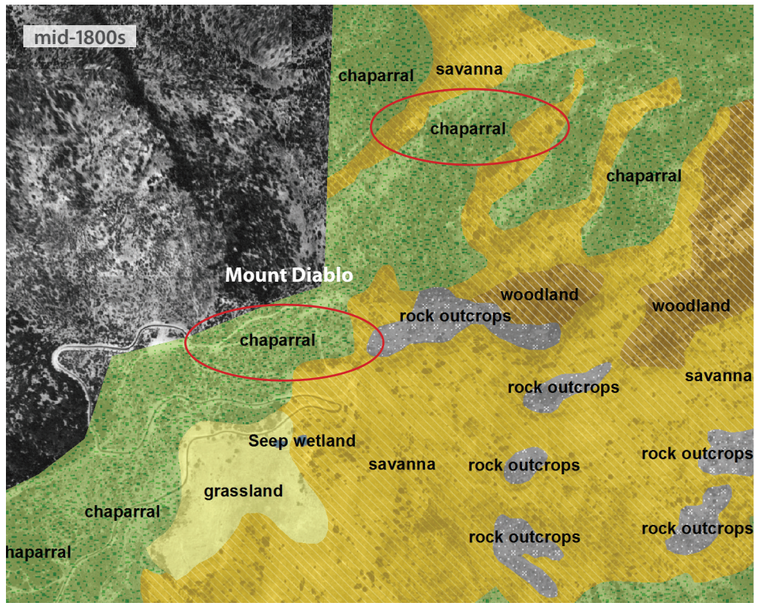


Figure 6.26. Changes in chaparral extent. The top set of historical and contemporary imagery shows a contraction of chaparral extent and density on the northern ridge's south slope in the upper Briones Creek watershed. The second set of historical and contemporary imagery show a contraction of chaparral on the south slope of neighboring Deer Creek watershed. Such areas of evident 1939-2005 change are not common but are potentially locally significant. (Left: USDA 1939, courtesy of Contra Costa County and Earth Sciences & Map Library, UC Berkeley; Right: USDA 2005, courtesy of NAIP)



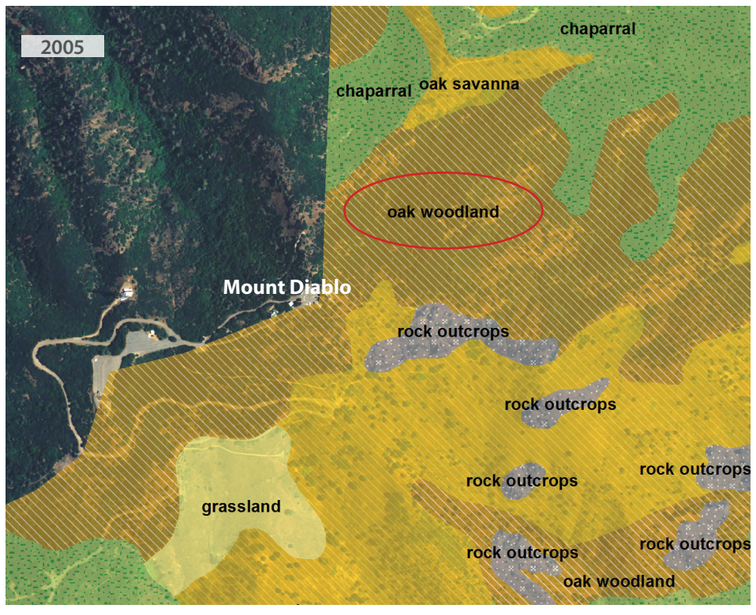
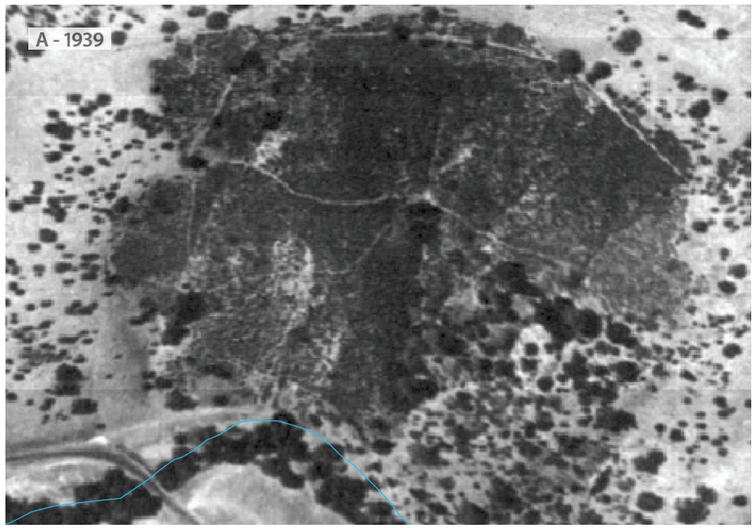
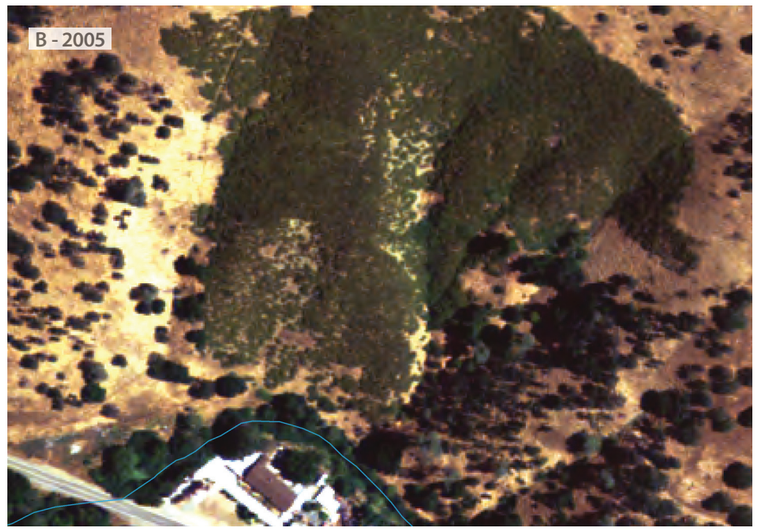
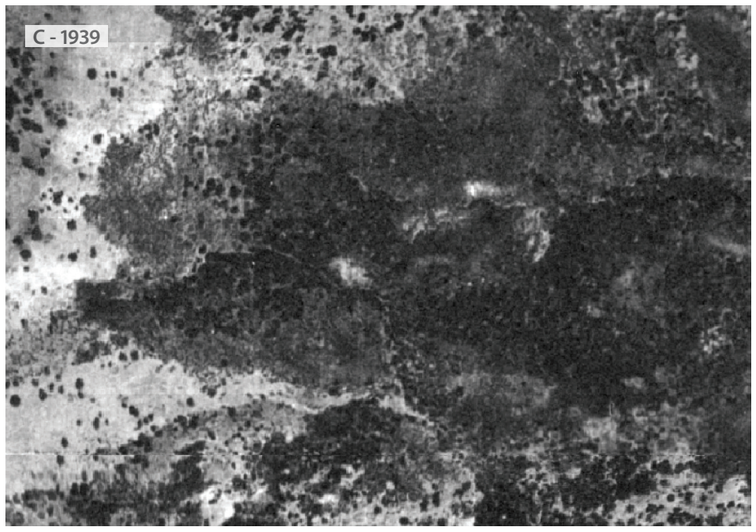


Figure 6.27. Apparent change on Mount Diablo: The area mapped as chaparral around the peak of Mount Diablo (top) from 1930s-era sources is mapped as woodland in the contemporary HCP mapping (bottom). This apparent change in vegetation community is likely a difference in classification and opposed to true habitat type conversion. Historical mapping was guided by chaparral species recorded by VTM, including scrub oak.







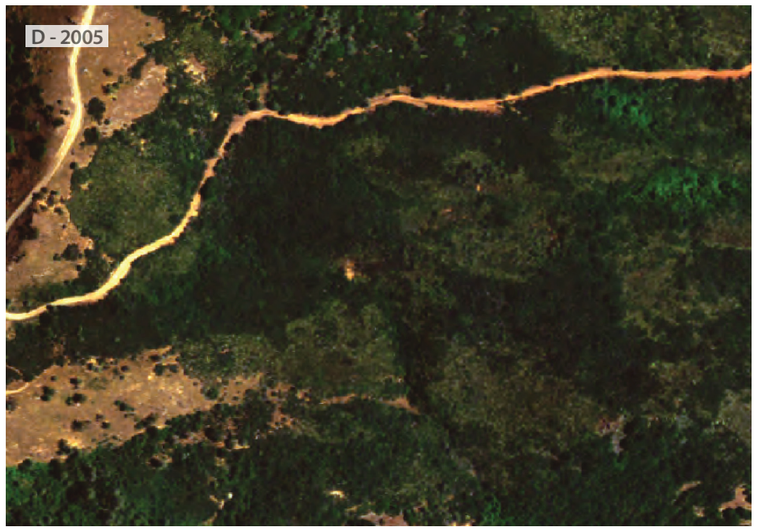


Figure 6.28. Changes in chaparral density. A, B) Chaparral appears to be somewhat less dense in the contemporary imagery in some parts of the patch, although the tonal differences in the black and white historical aerials are difficult to interpret. Also, the boundary seems to have contracted on the western side. C, D) As an example of a possible opposite trend, the few small open spaces within the chaparral apparent in the historical imagery have largely closed in by the time of the 2005 aerial imagery. Uncertainties in aerial interpretation do exist and it is also unknown whether these observed differences are simply localized natural flunctuations. (Left: USDA 1939, courtesy of CCC and Earth Sciences & Map Library, UC Berkeley; Right: USDA 2005, courtesy of NAIP)

The country is beautified by live oaks, where they have not been removed to make way for agriculture. The early settlers called this Eden Plains…East of Eden Plains, almost to Antioch, is a large tract of rolling, sandy, brushy country…It is a high, oak-dotted country…At yet it is a charming drive through this brushy, varied tract to Brentwood, especially when spring has spread the ground with a carpet of many colors, white, crimson, purple and yellow, in large continuous patches.

— CONTRA COSTA GAZETTE 1887

A young man was killed by one of them [a grizzly bear] in the dense forest of chamisal, three or four miles from Antioch. This chamisal is a short growth of underbrush, so dense as to be impenetrable by man, and covered about five thousand acres.

— CA. 1850 IN HULANISKI 1917

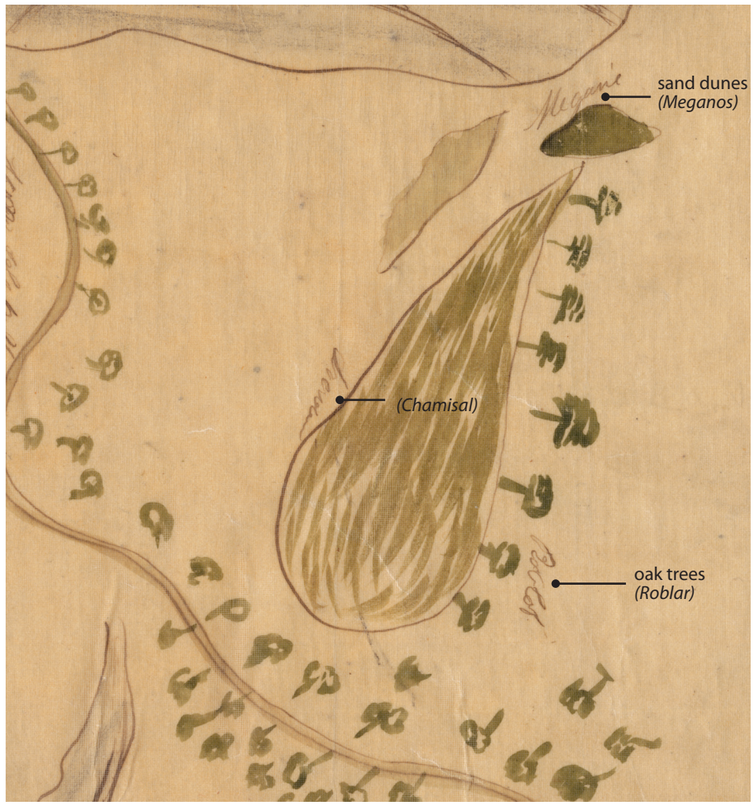


Figure 6.29. Interior dune habitats ca. 1840. This early map shows the chamisal, oaks, and dunes as major identifying features of ECCC. (U.S. District Court ca. 1840a. courtesy of The Bancroft Library, UC Berkeley)

Interior Dune Habitats

In the vicinity of present day Oakley lies a distinctive 6,800 acre area of sandy soils, remnant of eolian (wind-blown) processes during the Pleistocene. The sandy soils (termed Dehli or Oakley Sands) supported a dense 2,800 acre patch of scrub vegetation and scrubby live oaks, surrounded by a more sparsely-vegetated dune habitat covering an estimated 5,600 acres (fig. 6.29). Regional maps depicting Contra Costa in the 19th century often show the scrub patch, or "chamisal" as the defining feature of the area (Britton and Ray 1871, Whitney 1873, Hall 1887), and an early surveyor described "about 6000 acres of brushwood and sandy land" (Wolfe n.d.). The almost complete destruction of this dune habitat type is one of the largest changes to ECCC.

To depict this feature in the historical map, we defined two types of dune habitat - interior dune scrub and interior dune (vegetation undefined). Interior dune scrub (also known as inland dune scrub; CALFED 2000a, b) has been used to describe the Antioch Dunes by a number of recent sources (Holland 1986, Bettelheim and Thayer 2006, Thayer 2010). We further refined this class to distinguish the dense, scrub area from the more sparsely vegetated surrounding area. We mapped the dense portion as interior dune scrub, while the surrounding area (including the Antioch Dunes) is mapped as a more general interior dune type (interior dune, veg. undef.). These areas were historically vegetated, but we have less direct data about the vegetation cover and boundaries, so this class represents the likely range from live oak savanna to sparse scrub to herbaceous cover (fig. 6.30).

Together, these dune habitats historically supported a number of species. The most well documented are silver bush lupine (*Lupinus albifrons*) and live oaks (*Quercus agrifolia*). It was described as "a patch of considerable extent of chaparral and scrub oak" (History of Contra Costa County 1882). Today the most intact remnant, the Antioch Dunes, supports three rare species: Antioch Dunes evening primrose *(Oenothera deltoides spp. howellii),* Contra Costa wallflower (*Erysimum capitatum angustatum*), and Lange's metalmark butterfly *(Apodemia mormo langei),* for which the Antioch Dunes preserve was created (CNDDB, HCP). Silvery legless lizard (*Anniella pulchra pulchra*) is also found here and has been recorded since the 1940s (Miller 1940, Bettelheim and Thayer 2006). The far-flung patches of dune habitat today support herbaceous species such as *Croton californicus*, *Eriogonum gracile*, and *Lessingia gladulifera* (Thayer pers. comm.).

The patch of dense interior dune scrub covered much of Oakley, extending 1.8 by 3.8 miles at its widest point (the area roughly between the intersection of Highway 4 and Delta Road and the junction of 4 and 160). GLO surveyors from the 1850s to the 1870s described encountering a giant patch of "impenetrable chamisal" (Dyer 1962b) in the vicinity of Oakley that forced them to interrupt their survey and divert their lines "west to avoid thick brush" (Ransom 1851). Surveyors clearly noted entering and exiting the patch of "dense chemisal" and "high chamisal" (Dyer 1862b, Wackenreuder 1875b). (The term "chamisal" or "chemisal" as used here refers more generally to the impenetrable nature of the scrub rather than to the shrub species chamise (*Adenostoma fasciculatum*) (Brown 2005, Beller et al. 2010).) Based on the

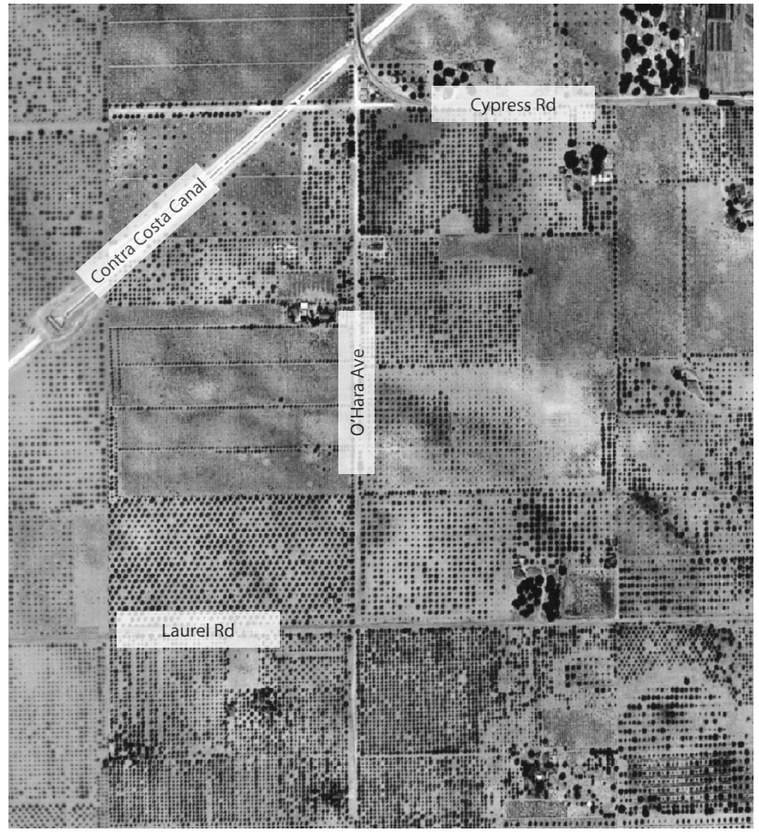


Figure 6.30. Remnant oaks and sand deposits in1939. Remnant sand patches create the light mottled pattern visible in this photograph, and contrast with the dark clusters of live oaks still present in areas that are not cultivated. (USDA 1939, courtesy of Contra Costa County and Earth Sciences & Map Library, UC Berkeley)

shape outlined by these notes and the accompanying map (Dyer & Wackenreuder 1862/1875), we estimate the scrub patch at approximately 2,800 acres. Maps and descriptions from the late 19th century show the scrub with slight variations in size and shape, ranging up to 5,000 acres in area (Hulaniski 1917).

This "forest of chamisal" was seen as worthless for agriculture because of the sandiness of its soil (Smith 1866, Hulaniski 1917). Little effort was made to clear the Oakley chamisal until the 1880s, when James O'Hara began clearing the brush and planting almond orchards. A local historian described that O'Hara "broke the heavy growth with a roller," burned the "grubby trees and chaparral," then used horses to "bring up all the shrub and tree roots which were gathered and burned" (Benyo 1972: 116-7). O'Hara slowly expanded outward, buying the land cheaply, clearing it to plant, and then reselling to others at a higher price. The California Agricultural Experiment Station stated that the almond trees "yield enormously, but the trees make very little growth; the sand is loose enough to drift when plowed" (Hilgard

1891). Once begun, the transformation of the Oakley Sands to agricultural land was rapid. In 1916 Oakley was advertised as "home of fruits, grapes, and almonds" *(Byron Times* 1916b). By 1939 (as visible in aerial photography) only tiny remnant clumps of scrub remain, and almost the entire historical extent had been covered with orchards and vineyards.

Surrounding the dense scrublands was a 5,600 acre expanse of scattered stands of live oaks and scrub (fig. 6.31). Although the Antioch Dunes were the most mounded portion of this interior dune habitat, GLO surveyors also documented a ridge along the southwest side of the dense interior dune scrub. Oaks were a notable part of this habitat. Surveyor Wackenreuder described "land, half covered with chemisal; balance with live oak timber. Soil, poor and sandy" (1875b). Descriptions repeatedly note the presence of both oaks and scrub: "grubby trees and chaparral," "short growth of underbrush," "chaparrelle and live oaks" (Metcalfe 1902, Hulaniski 1917, Benyo 1972). Contemporary species accounts indicate the presence of silver bush lupine (Bartosh pers. comm., Thayer pers. comm.). GLO surveyors emerging from the central patch of chamisal described entering "scattering oak timber" (Wackenreuder 1875b) extending north and east to the edge of the Oakley Sands, and recorded thirteen different live oaks as bearing trees. These trees were the only live oaks recorded within the plains geomorphic unit of ECCC (see fig. 6.17). The early *diseño* map labels this area as a *roblar* (U.S. District Court, Northern District ca.1840a; see fig 6.29). Although *roblar* is typically used to refer to valley oak woodlands and savannas (Minnich 2008), the GLO surveyors and other textual evidence suggest that the most accurate translation in this case is simply "oak woodland." Some quotes indicate that some of the oaks may have been large: the *Byron Times* in 1916(b) described that near Oakley "a dozen years ago the entire country was covered with giant oaks." In 1931 Jepson recorded "sandy field, scattered live oaks…*Quercus agrifolia* [coast live oak] I found about Oakley on the sandy flats at about 50 or 60 feet." Although some of the oaks were scrubby, others were large and well-developed. GLO tree data supports a range of sizes – the recorded trees range in size from 3 to 60 inches in diameter.

The interior dune habitat also historically extended in patches west along the Antioch-Pittsburg shoreline. Oaks occupied several larger sand deposits identified in modern geology maps, as well as smaller, previously unidentified deposits. The longest-surviving local oak groves were documented on the West Antioch shoreline in the vicinity of the Babe Ruth Baseball Field (Somersville Road). Trees were documented independently by maps (Davidson 1887, San Pablo-Tulare Railroad n.d.), oblique photography (Russell ca. 1925), and land grant testimony (Smith 1866). An early landowner stated explicitly that there "used to be quite a bunch" of oaks "standing in the Tule" and associated those trees with a "small mound of sand" (Smith 1866). The larger grove mapped west of Antioch also corresponds with an isolated deposit of eolian sand mapped by Atwater (1982). It is likely that the smaller groves nearby were associated with unmapped exposed portions of this formation within the surrounding alluvial deposits. We used this evidence to map several small patches of dune habitat on the sand deposits.

Figure 6.31. Savanna along the ECCC plains. (top) Individual oaks in the Antioch sand dunes are shown on US Coast and Geodetic Survey map in 1887. To the south of the dunes, an orchard has been planted across an area shown as oaks on the earlier map. (bottom) A live oak savanna (green tree symbols) surrounding the Oakley interior dune scrub (large green hatched area in center) to the north and east is depicted on an 1853 land grant map. Marsh Creek flows to the tidal marsh to the right of the scrub patch. The dark green boxes in the scrub surround letters spelling "chamisal." At the top right of this image, the area in the red box represents the Antioch Dunes, shown in detail in the top image. (Top: Davidson 1887, courtesy of NOAA; Bottom: Whitcher 1853a, courtesy of The Bancroft Library, UC Berkeley

To the east, patches of Oakley Sands extended well into the tidal wetlands and were mapped as far northeast as Bradford and Webb Tract, as well as south towards Point of Timber (fig. 6.32). Within the tidal marsh, sand mounds rose above the marsh plain as shown on topographic maps (USGS 1913 (Woodward Island)). These dunes formed prior to the development of the tidal wetlands in the Delta, and ranged from less than an acre to 25 acres in size (Atwater 1982). Although little is known about the vegetation of these sand mounds, some remnants support live oaks today. Others were likely covered with grasses and other dune scrub vegetation (Bartosh pers. comm., Thayer pers. comm.).

We include the Antioch Dunes as a subset of the interior dune habitat type, as they appear to have supported a mix of oaks and scrub, similar to the surrounding interior dunes (see fig. 6.31). Portions of the Antioch Dunes were bare, intermixed with live oak and scrub. The oaks in this region were well-documented. An oak-dotted stretch of riverbank along the dunes became popular with bathers such that it was known as "Oak Grove Beach" (Hohlmayer 1991). Towards the eastern edge of the dunes, towards present Antioch Bridge, explorer Anza described camping near "a green grove of live oaks and oaks" (Brown 1998). The early coast survey map depict trees growing along the sand ridges (Davidson 1887), and early maps show the Antioch Dunes as a distinct feature due to their height. The dunes were one of the notable natural features of ECCC (U.S. District Court, Northern District ca.1940a; Whitcher 1853a). Both Los Medanos and Los Meganos land grants take their names from the dunes.

To determine the boundary of the Antioch Dunes we used a combination of the 1887 T-sheet and detailed 1916 USGS map (Collinsville). Historically, we estimate that these dunes covered approximately 120 acres. Our estimate is smaller than some other estimates (e.g., Howard and Arnold 1980), but we find that the high mounded dunes were only a narrow strip along the river. Botanist Burtt-Davy described the dunes in 1895:

> A natural levee of sand some 150-200 (?) feet in height borders the river for several miles south *[sic]* of Antioch and produces a flora akin to that of the southern San Joaquin Valley, very different from that of *[the]* rest of the surrounding country. At this time these sand-hills are brilliant with flowers and, being left uncultivated, form fine botanizing ground: besides herbaceous plants there are oaks and shrubby Lupines. (Burtt-Davy 1895 in Howard and Arnold 1980:3)

The Antioch Dunes were mined heavily beginning in the 1880s to produce bricks and asphalt, significantly lowering and smoothing them (Davis 1958). The 120 foot height shown by USGS and the T-sheets may significantly underestimate their historical height. One early surveyor described the *meganos* or dunes "in some places 100 or 200 ft high and covered with brush" (Wolfe n.d.). Today the area within the refuge reaches only 50 feet above river level.

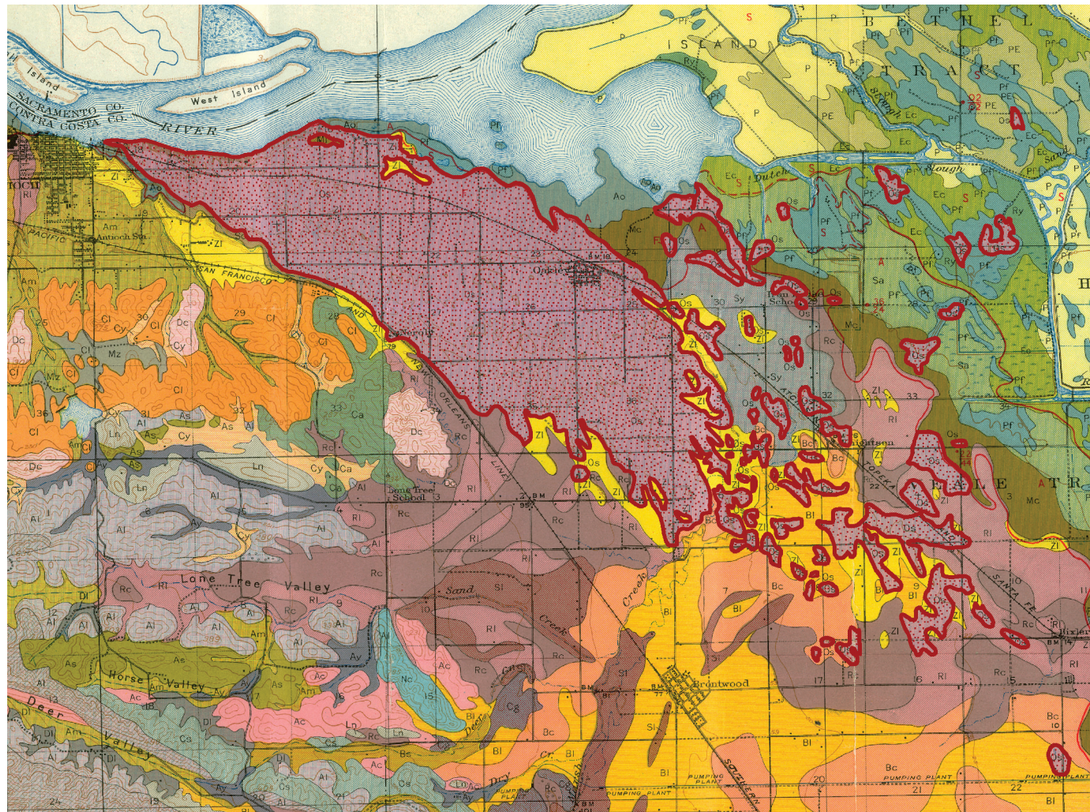
Only small, fragmented patches of dune vegetation remain today, and the dense Oakley interior dune scrub has entirely disappeared. However, the Antioch Dunes, the most intact remnant, have been substantially protected, and small additional patches of sands and live oaks remain scattered across Oakley (fig. 6.33).

Figure 6.32. Oakley sands and interior dune scrub. (right) At top, GLO quotes (1851-1872) indicating dense brush are displayed together with the historical habitat map. The extent of the Antioch Dunes is indicated, as shown in the legend. At bottom, the 1933 soil survey of the surrounding area is displayed. The large patch of "chemisal" fits within the area of Oakley sand (Os, purple), outlined here in red. Note the patches of purple Oakley sand continuing to the south and east. (Bottom: Carpenter and Cosby 1933)

Figure 6.33. Antioch dunes evening primrose. (below) The Antioch Dunes appear to have supported some species not found elsewhere in the interior dunes. This image was taken at the Antioch Dunes National Wildlife Refuge. (October 1, 2009, by Ruth Askevold)

The medano [dune] is a conspicuous and unmistakable natural object.

— JOHN MARSH 1865



DISCUSSION

Changes in historical dryland vegetation in East Contra Costa County (ECCC) are complex and heterogeneous. We found evidence for dramatic large scale landscape changes in the plains, including the loss of thousands of acres of savanna and interior dune scrub (fig. 6.34) that have not been well documented previously. On the other hand, changes in the montane and foothill regions are more subtle. Chaparral patches in the foothills and montane regions were historically relatively small and appear to have decreased in extent by several hundred acres overall in the past 70 years (fig. 6.35). In these same upper elevation regions, savanna and woodland distribution have also decreased in extent, though not dramatically (fig. 6.36). However, these habitats may be subject to longer term trends, due to the long-lived nature of the species, and within-habitat type shifts. For example, visual comparison and preliminary analysis suggests there may be trends in age class structure.

Vegetation Patterns and Local Land Use History

Within the montane and foothill regions, we found that available mid-1800s sources tended to corroborate the general distribution of habitat types represented in the 1930s-era habitat map, though generally without sufficient spatial resolution to evaluate localized changes, particularly due to heavy woodcutting that occurred in many areas in the late 1800s. We therefore consider that the mapping in these upper elevation areas represents a minimum mid-1800s distribution of oak woodlands, as it is likely that some areas shifted from woodland to savanna and savanna to grassland in the later decades of 19th century.

Evidence from the GLO dataset supports the general distribution and abundance of habitat types that are represented in the historical habitat map. For example, where bearing trees are found, our mapping usually shows either savanna or woodland. However, this data is not resolved at the level to detect localized shifts between woodland and savanna boundaries. Most GLO surveys were performed in the late 1850s and 1860s, at the onset of rapid settlement, mining, and the wheat boom of the late 1860s, which prompted the clearing of some areas. Although grazing and the absence of native fire management practices was a factor for several decades prior to the survey, substantial resulting changes to vegetation patterns such as tree distribution are unlikely to have taken place by that time. This interpretation is supported by Cook (1957), who makes the "tentative" conclusion that in the Bay Area "the distribution of vegetation in 1775 was substantially the same as described by the American settlers of 1850 and thereafter and allowing for the devastating influence of white man, more or less as it is today." For example, while oak recruitment may have been affected by this time, it is likely that the established oaks of the GLO survey largely reflect their historic distribution because they had yet to face wholesale clearing pressures.

The montane, foothills, and plains regions have vastly different land use histories, which are reflected in the current distribution and extent of historical dryland habitats. Evidence suggests that oak woodlands, savannas, and dune habitats have been dramatically reduced in extent across the plains. The plains region faced early and widespread modification. In 1862, one GLO surveyor noted that cutting had already occurred. He described the area as being "at one time covered with a heavy growth of oak timber but most of it has been cut down. A few of the limbs cut for wood and the rest are now rotting on the ground" (Dyer 1862a, referring to T1N R3E). Other evidence records oaks being cut for fuel in Clayton Valley ca. 1850, although such practices could have extended into the plains within the study area as well (Gehringer n.d.). This early cutting and a general paucity of many spatially explicit mid-1800s sources suggests the possibility that the historical extent of savanna and woodland on the alluvial plains and perhaps in the foothills is undermapped.

Dry farming of wheat may have had an especially significant impact on blue oaks and valley oaks within this region in the later decades of the 1800s (Adams pers. comm.). This occurred in the plains as well as along the foothill region, as often described in early histories of the county: "In the valleys and on the sloping foothills grain is grown in large quantities" (History of Contra Costa County 1882; see p. 16). Disking was practiced in some areas to improve rangeland for cattle or for dry farming (Jones & Stokes 2006). One example of this is Round Valley, where plowed land is visible in the 1939 aerial photography and GLO bearing trees suggest that trees may have been more numerous prior to cultivation (Adams pers. comm.).

Cultivation of the montane region of ECCC has occurred only in localized areas, although cattle ranching was well established across the area by the mid-1800s. Large numbers of trees were undoubtedly removed in the immediate vicinity of settlements and mines and used as fuel and for fence posts. The predominant land uses within ECCC into the late 1860s were livestock grazing and the production of hay and grain, which likely did not directly conflict with the presence of oaks initially (Jepson 1910, Bartlett 1928). However, trees were likely thinned; even through the mid-20th century, ranchers thinned hillside woodlands but left larger trees in place because they were too much work to fell (Engelhart pers. comm.).

Within the upper elevation regions, the extent and distribution of habitats in the ECCC dryland vegetation did not alter dramatically over the last 70 years and may not be substantially different from the mid-1800s picture. However, changes within habitat types may be significant (e.g., localized losses of individual trees, changes in density). More subtle shifts in vegetation type distribution and density have likely occurred in response to factors such as altered fire disturbance regimes, grazing and rodent pressures, and herbaceous understory community changes (Griffin 1977, Borchert et al. 1989, Davis et al. 2011). These trends may have contributed to some of the localized increases in density within some upper elevation montane woodlands and chaparral as well as decreases in some oak woodlands and savannas. However, our analysis did not find conclusive evidence of wholesale community shifts or large vegetation boundary changes. These boundaries may resist large-scale shifting due to physical controls. For example, one possible reason that chaparral boundaries have remained fairly stable could be because of strong topographic and edaphic controls (Edwards pers. comm).

Figure 6.34. Valley oak in "Valley de los Poblanos at the south end of Rancho." This oak is likely a remnant of the historical valley oak savanna near the confluence of Briones and Marsh Creek near the present day location of the Marsh Creek Reservoir. (Unknown n.d., courtesy of East Contra Costa Historical Society)

Figure 6.35. Vegetation in presentday Black Diamond Mines Regional Preserve. This photograph was taken as part of the Wieslander VTM project and a member of the mapping team can be seen roughly in the center of the image. Its caption reads: "1/2 mile south of Somerville. *Arctostaphylos andersonii auriculata* [Mount Diablo manzanita] on a rocky bluff where it ranges from 3 to 5 ft in height. Note *Pinus coulteri* [Coulter pine] and *sabiniana* [California foothill pine]." (Wieslander 1935b)

Figure 6.36. Mixed foothill land cover. This image shows a patchwork of agriculture, grassland, and scattered oaks, as foothills transition to plains. Marsh Creek Road is visible in the foreground, heading west to cross Marsh Creek just to the right of the image. Further upstream, riparian cover along Marsh Creek as it exits the foothills is visible in the background. This image is part of a series that includes the image in figure 6.15. (Russell ca. 1925, courtesy of the State Lands Commission)

In some locations, apparent trends toward a denser tree cover seem to be attributable to larger tree canopy sizes. This would suggest that size class distribution has changed over the course of recent history. This can be attributable, in part, to the early loss of older trees to wood cutting and the absence of young trees due to low recruitment rates. Such trends have been studied in second growth stands of blue oak that appear to have been established as a result of land use changes in the 1860s. For example, a study on Tejon Ranch in southern San Joaquin Valley concluded that second growth regeneration was due to the combined effect of severe drought and heavy grazing pressure in the early 1860s (Mensing 1992). In another study, Swiecki and Bernhardt (1993) found that a stand of blue oaks at one site in the northern part of Mount Diablo State Park was of the same age class due to early cutting. This observation is supported by a study by McClaran (1986), who concluded that 70% to 85% of blue oaks in California were from "stump sprouts." While overall extent of woodland and savanna habitat appears to have been relatively stable in recent history, present findings reiterate concerns about the long-term future of blue oak woodlands, which have been identified as a threatened habitat due to lack of regeneration (Allen-Diaz et al. 2007).

Indigenous management of California vegetation has received significant attention in recent years (e.g., Stewart et al. 2002, Anderson 2005). Specific understanding about how vegetation patterns were affected in particular areas, however, is generally not available. Indigenous populations along the Coast Ranges may have averaged relatively high densities of 1-3 persons/km^2 (Keeley 2002, Allen-Diaz et al. 2007). Native peoples routinely burned in coastal and foothill landscapes, a practice that would have promoted grasslands over shrublands (Keeley 2005) and maintained open understories in savannas (Anderson 2005), but may have had only small effects on oak establishment and early growth, depending on the fire temperatures (Bartolome et al. 2002, Tyler et al. 2006, Allen-Diaz et al. 2007).

Although the fire frequency under native management is relatively unknown in ECCC and the East Bay hills, some researchers have proposed that fires due to both natural and anthropogenic ignitions occurred every 5-15 years (D'Antonio et al. 2000). Relatively high burning frequency is supported by one account of the Mount Diablo area, which stated that "in the fall season… the Indians sometimes set large portions of the surface of the mountains on fire" (Olmstead 1962). In the absence of fire, we would expect to see a trend toward higher proportions of chaparral over the last 150 as the fire regime has been suppressed. This is under the assumption that fire played a role in keeping open areas of grassland that would have otherwise been replaced by a different climax community (McBride and Heady 1968, Mensing 1998). The relationship of fire to oak regeneration is less established, and depends largely on the fire frequency and intensity (Griffin 1977, Bartolome et al. 2002).

Fire regime changes over the historical period further complicate our ability to understand trends in the habitat distribution. After the cessation of native management in the early 1800s, fire frequency on Mount Diablo increased in the late 1800s and early 1900s as more tourists and activity caused an increase in human-caused fires. Frequency has since decreased as a result of fire suppression practices (Adams pers. comm.). It is not well understood how these frequencies compare to those of the native management period. Furthermore, some researchers have suggested that, while the structure and composition of the landscape encountered by Spanish explorers was likely modified by indigenous land management, subsequent Euro-American land use practices, such as grazing, may have replaced and, in some cases, exacerbated effects of the indigenous fire regime (Keeley 2002). It is also important to remember, when considering land management practices, that factors are interwoven. That is, even if one were to replicate native fire management practices, it is unlikely that it would have the same effect on the landscape that it once did, given the introduction of non-native and invasive species as well as the different land uses of today.

The fire record compiled by Mount Diablo State Park includes nine fires prior to 1930 (Shafer pers. comm.). The first fire on record occurred in 1891 on the east side of the mountain. The summit area of Mount Diablo was again burned in 1922. The largest fire in the record occurred in 1931 on 25,000 acres and started at Marsh Creek Road. Given that this large fire occurred within a decade of the Wieslander VTM project and the 1939 aerial photography, interpretations of the vegetation should consider that disturbance, in that it may affect the density and type of vegetation observed. For instance, in those burned areas chaparral may be thinner in the historical aerial photography compared to the same area today, given the more recent period of fire suppression (Nielson pers. comm.). Some find that chaparral today that hasn't been burned within the last several decades is, in many places, in the process of succession to oak woodland (Adams pers. comm., Shafer pers. comm.). The few years' time lapse between the VTM project and the historical aerials could be significant following such a substantial disturbance.

Along with the changing fire regime, grazing potentially had a wide influence on the landscape (see p. 67). In 1859, one writer stated that "stock may be seen grazing in all directions on the mountains" (Olmstead 1962). Swiecki and Bernhardt (1993) found that grazed areas had few saplings, supporting concerns about the effect of grazing on blue oak regeneration. Others have also found that browsing negatively impacts regeneration (Bartolome et al. 2002, Davis et al. 2011). However, the absence of grazing does not always translate to successful recruitment (Ertter and Bowerman 2002). Many scientists have shown the importance of grazing for oak establishment as grazing reduces the non-native grasses which can outcompete young tree for moisture (Jones & Stokes 2006, Allen-Diaz et al. 2007, Edwards pers. comm.).

Our mapping does not suggest, however, that significant changes in the extent of chaparral have taken place as a result of fire and grazing, although chaparral density may be affected. Chaparral extent in the upper elevation areas of ECCC does not appear to have altered significantly over the past 150 years, suggesting that there has been no substantial change in potential habitat for species of concern such as the Alameda whipsnake in this part of the study area.

Grasslands have also potentially been affected by fire and grazing pressures. However, more significant changes in the composition of native perennial

bunchgrasses and annual forbs have been wrought by the early invasion of exotic annuals. The impact of these invasives has caused native grasslands to become one of the more threatened ecosystems in California (Holmes 1990, D'Antonio et al. 2000). Such invasions may have been fostered by increased grazing and fire suppression. For example, local changes in grazing regimes have demonstrated an increase in native grasses (as well as invasives) under reduced grazing conditions. Crop agriculture is also suggested to have been a significant factor in the decline of native grasses (Stromberg and Griffin 1996, D'Antonio et al. 2000). Although the invasion of grasslands by woody vegetation such as chaparral is well documented elsewhere in the western United States (Keeley 2005), we found relatively little evidence of such a trend over the period examined. As discussed, density of chaparral and woodlands has certainly increased in some locations, but most loss of grassland is attributable to development and cultivation pressures. This suggests that the loss of habitat for species of concern such as kit fox has occurred primarily due to urban and agricultural expansion, as opposed to the indirect effects of vegetation type conversion as a result of fire and grazing.

Implications for Restoration

While many of the former valley and blue oak savannas are now intensively developed as urban areas or reservoirs, there is some potential for oak savanna restoration in the smaller alluvial valleys, such as Cowell Ranch, Round Valley, and Los Vaqueros and valleys east of Black Diamond (Adams pers. comm.). These areas have likely undergone transformations similar to the area along Marsh Creek just above the reservoir, which was occupied by oak savanna in 1939. Today it is covered with grassland and some agriculture, with some remaining scattered oaks. Restoration of these habitats in relatively undeveloped areas could help reestablish this underrepresented vegetation type. Additionally, local factors affecting tree establishment, such as grazing pressures and groundwater availability, would be important to consider.

Re-establishment of some of the functions of oak savanna could also be achieved by integrating oaks within developed landscapes. While this would not support all of the functions of oak savanna, well-designed oak planting strategy could offer significant ecological benefits (Whipple et al. 2011). Trees were widely spaced historically in areas such as Point of Timber and perhaps across much of the plains oak savanna. Re-establishment of widely-spaced oaks within the contemporary urban environment may be able to approximate this historical distribution. However, due to changing conditions and particularly changes in groundwater levels due to Marsh Creek Reservoir and irrigation of the eastern margin of ECCC, historical oak savanna habitats might no longer support oaks. Further investigation of contemporary conditions would be needed.

Restoration strategies could also seek to reintroduce some of the historical diversity of oak woodlands and savannas. Although blue oak woodlands still persist throughout much of ECCC, oaks exist in a much narrower setting than they once did. Historically, there were blue and valley oak savannas, oaks associated with sand hills and dunes, and giant valley (presumably) oaks in the vicinity of Point of Timber. Although the large interior dune habitats and associated live oaks near Oakley have largely been covered with development, some fragments remain. Protecting those remaining areas would provide important habitat for the species that rely on them.

We do not document extensive changes in oak woodlands in the hills, but data are suggestive of potential longer term trends that could threaten these habitats in the future. As is common throughout the state, these woodlands may not be regenerating and the stand age structure may not be supportive of a sustaining population. GLO data could be used to compare stand structure to contemporary field measurements to help develop target age class structure as a management goal.

Substantial changes have, however, taken place at the scale of individual sites. We identified a number of areas of historical clearing that could be considered for restoration, with potential significant benefits to the local ecosystem (fig. 6.37, 6.38). Using the tools generated here, finer scale assessments of particular sites of interest can identify opportunities for restoring chaparral, savanna, and woodland.

Figure 6.37. Buckeye capsules. Buckeye nuts from *Aesculus californica* in preparation for planting. (Photo by Abigail Fateman, CCC)

Figure 6.38. Buckeye restoration. Volunteers with Save Mount Diablo planting buckeyes and acorns in Irish Canyon. At top, a young buckeye sapling. (Photos by Abigail Fateman, CCC)

Next Steps

While our analysis did not demonstrate dramatic overall changes in dryland cover in upper elevation regions, smaller scale shifts within subregions and/or topographic settings (e.g., south-facing slopes, foothills) seem evident. Further exploration of vegetation density shifts should be performed in areas of particular concern. Imaging processing software such as ERDAS, Inc. provides sophisticated techniques for detecting such changes between sets of imagery. However, techniques used for processing recent satellite imagery may be limited by the resolution and detail in the 1930s black and white photography. However, methods do exist for using such early imagery and several published studies have used image processing to classify vegetation and detect long-term vegetation change (Carmel and Kadmon 1998, Byrd 2009). Such methods should be adopted if a further investigation of specific areas of change or hypothesis testing is desired.

This mapping effort offers a starting point from which to develop more detailed analyses, like those mentioned above, but we would also suggest that more detailed land use history, particularly for specific parcels or areas of conservation interest, will be important when considering specific restoration targets.

Given uncertainties associated with age class structure and stand density, field measurements should be undertaken to better understand the current age structure (fig. 6.39). It would be valuable to understand whether the areas where tree canopy sizes appeared to increase between 1939 and 2005 represent aging stands. Were a cohort of trees identified (that is, many trees of primarily the same age), it may suggest significant future changes as these trees are lost due to mortality, particularly if recruitment remains low. In addition, such data on contemporary size class distributions could then be compared to the tree sizes from the late 1800s General Land Office survey dataset.

Further research should assess and compare current conditions with these historical datasets to increase our understanding of changes and the potential implications for oak woodland and savanna viability in the face of future fire regime changes and water availability, climate change, and other anthropogenic modifications. Improving our understanding of potential distribution based on relating historical habitat patterns to various factors of change may help us identify and prioritize restoration opportunities in the context of likely future changes.

Figure 6.39. Contemporary dryland habitats Top: View of Mount Diablo from Irish Canyon, scrubby patches of dark green in the foreground are poison oak patches. Bottom: Remnants of historical habitats large and small: (left) A giant spreading oak and (right) a patch of sandy soils. (Left photo by Scott Hein, www.heinphoto.com; Right photos by Abigail Fateman, CCC)

SUMMARY OF FINDINGS

1. **Lowland vegetation was dominated by grassland, but also contained some significant, largely forgotten habitats,** including a 2,800 acre dune scrub patch at Oakley, a large swath of oak savanna east of Brentwood, and an oak savanna in a small alluvial valley near present-day Marsh Creek Reservoir.

2. **Point of Timber was a regionally recognized stand of large valley oaks north of Byron.** These trees were the first large oaks visible when traveling from the south, and extended north and east to the tidal marsh. The low density oak savanna extended west towards Brentwood and north to Oakley.

3. **The Oakley "chamisal," a large patch of interior dune scrub, was an unusual and defining feature of ECCC.** The scrub formed an impenetrable stand and was an important local landmark. Today, remnants at the Antioch Dunes and in the vicinity of Oakley continue to support live oaks, silver bush lupine, and silvery legless lizard, as well as a host of specialized Antioch Dune species.

4. **Scattered oaks were found in the lowlands, stretching from Antioch to Point of Timber.** Live oaks dominated the northern sandy soils, while valley oaks were found in the eastern alluvial soils.

5. **Historically the uplands formed a patchwork of chaparral, woodland, grassland, and savanna,** in patterns similar to those present today. Overall, we mapped 96,976 acres of grassland (58,840 acres in HCP), 17,067 acres of savanna (5,894 acres in HCP), 25,290 acres of woodland (25,198 acres in HCP), 3,310 acres of chaparral (3,016 in HCP), and 8,503 acres of interior dune habitat.

6. **The greatest losses in woodland, savanna, and grassland habitat have occurred in the plains region,** as a result of urban development and agriculture.

7. **Modification of upland vegetation has occurred at the local scale.** At the parcel-level, localized changes were apparent, but did not appear to translate to regional patterns of change in habitat type, at least over the last 80 years.

8. **In the uplands, some evidence was found for changes in stand density within particular habitat types.** Growth of individual trees may result in increases in density. In other cases, particularly in the foothills, individual tree losses are detectable, resulting in a decrease of density. Such losses may be due to mortality and a lack of regeneration as opposed to cutting.

9. **Our mapping shows some pronounced areas of local change** due to cutting in the foothill and montane regions. The areas of greatest woodland loss since the 1930s occurred in the upper Marsh Creek watershed.

10. **Significant habitat type boundary changes due to fire regime change, grazing, or invasive species are not clearly evident in our mapping.** These processes appear, at least in some cases, to have resulted in density changes rather than a shift of vegetation type.

MANAGEMENT IMPLICATIONS AND NEXT STEPS

1. **This mapping effort is a starting point** to develop questions and further research and analysis for future localized or topical projects (i.e., detailed land use and fire history, remote sensing techniques to classify vegetation and detect change). Local-scale restoration projects could benefit from more detailed historical analysis and on-the-ground assessments of individual parcels building on these datasets.

2. **Further research on parcel-scale land use trajectories could help extend the 1930s upland mapping further back in time.** For example, information on burning and clearing practices and property ownership in the historical period would clarify interpretations of 1930s vegetation patterns. This information could also help land managers understand why tree and chaparral density have increased in some areas and decreased in others.

3. **Future research to determine the age structure of woodlands and savannas,** such as ground truthing and tree coring, could help decipher mid-1800s conditions and lend insight into stand density shifts. For example, studies of some blue oak woodlands in California suggest that single age cohorts can dominate the area, which would affect assumptions about mid-1800s conditions. This research should also consider potential future threats as a result of climate change.

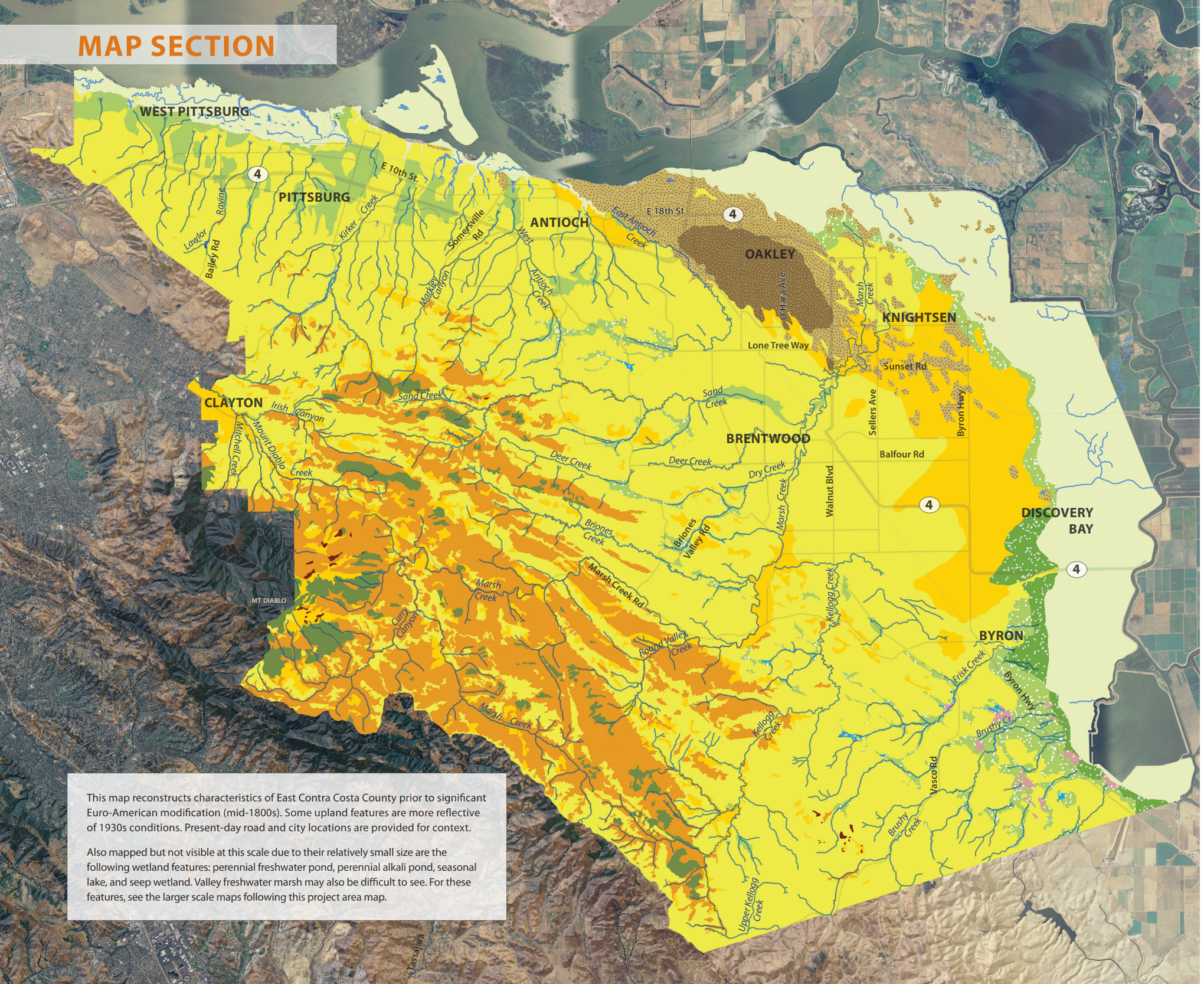
4. **Patches of interior dune scrub still exist and still support native flora and fauna,** including the distinctive silver bush lupines and live oaks. The potential significance of these areas should be considered in coordination with willing land owners.

5. **Planting blue oaks, particularly within foothill savannas and small alluvial valleys,** may help address the noted loss of individual trees and the overall decline in California blue oak woodlands and savannas.

6. **Some lowland areas provide potential for oak reintroduction.** Scattered oaks could be reintroduced to urban and some agricultural areas and grasslands providing some of the ecological functions of the former habitats. Even low density oaks can provide important habitat for birds and other wildlife.

Figure 6.40. Dryland habitats of ECCC. (Photo by Scott Hein, www.heinphoto.com)

MAP SECTION



This map reconstructs characteristics of East Contra Costa County prior to significant Euro-American modification (mid-1800s). Some upland features are more reflective of 1930s conditions. Present-day road and city locations are provided for context.

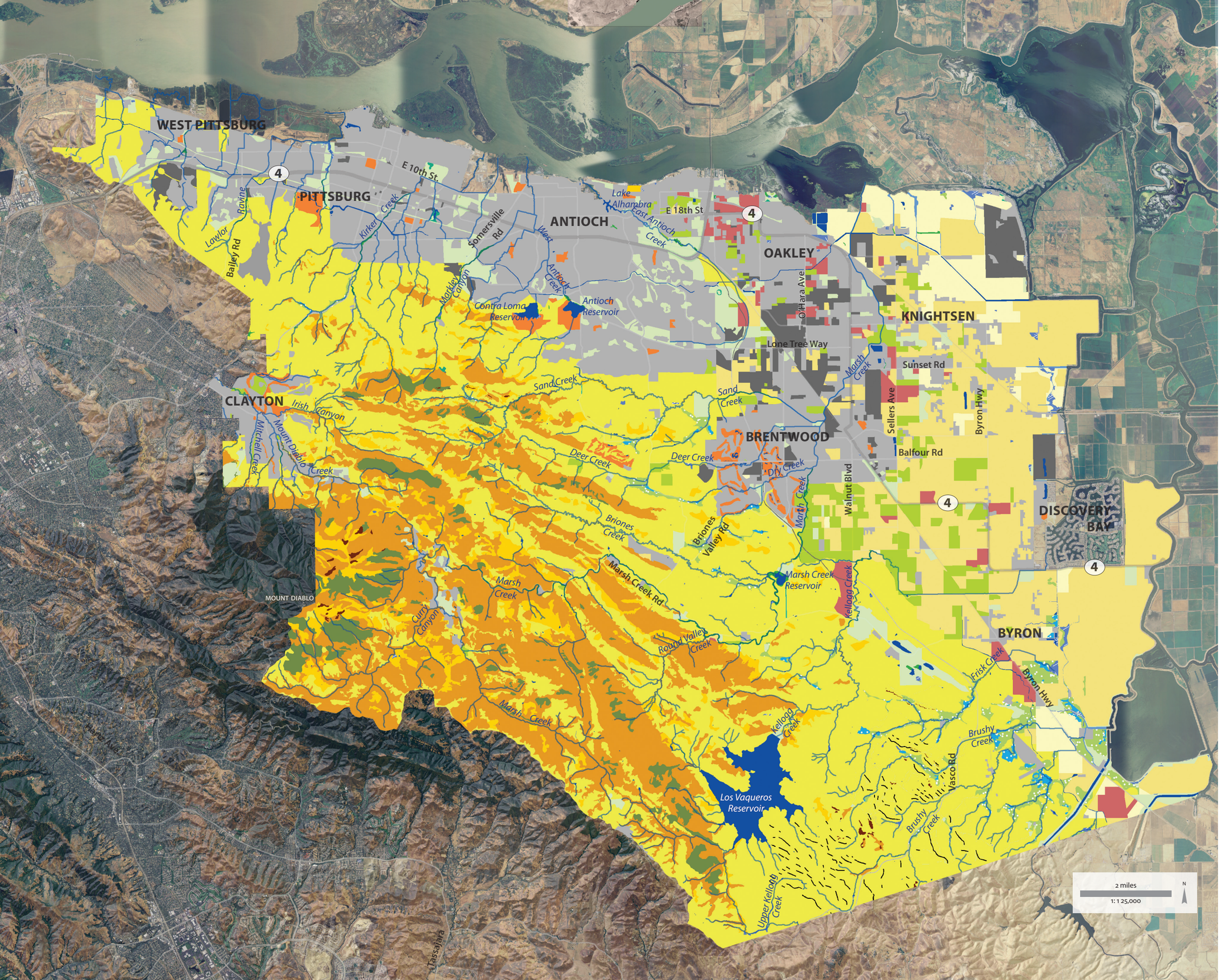
Also mapped but not visible at this scale due to their relatively small size are the following wetland features: perennial freshwater pond, perennial alkali pond, seasonal lake, and seep wetland. Valley freshwater marsh may also be difficult to see. For these features, see the larger scale maps following this project area map.

HISTORICAL LAND COVER, MID-1800s

- Tidal Marsh, Pond, Slough
- Valley Freshwater Marsh
- Wet Meadow
- Alkali Meadow
- Alkali Sink Scrub
- Alkali Flat
- Alkali Marsh
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Interior Dune Scrub
- Interior Dune (veg. undefined)
- Rock Outcrops
- Stream
- Distributary

USDA 2005, courtesy of NAIP

2 miles
1: 1 25,000
N

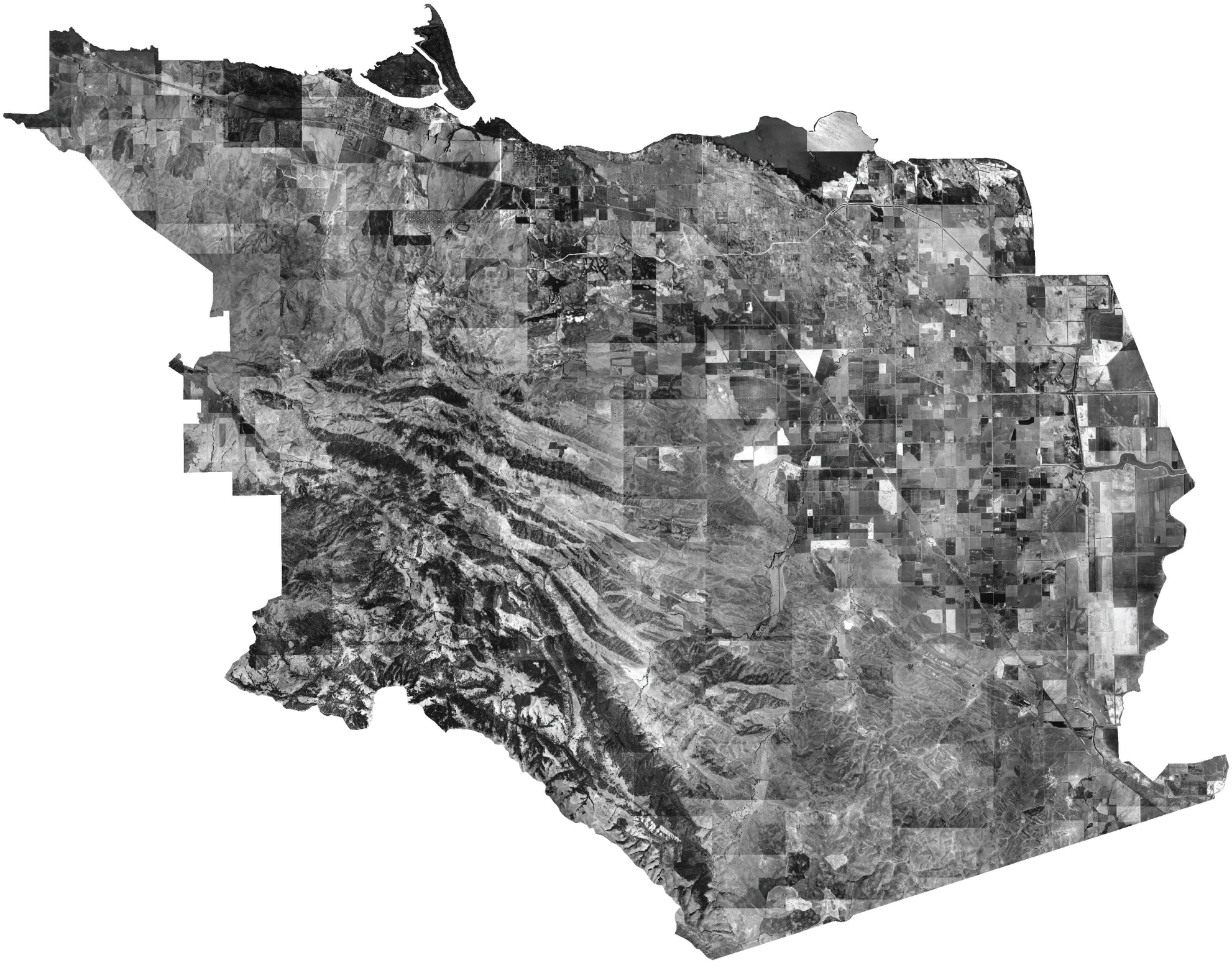


CONTEMPORARY LAND COVER (HCP/NCCP Jones & Stokes 2006)

- Slough, Channel
- Aquatic, Aqueduct, Pond
- Wetland
- Seasonal Wetland
- Alkali Grassland
- Alkali Wetland
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Ruderal
- Riparian
- Rock Outcrops
- Pasture
- Cropland
- Orchard
- Vineyard
- Urban/Future Urban
- Non-native Woodland
- Turf
- Wind Turbines
- Landfill
- Stream

USDA 2005, courtesy of NAIP

AERIAL VIEW, 1939



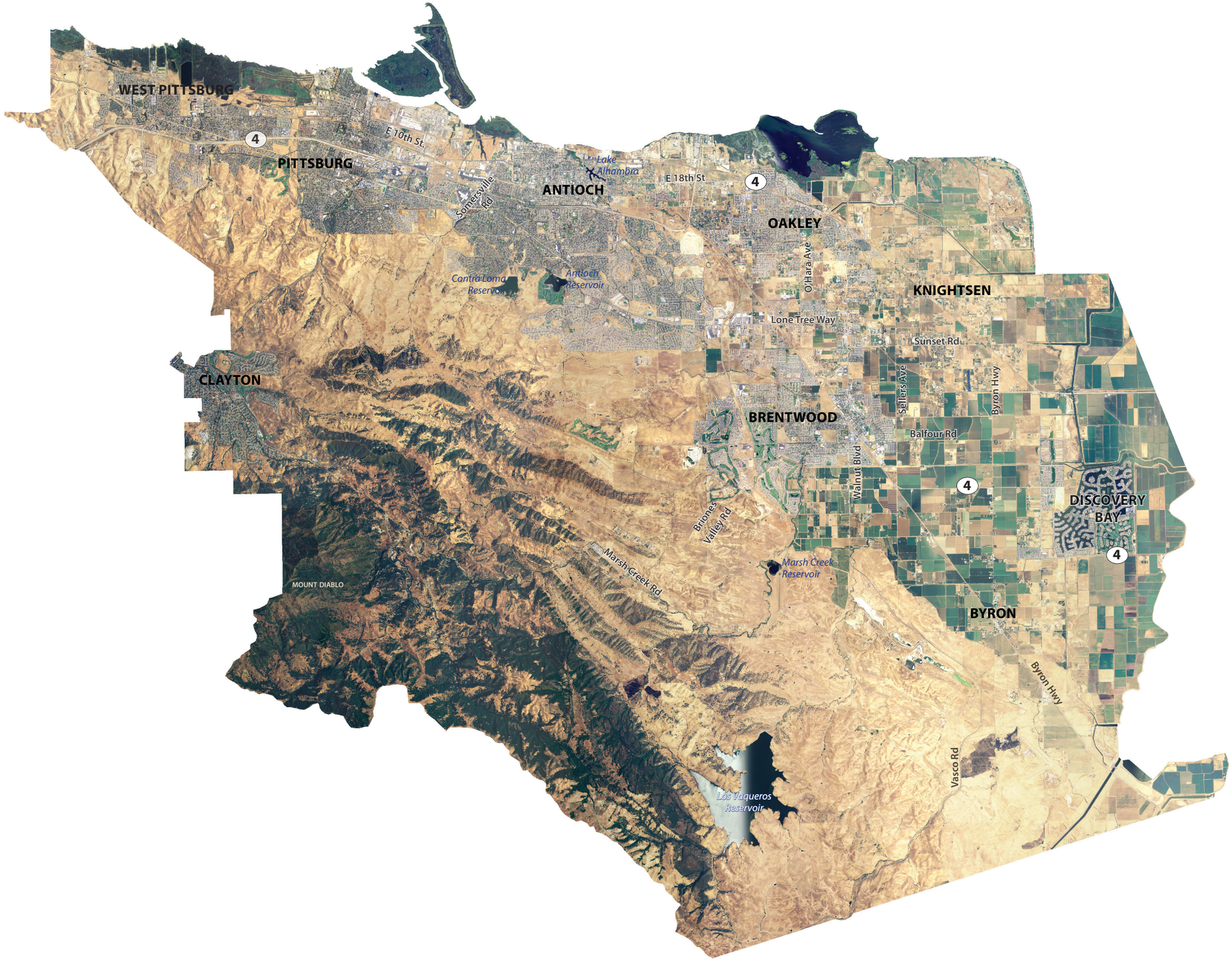
2 miles

1: 1 25,000

N

USDA 1939, courtesy CCC and Earth Sciences & Map Library, UC Berkeley

AERIAL VIEW, 2005



2 miles
1: 1 25,000

N

USDA 2005, courtesy of NAIP

1 mile
1: 62,500
N

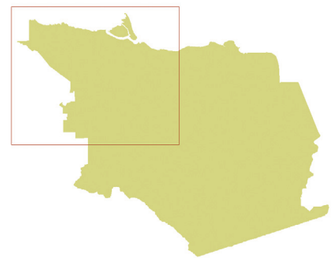
WEST PITTSBURG
PITTSBURG
ANTIOCH
CLAYTON
4

E 10th St.
Kirker Creek
Somersville Rd
West Antioch Creek
East Antioch Creek
Markley Canyon
Lawlor Ravine
Bailey Rd
Irish Canyon
Mitchell Creek
Mount Diablo Creek
Sand Creek
Deer Creek
Briones Creek

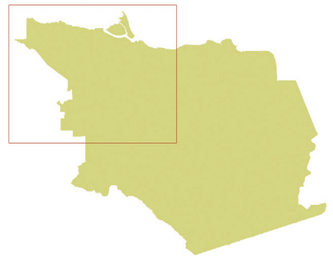
HISTORICAL LAND COVER, MID-1800s
Northwestern section of study area

- Tidal Marsh, Pond, Slough
- Valley Freshwater Marsh
- Perennial Freshwater Pond
- Seasonal Lake/Pond
- Wet Meadow
- Alkali Meadow
- Alkali Flat
- Alkali Marsh
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Interior Dune (veg. undefined)
- Rock Outcrops
- Stream
- Distributary
- Spring

USDA 2005, courtesy of NAIP



AERIAL VIEW, 2005
Northwestern section of study area
with contemporary drainage network

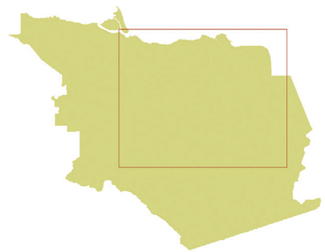


USDA 2005, courtesy of NAIP

HISTORICAL LAND COVER, MID-1800s
Northeastern section of study area

- Tidal Marsh, Pond, Slough
- Valley Freshwater Marsh
- Seasonal Lake/Pond
- Wet Meadow
- Alkali Meadow
- Alkali Sink Scrub
- Alkali Flat
- Alkali Marsh
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Interior Dune Scrub
- Interior Dune (veg. undefined)
- Rock Outcrops
- Stream
- Distributary
- Spring

USDA 2005, courtesy of NAIP



1 mile
1: 62,500
N

ANTIOCH
OAKLEY
BRENTWOOD
KNIGHTSEN
DISCOVERY BAY
E 18th St
Somersville Rd
West Antioch Creek
East Antioch Creek
Antioch Creek
O'Hara Ave
Marsh Creek
Lone Tree Way
Sunset Rd
Sellers Ave
Byron Hwy
Balfour Rd
Sand Creek
Deer Creek
Dry Creek
Walnut Blvd
Briones Valley Rd
Briones Creek
Marsh Creek Rd
Kellogg Creek
4

AERIAL VIEW, 2005
Northeastern section of study area
with contemporary drainage network

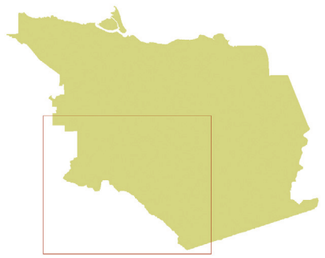
USDA 2005, courtesy of NAIP

Mount Diablo Creek
Deer Creek
Dry Creek
1 mile
1: 62,500
N
Briones Creek
Marsh Creek
MOUNT DIABLO
Curry Canyon
Round Valley Creek
Marsh Creek
Kellogg Creek
Upper Kellogg Creek

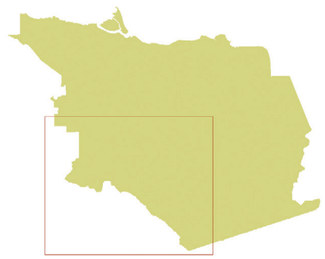
HISTORICAL LAND COVER, MID-1800s
Southwestern section of study area

- Seasonal Lake/Pond
- Seep Wetland
- Wet Meadow
- Alkali Meadow
- Alkali Marsh
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Rock Outcrops
- Stream
- Distributary
- Spring

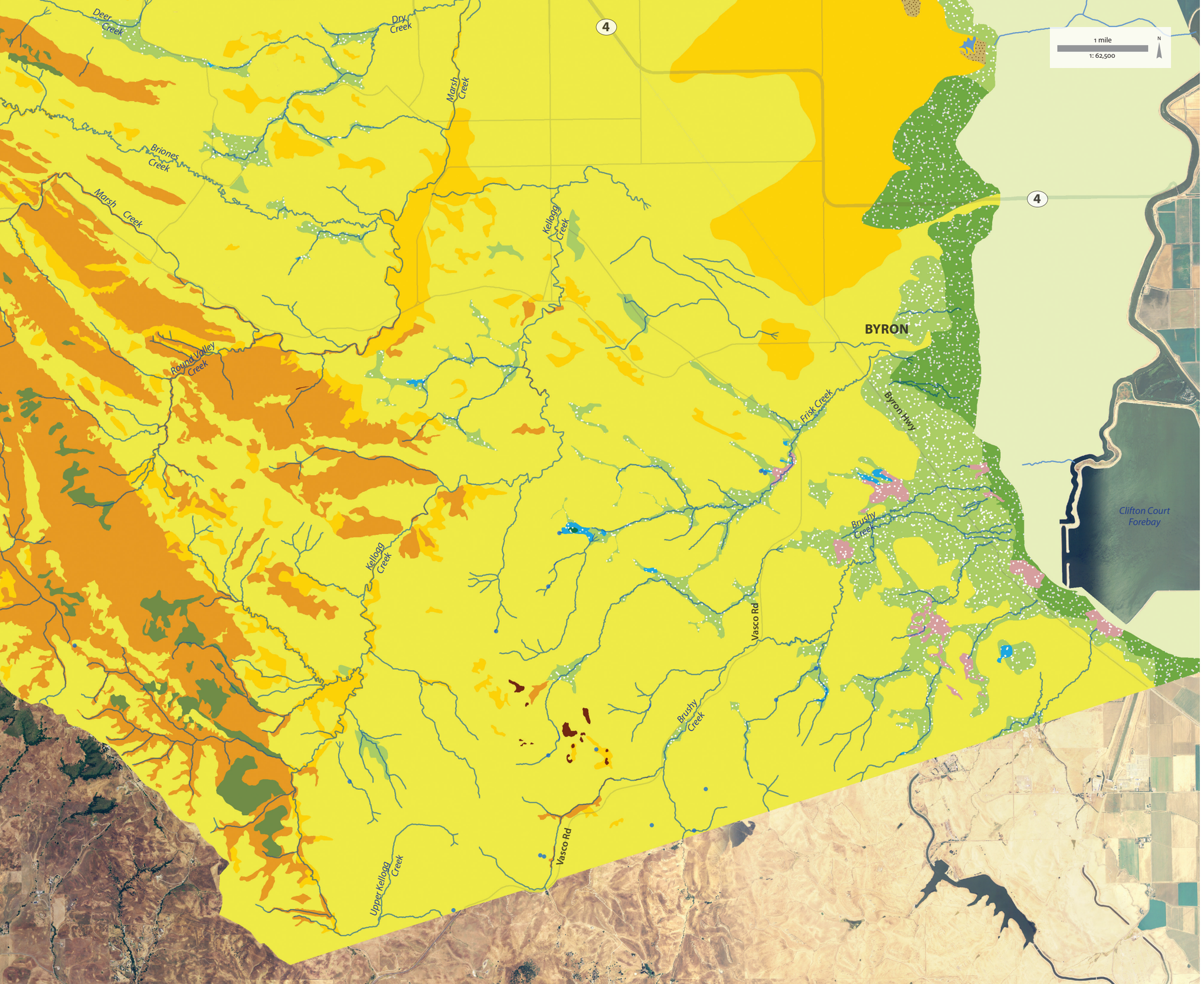
USDA 2005, courtesy of NAIP



AERIAL VIEW, 2005
Southwestern section of study area
with contemporary drainage network



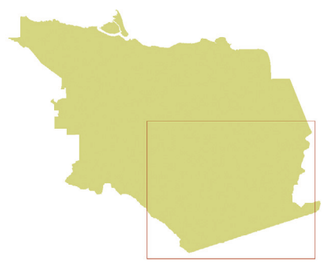
USDA 2005, courtesy of NAIP

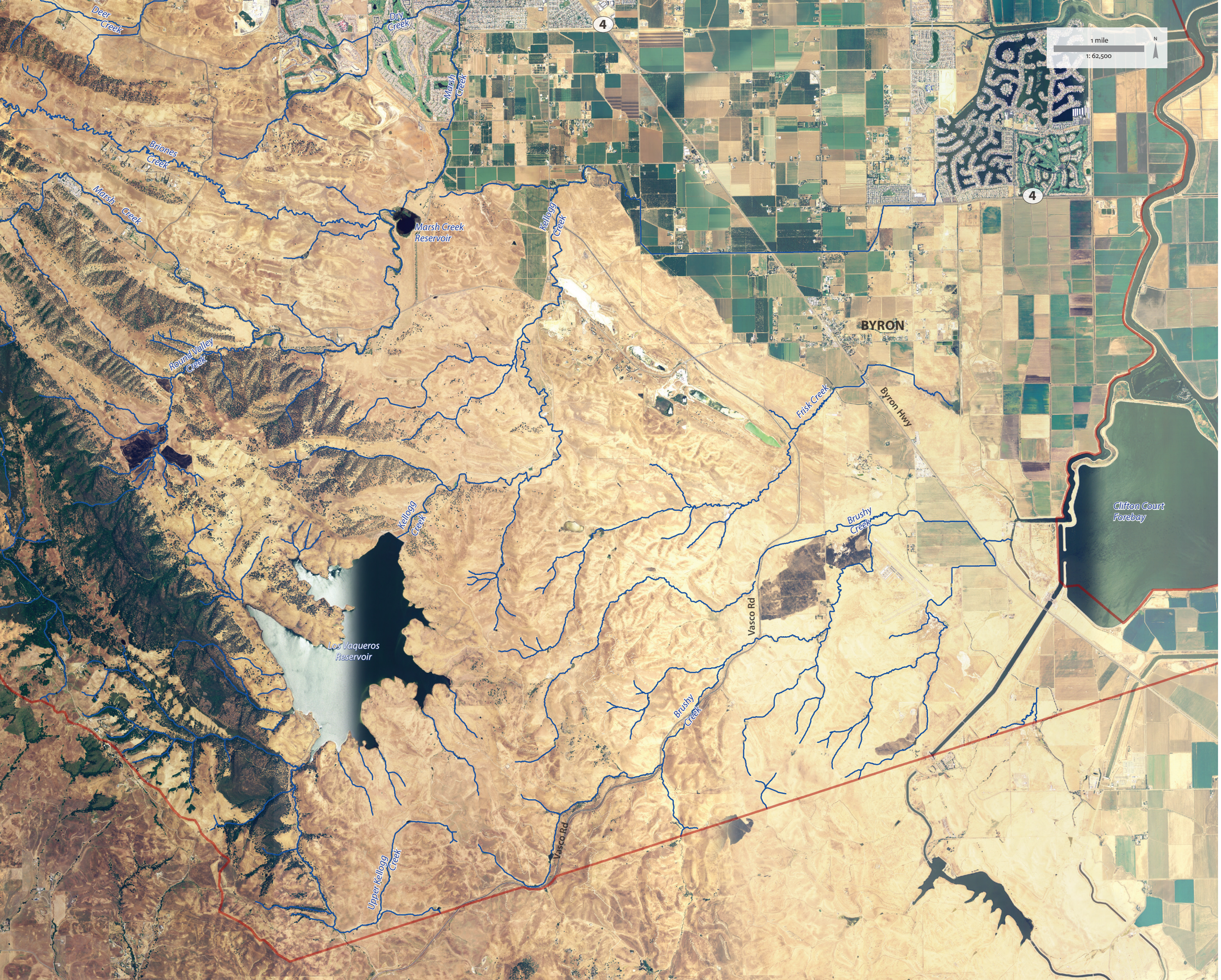


HISTORICAL LAND COVER, MID-1800s
Southeastern section of study area

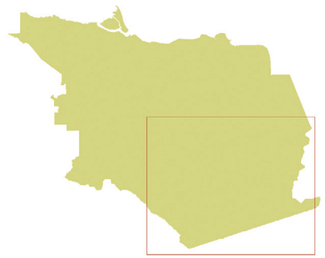
- Tidal Marsh, Pond, Slough
- Valley Freshwater Marsh
- Perennial Freshwater Pond
- Wet Meadow
- Alkali Meadow
- Alkali Sink Scrub
- Alkali Flat
- Alkali Marsh
- Perennial Alkali Pond
- Woodland
- Oak Savanna
- Chaparral
- Grassland
- Interior Dune (veg. undefined)
- Rock Outcrops
- Stream
- Distributary
- Spring

USDA 2005, courtesy of NAIP





AERIAL VIEW, 2005
Southeastern section of study area
with contemporary drainage network



USDA 2005, courtesy of NAIP

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APPENDIX: DETAILED METHODS

WETLAND CHAPTER

Mapping Tidal Marsh

We used a combination of 19th and 20th century data sources to reconstruct the location of historical tidal marsh. In particular, we focused on determining the location of the tidal marsh-upland boundary. Defining the historical extent of tidal marsh in East Contra Costa County is somewhat more complicated than in other parts of the San Francisco Bay. The 1850s-era U.S. Coast Survey (USCS) Topographic-sheets (T-sheets), which provide a highly accurate and detailed (1:10,000 scale) delineation between tidal marsh and solid land for most of the Bay margin (Grossinger et al. 2005), do not exist for most of East Contra Costa County. The northern shoreline bordering Suisun Bay was not mapped by the Coast Survey until 1866, and then only at a relatively coarse, low resolution (1:20,000). Along the Delta margins, the Coast Survey produced no detailed maps before extensive levees were built. Data were available to define most portions of the shoreline, but alternative, often more recent, sources were used.

The northern shoreline, between Port Chicago and Antioch, was mapped at 1:10,000 scale in the 1880s as part of the resurvey of the San Francisco Bay shoreline by the U.S. Coast and Geodetic Survey (as the agency was referred to at that time). Three T-sheets (1803 (Davidson 1886a), 1830 (Davidson 1887), and 1793 (Davidson 1886b)) provide detailed pictures of the shoreline at that time. The bayward marsh margins as represented in 1866 and 1886 mapping correspond closely, suggesting a stable shoreline during this time and accurate mapping. We digitized boundaries from the later maps because of their greater scale and spatial accuracy for both the bayward and landward margins. In a few places, the landward margin showed evidence of modification (e.g., straight boundaries following the railroad, early factory sites), or features shown in 1886 were not present on the earlier map. In these cases, we supplemented the boundary shown by the 1880s T-sheets with additional data, including the 1866 USCS map (Rodgers and Chase 1866); an early property survey (Robinson 1880); the zero and five foot contours from the Collinsville and Honker Bay USGS quadrangles (1918); and the early soil survey (Carpenter and Cosby 1933). We also compared this reconstructed shoreline to the previous estimate by Atwater (1982) based on the 1918 USGS Collinsville map (the westernmost extent of Atwater's mapping).

Tidal marsh sloughs shown by Rodgers and Chase (1866) and Davidson (1886) were integrated to maximize accuracy and detail. Where features were shown similarly by both maps, we used the later map because of its greater spatial accuracy. A number of smaller sloughs were added based on their presence on the earlier map. The 1866 T-sheet also showed a number of substantial marsh pannes not shown by other sources.

East of Antioch, later T-sheets were not available. Atwater (1982) delineated this margin as part of a geologic study of Delta soils; his hardcopy maps were later digitized and georeferenced by The Bay Institute (1998).

In the absence of T-sheets, Atwater used remnant marshes indicated by historical USGS quadrangles and topographic contours from the same maps to extrapolate in areas where marshes had already been reclaimed (which was most of the area). Since most extant tidal marsh circa 1982 was found at 2.5-3.5 foot elevation, Atwater defined a probable boundary midway between the zero and five foot contours (Atwater 1982). Nineteenth-century GLO data do, in fact, consistently place the marsh margin between the zero and five foot contour, confirming Atwater's interpretation. (See additional discussion of this source in Drylands Chapter 6.)

Because contemporary wetland and sea level rise planning require an understanding of the Delta margin, we revisited the boundary based on an array of local sources, including the GLO data, the early soils survey, early aerial photography, and historical and modern topographic maps. This new boundary is generally consistent with Atwater's 1982 estimate, but does differ in places (generally by less than 250 feet but up to as much as 1,000 feet in a few places).

GLO surveys indicated the transition to tidal wetlands with phrases such as "enter tule," "enter swamp and overflowed lands," and "to overflowed lands." We included areas described by Carpenter and Cosby's 1939 soil survey report as "subject to inundation at high tide by brackish tidal water" (Carpenter and Cosby 1939:60). Historical topography (USGS 1910 (Jersey), 1912 (Bethany), 1913 (Woodward Island)) provided a detailed depiction of the 5 foot contour line, indicating low areas subject to inundation by the tides. In many areas, prominently dark regions in the early aerial imagery also showed former tidal extent. We integrated these sources to make a best estimate of the tidal marsh boundary on the east side. This is generally a conservative estimate; in places, some sources suggest that tidal marsh could have extended 500 to 1,000 feet further inland. The boundary should be considered a transitional zone, particularly where there is a low topographic gradient to adjacent salt-affected alkali meadows.

Mapping Alkali Extent

To map alkali extent, we used a minimum mapping unit of five acres, although individual polygons may be divided into smaller areas due to different source combinations or due to a change in type (alkali meadow v. alkali marsh). We used four primary mapping sources: the 1933 soil survey map showing alkali-influenced soils and the accompanying report (Carpenter and Cosby 1939), the 1977 soil survey alkali soil types (Marcuse clay, Pescadero clay loam, Sacramento clay, and Solano loam; USDA 1977), a study and map of alkali vegetation types near Kellogg Creek (Jones & Stokes 1989), and HCP mapping (Jones & Stokes 2006). Secondary (supporting) sources included textual descriptions from the GLO survey, the historical aerial imagery, and the contemporary slope raster derived from LIDAR data. Since we found no maps of alkali extent produced prior to USDA soil surveys (locally circa 1930), our estimation of historical alkali extent is based on this source. However, it is supported by additional 19th century textual data.

We used the contemporary HCP mapping of alkali areas as the base layer and used our additional sources to modify boundaries and add additional areas. We did not modify boundaries unless earlier sources showed substantial (> 150 ft) deviation from the contemporary extent. Polygons were split such that each polygon reflects the unique combination of sources that support it. Polygons were then trimmed to fall within a slope of six degrees (10.5%). This slope cutoff is based on observations and general understanding that alkali habitats tend to occur on relatively flat terrain (Howard pers. comm.). The slope cutoff allowed us to use the detail provided by the LIDAR dataset, which was unavailable to the previous mapping efforts from which our original polygons were based.

We attributed polygons based on their primary (digitizing) and secondary (supporting) sources. We assigned certainty levels to each of these sources (table A.1), and applied these to individual polygons. We assigned a high certainty level to "alkali affected" soil types from the 1933 Carpenter and Cosby soil survey as well as to USDA 1977 "strongly alkali" soil types. The Carpenter and Cosby 1933 soil survey had two other means to indicate possible alkali areas: areas defined as "spotted alkali" and areas with descriptions of alkali-influenced vegetation and soils in the accompanying

soil survey report. These were assigned medium and low certainty levels, respectively. Other modern sources (Jones & Stokes 1989, contemporary HCP mapping) were assigned a medium certainty level, reflecting the presumption of historical presence. Soil types from the USDA 1977 soil survey that were associated with alkali, but were not specifically assigned as an "alkali" subseries were attributed with a low certainty level. In the cases where multiple sources contributed to a single polygon, certainty levels were assigned according to the source with highest level associated with a particular polygon. Approximately 10% of our mapped alkali received a low interpretation certainty, while 65% received high certainty.

Our sources occasionally provided conflicting information. In some cases, areas that were explicitly mapped as alkali 'free' by Carpenter and Cosby (1933) fell within an alkali zone from the 1977 soil survey, and so received a classification as low-certainty alkali. (A classification as "free" indicates alkali level of less than 0.2 % in the top six feet of soil (Carpenter and Cosby 1939).) This difference in classification could reflect an error in either soil survey, a change in conditions, or a difference in alkali mapping threshold.

Table A.1. Interpretation certainty levels associated with individual and multiple sources used to map historical alkali grassland and wetland extent. Certainty levels were assigned according to the source with highest level associated with a particular polygon.

Source_1	Interpretation Certainty
Carpenter and Cosby 1933, alkali affected	High
Carpenter and Cosby 1933, spotted alkali	Medium
Carpenter and Cosby 1933, or USDA 1977, soils description includes discussion of salt tolerant plants	Low
Jones & Stokes 1989	Medium
USDA 1977, strongly alkali	High
HCP 2009	Medium

Alkali Classification Crosswalk

The four historical alkali subtypes differ from those developed for the 2006 HCP (Jones & Stokes 2006). For the HCP, alkali habitats were divided into alkali grassland and alkali wetland; alkali wetland included both seasonal and perennial wetlands. Our classification distinguishes seasonal and perennial wetlands, albeit potentially with a more inclusive definition of seasonal wetlands, as our meadow class can include regions that are flooded only temporarily. The differences in approach and source materials prevent a direct correspondence between the subtypes of the two classification systems. In general, areas mapped as alkali grassland by the HCP correspond to historical alkali meadow and alkali sink scrub, while HCP alkali wetland could correspond to any of the four classification subtypes (see table A.2). Total past and present extent can be compared by lumping all alkali-influenced habitats.

Although some studies (including Jones & Stokes 1989, 2006) have distinct alkali meadow and alkali grassland classes, these are often indistinguishable and considered equivalent terms (Jones & Stokes 1989). Our alkali meadow class includes areas of alkali grassland as classified by the HCP (Jones & Stokes 2006). Alkali grassland and meadow are both dominated by herbaceous species, but grasslands have more annual species, while meadows have more perennial species (Jones & Stokes 1989).

Table A.2: Crosswalk between HCP and historical ecology alkali habitat types.

Historical Ecology classification	HCP classification	Seasonality
alkali marsh	alkali wetland	perennial wetland
alkali playa	alkali wetland	seasonal wetland
alkali sink scrub	alkali wetland or grassland	seasonal wetland
alkali meadow	alkali wetland or grassland	seasonal wetland

DRYLAND CHAPTER

Density Estimations

We performed quantitative analysis of the GLO bearing tree dataset by calculating point density estimates. This information was used to estimate average densities for selected populations and to compare across different regions of the study area. Various different methods have been used to estimate density based on GLO bearing tree data (Bouldin 2008). The most commonly used is the point-centered quarter method developed by Cottam and Curtis (1956), who showed empirically that density is equal to the inverse of the square of the mean distance from a point to a tree (Radeloff et al. 1999). However, this method is problematic with a small sample size or when applied to populations with large-scale non-randomness (Bouldin 2008). For this reason, we also used the more robust Morisita (1957) formula:

$$D = \left(\frac{gk-1}{N}\right)\sum_{i}^{N}\frac{k}{\pi\sum_{j=1}^{k} r_{ij}^{2}}$$

where g is the bearing tree distance rank for the quadrant (g=1), k is the number of quadrants with bearing trees, N is the number of survey points, r is the distance from the survey point to a bearing tree, and i and j are the index numbers for the survey points and quadrant numbers. By estimating density at single points prior to aggregating across an area, this method avoids some of the limitations of the point-centered quarter method. For this equation, we must assume that the trees are randomly distributed locally about a single survey point and that the points are well distributed across aggregated areas. Unfortunately, this method requires two or more bearing trees, and thus we used only a subset of the survey points with bearing trees.

Although the possible bias mentioned above could influence the results, the differences across regions reflect actual variability and would allow for comparison to size and population distribution today, if such surveys were carried out.

Density Change Detection Using Raster Analysis

To explore within-habitat class density shifts over the past 70 years and the type of change, we developed a preliminary method of raster image analysis that would, for a given area, show the location as well as trajectory of change between

woody vegetation cover (chaparral or trees) and no cover (grassland). A true analysis to test vegetation change hypotheses using remote sensing techniques was outside the scope of the project. Also, the most common remote sensing methods are not options when using historical imagery as it is composed of a single color band, whereas the contemporary color NAIP imagery is composed of three bands: Red, Green, and Blue. In order to use the same methods on both sets of imagery, we averaged the pixel values of the 3-band NAIP imagery to create a single-band contemporary dataset. This resulted in two comparable datasets, each with pixel values ranging from 0 (black) to 255 (white). We used the Spatial Analyst extension of ArcGIS to perform the raster analysis.

We used methods of gray tone density slicing (Mast et al. 1997) with the contemporary and historical imagery to determine areas of tree cover and those without. We determined a range of pixel brightness values that exemplified tree cover and reclassified the raster data into binary images with pixels of cover and no cover. This provided a systematic and efficient way to determine extent of cover and no cover and detect change between the 1939 and 2005 imagery. We did not perform comprehensive analysis, but provide examples of possible approaches and outcomes.

However, this method requires that a single pixel value be chosen for each image that represents the breakpoint between cover and no cover. That is, determining the pixel values that represent cover versus no cover is dependent on visual analysis and the breakpoint will vary from image to image, so no single standard pixel value can be used for both the historical and contemporary imagery. Therefore, it is inevitable that some areas of shadow and darker grass will have lower pixel values than the chosen breakpoint and will be included in the "cover" class, while some light-toned trees with higher pixel values than the chosen breakpoint will be included in the "no cover" class. For each analysis, several breakpoints were chosen to explore the sensitivity of the results to slight changes in the break points. Difficulties also arise when the images were taken at different times of the day, resulting in shadows at different angles and sizes. Corrections for slope, aspect, and solar insolence have been utilized with varying success by other researchers (Teillet et al. 1982, Carmel and Kadmon 1998), but were too extensive to include here. This is of particular concern when evaluating change in factors affected by variables such as slope and aspect. Finally, overall percentage of change is likely overemphasized given slight orthorectification errors (i.e., trees do not necessarily overlap perfectly).