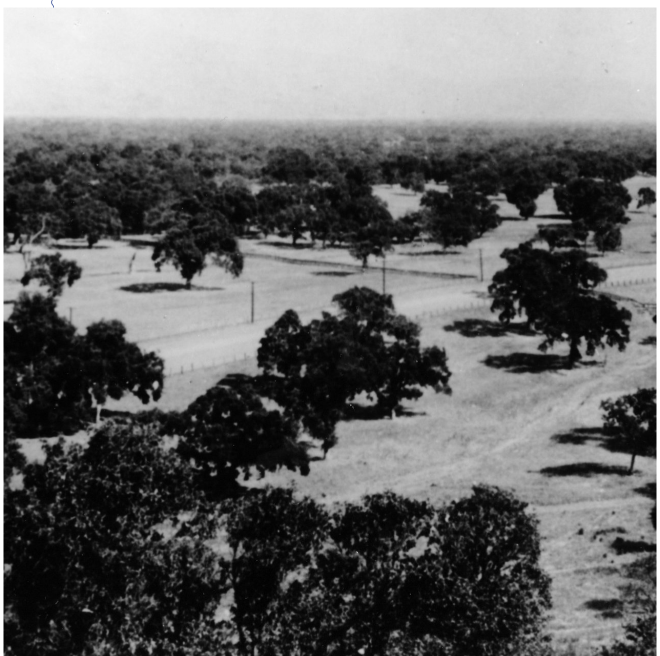
6 OAK SAVANNAS AND WOODLANDS



Above. 19th century view of South Valley oaks.

Below. A South Valley oak in the contemporary landscape.

OAK SAVANNAS AND WOODLANDS

Oak woodlands and savannas once dominated much of California's inland valley floors, including the south Santa Clara Valley, providing critical habitat for a diverse range of native plant and animal species. The acorn woodpecker (*Melanerpes formicivorus*), white-breasted nuthatch (*Sitta carolinensis*), oak titmouse (*Baeolophus inornatus*), and Pacific pallid bat *(Antrozous pallidus pacificus),* along with over 330 vertebrates, can be found living in these habitats. Researchers have recognized that oaks play a central role determining ecosystem function in these inland valleys, providing essential food resources, nesting canopies, shaded understory plant communities, and other services (Mahall et al. 2005). The loss of the dominant species of these oak lands, the once common valley oak (*Quercus lobata*), raises concerns for the health of the systems they support.

Despite losses in range and density (Sawyer and Keeler-Wolf 1995), valley oaks remain iconic within the cultural landscape of inland valleys as majestic trees often revered as part of the local natural heritage. In just the period of 1945 to 1973, estimates indicate that rangeland "improvement" (clearing), agriculture and urban development in California have led to the loss of 1.2 million acres of oak woodlands and savannas of the original 10 to 12 million (Bolsinger 1988). Much greater losses occurred prior to 1945 (Mahall et al. 2005). The remaining areas are largely unprotected, making conservation key to the preservation of these communities (Bolsinger 1988, Davis et al. 1998). Not surprisingly, agricultural and urban development seeking rich soils and flat lands come in direct conflict with oak woodlands and savannas (Griffin 1973). The result of this conflict is evident from the relative scarcity of oaks in the south Santa Clara Valley today.

Statewide trends show a steady decline in density and lack of oak recruitment over the last century, which raises concerns of reproductive isolation (Brown and Davis 1991, Davis et al. 2000, Sork et al. 2002). Oak mortality has also been linked to more indirect effects due to land use change, such as declining groundwater tables, making it more difficult for taproots to sustain trees through the summer drought months (Griffin 1973). Studies raise the concern that natural rates of oak regeneration may be less in some areas than the rate of loss due to added pressures of land use conversion and climate change (Sork et al. 2002, Mahall et al. 2005). Such evidence makes conservation and restoration of these landscapes and the ecosystems they support a priority.

Despite these concerns, relatively little is known about the finer scale pre-European contact characteristics of California's valley oak woodland and savanna landscapes – a scale important for restoration efforts (Brown 2002). Studies of the historical density and distribution of oak lands have rarely quantitatively addressed periods prior to the mid-1900s, when aerial photography becomes available. Such a long-term perspective is important because while the most intensive local urbanization occurred following World War II, European land use (including ranching as well as orchards and other row crops) has been a dominating force in the south Santa Clara Valley since the mid- to late-1800s. This study uses a range of data sources from the 1770s to contemporary times – with particular attention to mid-1800s surveys and maps – to assess the historical spatial patterns of valley oak lands and historical changes over that time. We use early settlement-era sources, including local maps, U.S. General Land Office (GLO) surveys, county surveys, narrative descriptions, and landscape photography, to provide valuable evidence for reconstructing the pre-contact landscape. Informed by these sources, the later (mid-1900s) aerial photography provides an additional valuable dataset.

With these data from the early settlement period, supported by information from the early 20th century, we endeavored to document the historical density and distribution that characterized valley oak landscapes as a basis for future landscape conservation and restoration efforts. Mapping historical oak density distribution is an important component of restoration efforts for several reasons. Refining our knowledge of ecologically suitable areas and physical factors limiting oak distribution through historical analysis could improve the likelihood of success of restoration and regeneration efforts. Restoration at the landscape level is important to help ensure genetically viable communities and successfully support oak-dependent species. Given the competing demands for fertile valley land, spatial patterns of density and distribution are critical pieces of information for designing a conservation plan and a planting template. As valley oaks are reintroduced into areas within their historical range (or anticipated future range under climate change scenarios), such information can guide how woodlands and savannas are reincorporated into our contemporary landscapes.

METHODS

Our analysis of oak savanna and woodland habitat uses a variety of sources and methods in order to benefit from the broad but heterogeneous range of historical data available (Grossinger et al. 2007a). We took an integrated approach that made use of both quantitative data and textual descriptions, each with their own level of accuracy and uncertainty. The methods used in this assessment reflect the desire to incorporate quantitative data such as GLO survey notes, and yet not exclude other, more qualitative data that nevertheless have valuable information about historical oak patterns which is not otherwise available. The way we used these sources is outlined below.

Our estimates of historic stand density in oak savannas and woodlands rely primarily on GLO surveys, with other early sources used to independently corroborate or adjust our initial calculations. To map distribution beyond the GLO survey lines, we used all other available historical data sources, most notably the relict 1939 canopy-sized (> 15 m/50 ft) valley oaks visible in aerial imagery and their correlations with soil type and texture (Davis et al. 2000). We also used a number of earlier historical records that illustrate oak patterns such as landscape photography and textual material. We developed a several step process to integrate and inter-calibrate data from different eras to illustrate changing oak landscapes (table 6.1).

General Land Office data

An important source for reconstructing historical vegetation patterns is GLO survey data. Although researchers note that these surveys were not intended as ecological studies, and thus should be used with care, they nevertheless contain valuable and extensive information on historical vegetation, soils, and water features (Collins and Montgomery 2001). While only rarely employed in studies of valley oak density and distribution (Bloom and Bahre 2005, Brown 2005, Dawson 2006), the field notes from these surveys have been used successfully in many projects in the Midwest and Northwest to determine historic forest stand densities (e.g., Buordo 1956, Manies 1997, Radeloff et al. 1999, Sickley et al. 2000, Collins and Montgomery 2001). The surveys have allowed researchers to place data at a level of accuracy and consistency rarely available from other sources of this era.

Initiated by the U.S. Continental Congress's Land Ordinance of 1785, the GLO's Public Land Survey provides some of the most detailed descriptions of landscape and vegetation prior to the extensive environmental changes following European contact (Buordo 1956). The survey stemmed from the U.S. government's desire to populate the West and pay off debt through assigning public land to homesteaders or selling the land to timber, railroad, and mining interests. Systematically conducted from

Table 6.1. Available sources for different time periods.

Data Time Frame	Era	Sources
1770s to 1830s	Spanish	Early explorers' journals
1830s to 1860s	Ranching and early agriculture	GLO bearing tree and descriptive data, travelers accounts, land grant case testimony and maps
1870s to 1910s	Agricultural intensification	Landscape photography, local histories
1939	Pre-World War II	Aerial photography
2005 to 2008	Contemporary	Aerial photography, groundtruthing

Ohio to the West coast, the GLO surveys established the township and range lines we are familiar with today. They reached Santa Clara County in 1851, and continued in the area until 1884.

The GLO surveys divided public land holdings into six mile square townships with 36 one mile square sections. This was done by first creating two principal lines: an east-west baseline and a north-south principal meridian. The township and range lines were then drawn parallel to these established lines. The section and township corners thus ideally form a spatial dataset of regularly spaced points across the landscape at a resolution as fine as the quarter-section (0.8 km/0.5 mi). However, many areas in California lack a complete network of inner township section lines as a result of the U.S. government honoring the Mexican land grant holdings, many of which were located in the rich coastal valleys of California, including the south Santa Clara Valley (White 1991). As a consequence, GLO surveys in the valley include those for the principal township and range lines as well as the land grant lines, but lack section subdivision surveys. The confirmation surveys of the irregular land grant boundaries were performed by official GLO surveyors, but instructions were often less strictly followed, resulting in more irregular data.

We obtained GLO surveyor notebooks from the microfilm archives at the Bureau of Land Management Office in Sacramento, CA. This included the official surveys for the Mexican land grants.

We adapted methods developed by the Forest Landscape Ecology Lab at the University of Wisconsin-Madison that use Geographic Information System (GIS) to store, display, and analyze the GLO data (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 its ability to place the survey points efficiently and accurately within a contemporary spatial coordinate system (although only as accurately as the lines layer upon which the points are placed) based on distances given in the field notes. In addition, this system efficiently establishes a database that can be easily used in subsequent analyses both in and out of a GIS environment.

Our oak analysis makes use of the bearing tree information as well as more qualitative descriptive notes, which the GLO instructed surveyors to obtain along with other data as they passed through the landscape. To establish the location of section corners and half mile points ("quarter sections"), surveyors noted up to four bearing trees, recording the species, diameter, azimuth, and distance from the points. If no trees were available within “convenient and suitable distances,” surveyors were instructed to establish a mound and trench (GLO 1871). Thus, the absence of trees gives evidence for areas of sparse tree coverage. Quantitative information available from these surveys include species, trunk size, and distances to bearing or witness trees (used to establish survey corners) from survey points, the latter of which have been used to map density of tree cover (Radeloff et al. 1999).

Some researchers have noted a possible bias toward long-lived trees or trees with easily marked bark (Radeloff et al. 1999, Collins and Montgomery 2001). However, we believe that a preference to long-lived species such as oaks would not have a significant impact on our analysis. We also note evidence that surveyors were, in fact, responsive to the actual closest trees: while oaks are commonly recorded in some areas, in areas shown by other maps as willow swamps, the GLO surveyors used willows, while sycamores were recorded in sycamore alluvial woodlands along local streams.

In addition to bearing trees at section corners and quarter sections, GLO surveyors also noted trees they encountered in the path of their survey lines, referred to as “line” trees. The relative frequency of their occurrence also suggests density trends, although we used these data solely for visual comparison and corroboration given the limited number of such trees. As part of their field notes, surveyors described the land cover at every mile point, including general remarks on timber characteristics of the previous mile such as “scattered oaks,” “oak groves,” or “open plain.” Such descriptions are useful when attempting to extrapolate density and distribution at a larger landscape scale.

Other data sources

We obtained copies of Spanish explorers’ journals, traveler accounts, local histories, and landscape photography from local libraries and historical societies. We acquired confirmation and diseños and reviewed text of Mexican land grant cases at The Bancroft Library. The land grant maps and other early cartographic sources were also used to corroborate general density differences and refine the distribution of oak stands. Like the surveyor descriptions, historical narrative accounts provide additional qualitative evidence of pre-settlement density and distribution characteristics of oak savanna and woodland habitat. Where possible, we incorporated these accounts into the GIS. Based on density and descriptive relationships established through the GLO data, narrative accounts of oak woodlands and savannas helped us classify the habitat, particularly in areas with little quantitative data. Landscape photography provided visual representations and also helped us understand spatial clustering and patterns within the oak habitats. Although density calculations could not be performed, these sources show presence/absence and relative density, allowing for calibration of the GLO dataset. Eighteenth and early 19th century sources, while limited, helped assess whether or not GLO data reflect significant changes to oak distribution and abundance since Spanish contact.

We used historical aerial photography taken by the USDA in 1939 to inform our early contact-period picture as well as analyze the presence of oaks just before World War II. Most importantly, this is the earliest available source showing a complete distribution of oaks within the study area. The images were orthorectified using the Leica Photogrammetry Suite module of ERDAS Imagine 8.7. We digitized probable canopy sized valley oaks (> 15 m/50 ft), based upon their distinctive size, shape, and groupings (Brown 2002, Sork et al. 2002, Mahall et al. 2005) and compared this dataset to contemporary 2005 NAIP imagery, noting the trees that remained in 2005. We identified 1,976 trees from the 1939 imagery as “probable valley oaks.” Although research has used the rings of root rot in orchards to digitize locations of historic oaks (Brown 2005), we did not find significant evidence in our aerial photography. We believe our digitizing is a conservative estimate of the population, as individual trees are often difficult to distinguish from one another in urban areas or when canopies overlap. However, given that comparisons to pre-contact and contemporary distribution are based on relationships established from this dataset, we do not expect this underestimation to significantly affect observations of change over time and estimated areas of local losses.

Contemporary soil survey data for south Santa Clara County (USDA [1972]2007) provided our basic mapping units. We related soil types and textures to the presence and absence of our mapped 1939 relict oaks to determine likely areas of oak woodland and savanna. We also compared the distribution of 1939 oak trees to the distribution of wet and alkali meadows, which were acquired primarily from soils data (see Chapter 5). We also consulted the Vegetation Type Map collection (Wieslander 1935), which consists of vegetation maps and plot data of overstory and understory vegetation across California. However, we found that most of the valley floor had been mapped as cultivated, and the few related plot data from the surveys were restricted to the margins of the study area.

Estimating pre-contact stand density and canopy cover

To estimate pre-contact stand density from our GLO bearing tree database, we applied formulas relating stand density and distance from a given point (our section corners) to the nearest tree (Cottam and Curtis 1956, Radeloff et al. 1999). Density (*d*), the number of trees per unit area, is the inverse of the mean area, the area per tree. The square root of the mean area (*M*), or the distance between trees, is equal to the average of the distances from a given survey point to four trees, one in each quarter (quadrant). Based on this relationship, researchers have shown that the distance to the nearest tree from a point theoretically equals 0.5 times the square root of the mean area ($0.5\sqrt{M}$) (Cottam and Curtis 1956). However, Cottam and Curtis (1956) found that a factor of 0.6 improved their density estimation. Using representative stands from historical aerial photography of both Santa Clara and Napa counties to reproduce the point centered quarter method, we determined that the factor best representing the actual density of these stands was 0.53. Using this correction factor with the relationships discussed by Cottam and Curtis (1956), we calculated the density at each survey point using the equation, $d = \frac{1}{(1.89Q_1)^2}$ where Q_1 is equal to the distance in meters to the nearest tree. Even though this meant reducing our tree dataset from 88 oaks to 46 oaks, we determined that using only the nearest tree, rather than all bearing trees at each data point, would be a more accurate estimation of density. Had we used all bearing trees, the average of all tree distances about each point would have been biased toward a higher density, as four bearing trees were rarely noted in the surveys. Where no bearing trees were available, we estimated a maximum possible density using the maximum distance surveyors were willing to travel to obtain a bearing tree as the Q_1, which based on the dataset was 185 m (600 ft).

As an initial exploration of the data, we calculated an average density for all GLO survey points with bearing trees. The limited quantity of GLO data and its high variability prevented us from interpolating density levels spatially from the point data. However, these data provided quantitative evidence for large-scale density patterns across south Santa Clara Valley, which were then refined using additional data sources. Subsequently, these density data, which we averaged for the mapped oak woodlands and savannas, were used to estimate historical numbers of oaks. Our density analysis included all oak species, both for practical purposes and because all oak species together create the function and appearance of the woodlands and savannas.

To translate these density data into mapping units, we established oak habitat types, based on classification systems of Allen-Diaz et al. (1999), the Federal Geographic Data Committee (1997), and Sawyer and Keeler-Wolf (1995). We used three dry land habitat types to indicate a range of oak densities: grassland, savanna, and woodland (table 6.2). Although Allen-Diaz et al. (1999) defined oak savanna as canopy cover less than 30%, we used a cutoff of 25% to match the Federal vegetation definition of woodland systems, with canopy cover between 25 and 60% (FGDC 1997, Allen-Diaz et al. 1999). Although these contemporary classifications do not define a savanna class between grassland and woodland, we were interested in highlighting the presence of valley oaks at a finer resolution for percent canopy covers less than 25%. We used 10% canopy cover as the approximate lower boundary for oak savanna, which has been used in other studies, despite the fact that even lower densities can still function as oak savannas (Davis et al. 2000). Given our dataset and other evidence that live, black, and possibly blue oaks also grew in the valley, these classes were used to define a mixed cover dominated by valley oak, which corresponds to the mixed cover series in modern classification schemes.

To relate density to our classified habitat types, we estimated percent canopy cover from a linear regression of density and percent canopy cover using six representative stands found in the 1939 aerial photography of the south Santa Clara Valley. These representative stands of 25 to 50 trees were selected visually for a range of densities, where confidence was relatively high in distinguishing individual trees. We drew three possible polygons around the stands, which were averaged to estimate the stand area and capture the uncertainty in defining an exact stand area. Tree canopies were then digitized within each stand. Using GIS, we summarized the stand area, canopy area and the number of trees. We found that the percent canopy cover was equal to 0.04 times the density (trees/ha) (R^2 = 0.98) and used this relationship to roughly estimate the percent canopy cover of the densities determined from the GLO dataset (fig. 6.1). This relationship could vary if trees, on average, were smaller (or larger) in the 1850s than in 1939, so the translation from stand density to canopy cover should be considered only an approximate measure. It should also be noted that adding several higher density stands to the dataset would increase confidence in this factor.

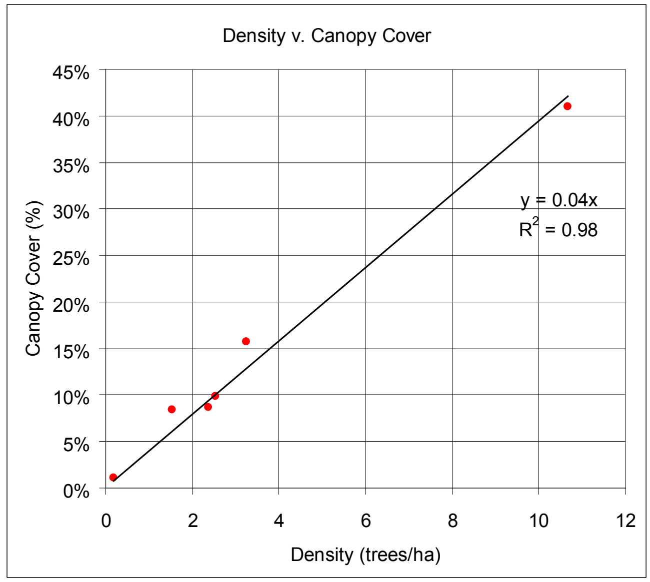


Figure 6.1. Density versus canopy cover for six representative stands using a linear regression with a fixed intercept.

Refining distribution of oak woodland and savanna

We took an iterative approach to mapping the regions of grassland, savanna, and woodland habitat types. We correlated the distribution of relict valley oaks in the 1939 aerial photography with soil type and texture to determine specific soils associated with likely presence

Table 6.2. Mapped habitat types, corresponding modern vegetation class, and percent tree canopy cover.

Habitat type	Modern vegetation class (FGDC)	Canopy cover
Grassland	Temperate or subpolar grassland with a sparse tree layer	0 - 10%
Savanna	Temperate or subpolar grassland with a sparse tree layer	10 - 25%
Woodland	Open tree canopy	25 - 60%

or absence of oaks. Such techniques have been used by researchers to show the importance of soils as a factor in determining valley oak distribution (Davis et al. 2000, Brown 2002, Dawson 2006). For each soil type and texture, we calculated the number of relict 1939 oaks in each soil class using a spatial join in GIS. We followed methods employing a chi-square statistical test to determine whether actual distributions of oaks on soils were significantly different from a random distribution (Neu et al. 1974, Davis et al. 2000). Both positively and negatively correlated soils (confidence level of 90%) were used as the first cut to map probable oak woodland and savanna areas and grassland regions.

> *"... surrounded in every direction, far and near, with golden lakes of wild oats, thickly studded and shaded by the oaks."*
>
> —WISE 1850

Areas of oak woodland were mapped first, by integrating areas around GLO points of high density, descriptions by surveyors and explorers defining denser regions, and early maps depicting groves. We found that these denser woodland areas were consistently described by each source type. Detailed accounts by explorers and surveyors provide a wealth of information that includes both locally specific and regional accounts. Several landscape photographs were also used to corroborate evidence of relative densities suggested by the explorers' accounts, GLO dataset, aerial photography, and soil correlations.

In contrast, we found that savanna regions appear to have more fluid boundaries with grassland regions, so we used early accounts to confirm the basic trends apparent in the distribution set by the soils correlations; however, we rarely found need to modify the extents of these polygons. Data noting the absence of trees were equally valuable when defining the extents of habitat areas. Unmapped areas outside the mapped oak savanna and woodland polygons and other habitat types were assigned to the grassland habitat type.

We also used the extents of selected and digitized wet meadow/seasonal wetland soil types from the USDA soil surveys to confirm areas unlikely to contain oaks. Soils with poor drainage, heavy texture, herbaceous vegetation, or salts and alkali have been found in north Santa Clara Valley to be particularly unsuitable for oaks (Grossinger et al. 2007a). This independently mapped distribution largely matched areas where no trees were found in the GLO surveys. In our mapping hierarchy determined from our mapping confidence levels, the extent of these wet meadow/seasonal wetlands was modified to match our mapped woodland polygons, but was used to define boundaries of our savanna and grassland polygons.

Estimating changes in oak presence

To illustrate the change in oak savanna and woodland habitats over time, we calculated our baseline, pre-contact number of trees by averaging estimated densities of GLO data points that fell within our mapped habitat extents. We used an average of all GLO points outside woodland to define an average historical savanna density and assigned grassland as zero tree density. Contemporary mature trees were mapped by comparing locations of trees in 1939 to 2005 imagery in order to identify corresponding trees. This produced an initial estimate supported by limited ground truthing and does not include new trees established after 1939. A field survey of contemporary trees could greatly improve the present-day estimates.

RESULTS

Stand density and canopy cover

We found evidence that historical stand densities in south Santa Clara Valley were dramatically higher than today and considerably higher than what might be assumed using 1939 aerial photography. The areas of highest density were coincident with large alluvial fans present in the valley.

Our mapping suggests that oak woodland dominated the northern Morgan Hill area, while more southerly regions – outside wet meadows – were largely covered by less dense oak savanna or grassland. Within the savanna systems areas of dense groves appear at locally favorable sites, with only the largest and most well defined of these actually distinguished by the habitat mapping.

The GLO tree dataset contains a total of 134 trees with distance information, of which 84% are oaks and 74% are white oaks (assumed valley oaks), located at 58 survey points (table 6.3, fig. 6.2). Based on these 58 points and their associated "nearest tree," we analyzed only the nearest oaks (88% valley oak), of which there were 46, and found an overall average oak stand density of 4.9 trees/ha (2 trees/ac). Based on our regression relationship between density and percent canopy cover, we estimate an average 19% canopy cover for these survey points, which falls within the range of our savanna habitat type class. It is important to note that this value is not a representative average density for the study area, as it does not include points with no bearing trees. For these points where no bearing trees were noted, we calculated a maximum density of <0.1 trees/ha (0.04 trees/ac), or less than 0.5% canopy cover.

Corroborated by other sources, our initial exploration of the GLO data showed a visible break in tree cover between the Morgan Hill area and the rest of the study area, distinguished by points with no bearing trees. Also, 20 of the 30 line trees were located in this northern extent. GLO point density data in the Morgan Hill area have an average of 9.8 trees/ha (4 trees/ac; approximately 39% canopy cover), which falls within the woodland class. This estimate is based on 17 nearest oak trees (82% valley oak; table 6.3, fig. 6.2). When woodland groves identified by other sources were mapped, the average density associated with the 20 GLO nearest oak data points falling within woodland polygons was 13 trees/ha (5 trees/ac), roughly 50% canopy cover. Due to a larger estimated margin of error in the mapped savanna versus grassland and the few data points available, we used all other points (23 points with nearest oaks) in savanna and grassland polygons estimate savanna density, leaving grassland at zero. We found an average of 2.9 trees/ha (1.2 trees/ac) for the oak savanna habitat (a 12% canopy cover) within the lower range of the savanna class. Representative contemporary illustrations of these classes from the study area are limited, but examples are provided from 1939 aerial imagery and recent landscape photographs (figs. 6.3 and 6.4).

Table 6.3. Estimated oak density and approximate canopy cover based on GLO point data showing the average minimum distance to trees from given points. Includes data averaged over the whole study area, the general Morgan Hill region, and woodland and savanna habitats.

	Number of oaks	Average distance to oak (m)	Density (trees/ha)	Estimated % Canopy Cover
All Oaks	46	24.0	4.9	19%
Morgan Hill area	17	16.9	9.8	39%
Woodland	20	14.7	13.0	52%
Savanna	23	31.3	2.9	12%

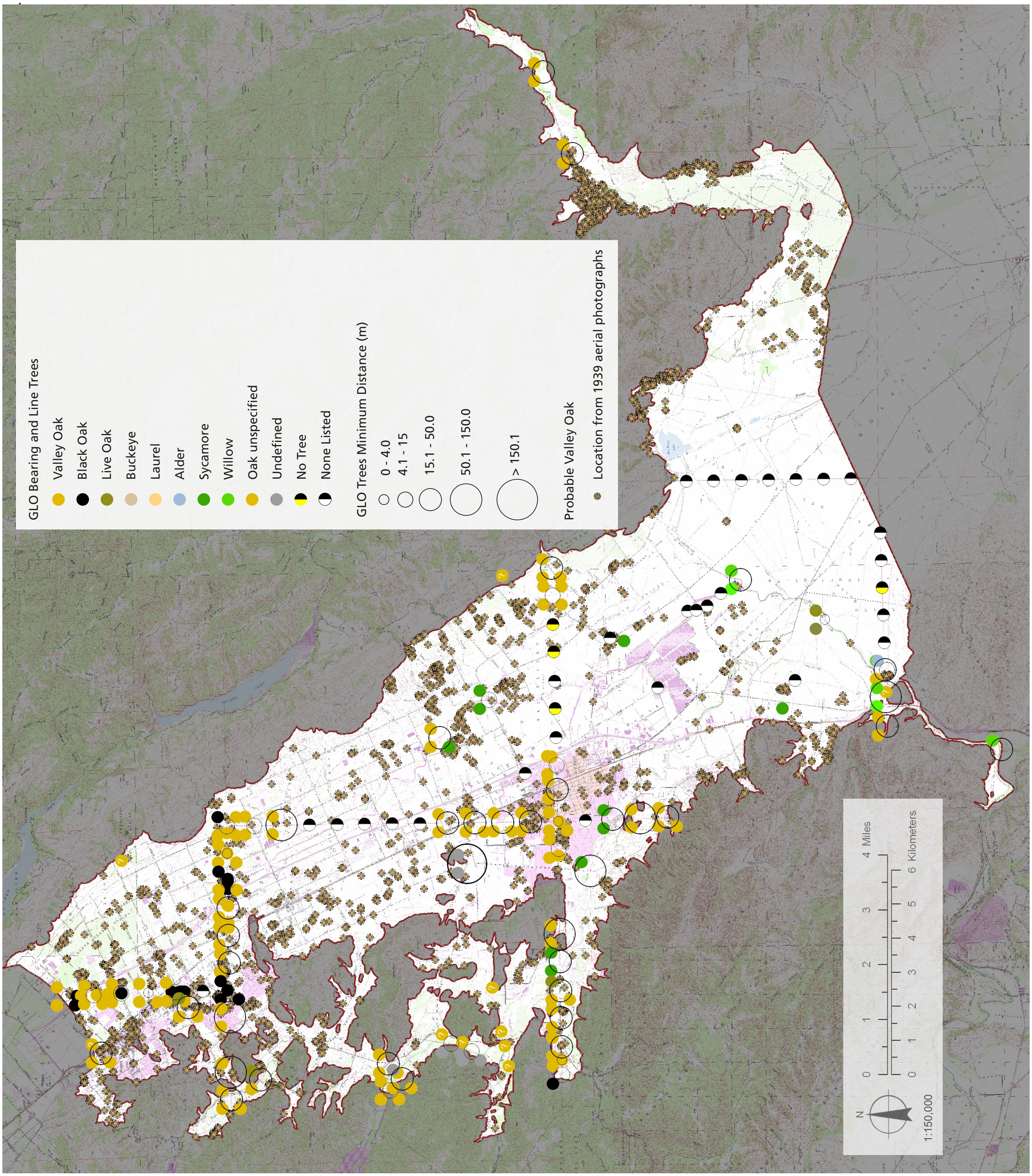


Figure 6.2. Data compiled from mid 19th-century General Land Office surveys (tree species and minimum distance to nearest tree) are shown here, along with valley oaks mapped from 1939 aerial photography (brown stars).

Oaks were clearly distinctive features within South Valley, and many of the earliest sources available highlight the prevalence of oaks and the general character of the woodlands and savannas. Such sources bring historical landscapes to life and provide general corroboration of the GLO bearing tree data. Landscape photography gives a visual sense of densities in places that were not cleared by the time the photographs were taken, while narrative descriptions provide further evidence of the oak woodland and savanna extent and density variations at both local and valley scales.

Based on the GLO data available, we were able to create a crosswalk from descriptive terms to our savanna habitat classification. Textual accounts of "scattered" oaks associated with data points of an average density of 3 trees/ha (1.2 trees/ac) or about 12% canopy cover (within the savanna class). In support of this finding, descriptors such as "scattered timber," "thinly scattered white oak," and "open plain, scattering oak timber" are encountered more frequently in the southern portions of the study area, where we have less evidence of large areas with dense woodland characteristics (Day 1854). Other common terms, such as "grove" or "woodland," supported our classification of woodland habitats, while descriptions of "open plains" were used to classify grassland. (However, these latter terms were not common enough to relate to a specific density.)

The dispersed or scattered nature of savannas, with grass under-story cover, was characterized as having a "natural park-like appearance," while others described the spacing like that of an orchard (Shortridge [1896]1986). In one of the first explorations of the valley in 1772, Crespí (Crespí and Bolton 1927) recalled that "much of it [south Santa Clara Valley] was well grown with oaks and live oaks." In 1776, Anza (Bolton et al. 1930) found the valley a "spacious plain with many oaks and live oaks." A broad view of the valley, most likely from the Llagas area, is captured by one traveller who was "surrounded in every direction, far and near, with golden lakes of wild oats, thickly studded and shaded by the oaks" (Wise 1850). Descriptions also reiterate the heterogeneous pattern suggested by GLO data, indicating that oak savannas did not entirely cover the valley. Geologist William Brewer noted entering a "belt of scattered oaks" in the Pacheco Pass area and a region of oaks south of Morgan Hill that was "four or five miles wide covering the middle" (Brewer [1930]1974).

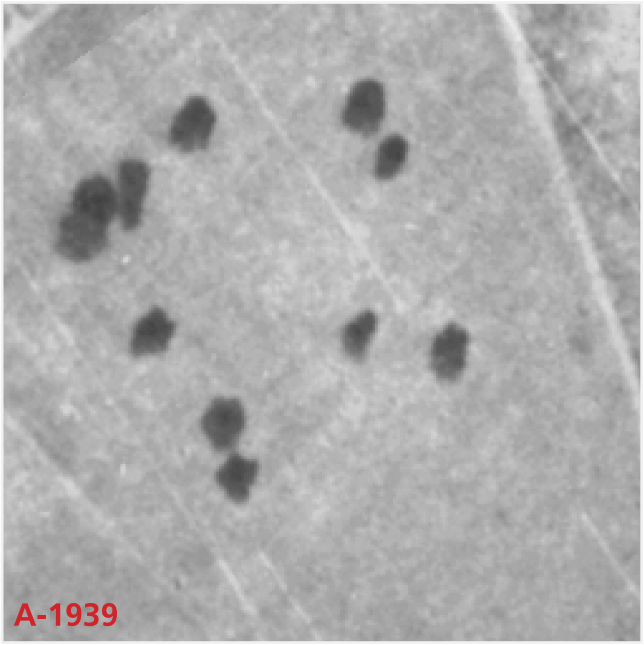
> Commonly used historical terminology appears to translate into classifications we recognize today.

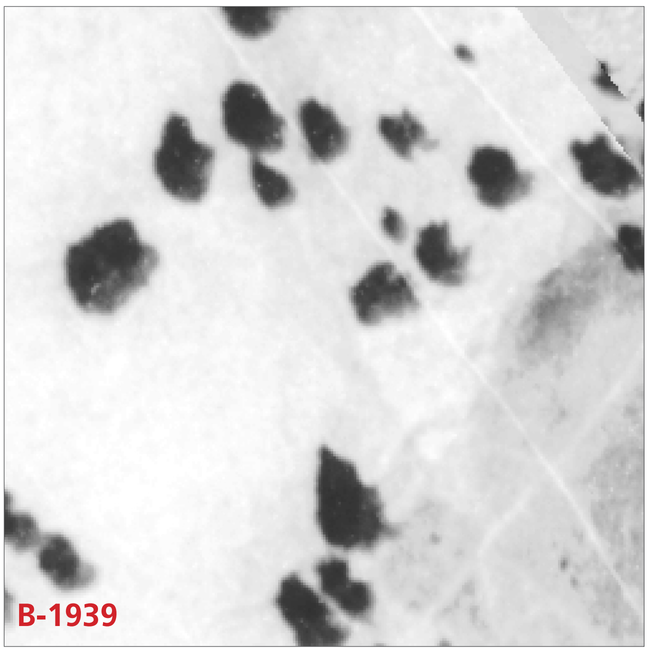
In addition to determining that "scattered" timber referred to what we would today call oak savanna, we found that denser woodlands were also consistently identified by surveyors, written descriptions, and visual evidence. Indicators of higher stand density included descriptions such as "valley land covered with oak timber," "a heavy growth of oak timber," or "densely timbered" (Thompson 1857a, Harrison ca. 1888). In particular, the terms "woodland" and "grove" appear to have described what was a fairly recognizable or self-evident pattern of higher density areas on the valley floor. Wooded regions shown on maps consistently corresponded to areas reported as woodlands or groves by GLO surveyors. For example, a diseño from the 1840s likely depicts a large oak woodland, or "roblar," in the shape of a fan on the eastern side of the valley across from Morgan Hill (fig. 6.5). Two accounts of this area confirm the feature:

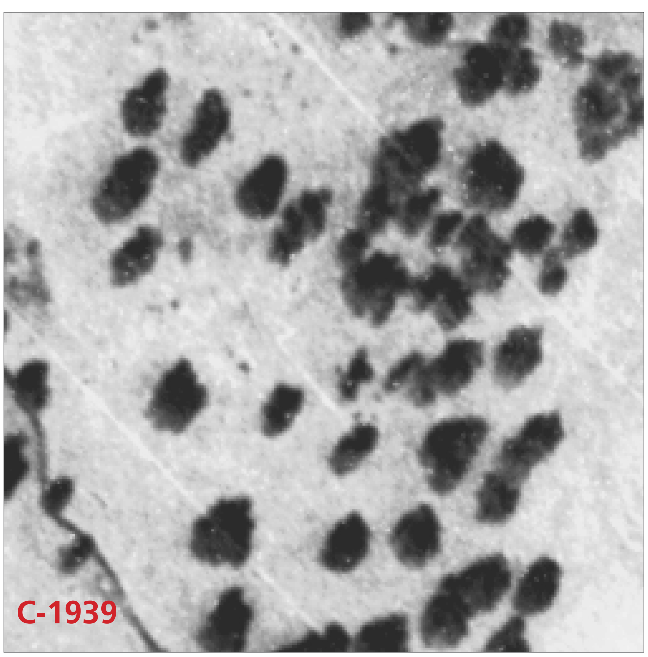
> …on the eastern side of the valley, is a large area of virgin soil, beautiful level valley land, covered with wide-reaching oaks, ably fine vine land, and is the least populous of all the Gilroy section of country. (Harrison ca. 1888)

> A large body of oak timber… (Day 1854)

Turn of the century landscape photographs from the Morgan Hill area also suggest a high density,







corresponding to the high densities calculated from GLO data (fig. 6.6). These data correspond with observations from an explorer "that the timber grew more plentiful and the trees larger" moving north from Gilroy (Manly 1894). Surveyor Richard Howe (1851) characterized an area near Morgan Hill as "low scrubby mossy oak timber," which still connotes the idea of dense woodland, but perhaps suggests smaller and younger trees. Additionally, a confirmation map drawn from the survey for the Ojo de Agua de la Coche rancho land grant (encompassing Morgan Hill) shows a continuous tree cover across the grant line in this part of the valley (fig. 6.7). The trees in this area correlate with the inactive fan of historical gravelly soils shown by both historical and modern soils maps. While it is difficult to quantify these depictions of the landscape individually, the volume of these data and their close correspondence with the GLO bearing tree data and to each other contributes to a consistent view of the distribution and character of oak savanna and woodland.

We also found evidence for finer scale variation in oak distribution within the general cover classes. While open savanna characterized much of the study area, smaller patches of oak woodland are often distinguishing features within the more sparse savanna setting. Encompassed within a landscape view of "scattering oak timber," denser zones, or "roblars," are consistently distinguished in early maps and by GLO surveyors as they

Figure 6.3. Exemplary 1939 aerial photographic views of a grassland (A) with a low but significant valley oak density (1.7 trees per hectare/0.7 trees per acre; 3-5% cover), a savanna setting (B) with 2.8 trees/ha (1.1 trees/ac; 9-10% cover), and a grove or woodland (C) (7.6 trees per hectare/3 trees per acre; 25-30% cover). Each view covers 6.4 ha (16 ac) and is shown at 1:3000 scale. These views also illustrate some of the different landscape patterns possible, from more even distribution to pronounced clumping. Differences in the average size of trees in a given area also result in local variations in the relationship between stand density and canopy cover. (A, B, and C: USDA 1939, courtesy of the Science & Engineering Library Map Room, UC Santa Cruz)

entered or left "groves" (Day 1954). In 1774, explorer Palou summed up this multi-scale pattern:

> ...the plain we were keeping on through was much grown up with white oaks and live oaks, and we came across some patches of thick woods of these same trees. (Brown 2005)

An alternate translation refers to the "thick woods" as "dense groves" (Bolton et al. 1930).

Another account from 1896 referred to the valley in the Gilroy area as "formerly covered with groves of magnificent oak trees" (fig. 6.8; Shortridge [1896]1986). Farther north in 1850, "magnificent clusters of oaks" created "one continuous vista of unexampled beauty" (Wise 1850). We expect that, although we were only able to map the location of several of the most notable small-scale groupings (on the order of 10 ha/25 ac), these small stands or groves were common within the larger savanna setting. Differences in density distribution are also addressed through glades, openings, or "abras" that occur in overall denser woodland areas (Lewis 1850a,

Figure 6.4. Contemporary landscape photographs of valley oak savanna and woodland. The first two images show the same small savanna (7 trees in 0.8-1.2 ha/2-3 ac) from two vantage points. From a distance (A), the relatively wide distance between trees can be seen; a closer view (B) captures the combined effect of the trees despite the wide spacing (generally 50-100 m/160-330 ft apart). In the foreground of C, valley oaks in a savanna setting leaf out in early spring. Clumps of valley oaks can be seen on the valley floor and live oaks are common on the hillside behind. A rare remnant grove of valley oak woodland (D) is found along Highway 152. This is the same site as the 25-30% cover 1939 example in fig. 6.3 (bottom).

Figure 6.5. (Left) Early diseño of the Ojo de Agua de la Coche Grant depicts a fan-shaped oak woodland area on the eastern side of the valley, just south of where Coyote Creek bends northward. The land grant confirmation map of this same land grant depicts widespread trees within the valley. (U.S. District Court, Northern District [184-?]a, courtesy of The Bancroft Library, UC Berkeley)

Day 1854; see fig. 6.13). Thus, while it may be difficult to imagine a continuous expanse of evenly distributed trees at a density of 11 oaks/ha (45 oaks/ac), woodlands at the landscape scale may simply appear as more tightly spaced groves at the local scale. It is easy to imagine early settlers establishing roads, towns and small fields within the trees, but between groves.

Species composition

Of the 182 bearing and line trees recorded by GLO surveyors, 65% were white (presumed valley) oak, 9% black oak, 3% live oak, and 5% unspecified oaks. These data indicate that most of the trees on the valley floor were oaks, and most of those were valley oaks (table 6.4). Black oaks and live oaks were a minor, but significant, component of the oak woodlands and savannas of south Santa Clara Valley.

Virtually all the black oaks are located in the Morgan Hill region, interspersed with valley oaks. Eight of the 17 were recorded as “Red oaks,” an eastern species with leaves similar to black oaks. Several narrative descriptions support mixed

Figure 6.6. (Right) Late 19th-century views of the oak woodlands that dominated south Santa Clara Valley near Morgan Hill. (A (Unknown 1892) and B (Unknown ca. 1900c): courtesy of the Morgan Hill Historical Society)

A-1892

B-ca. 1900

Figure 6.7. Trees are indicated continuously along the boundary line of the Ojo de Agua de la Coche land grant on this 1857 map, which crosses the full extent of the valley floor. (Thompson 1857b, courtesy of the Bureau of Land Management)

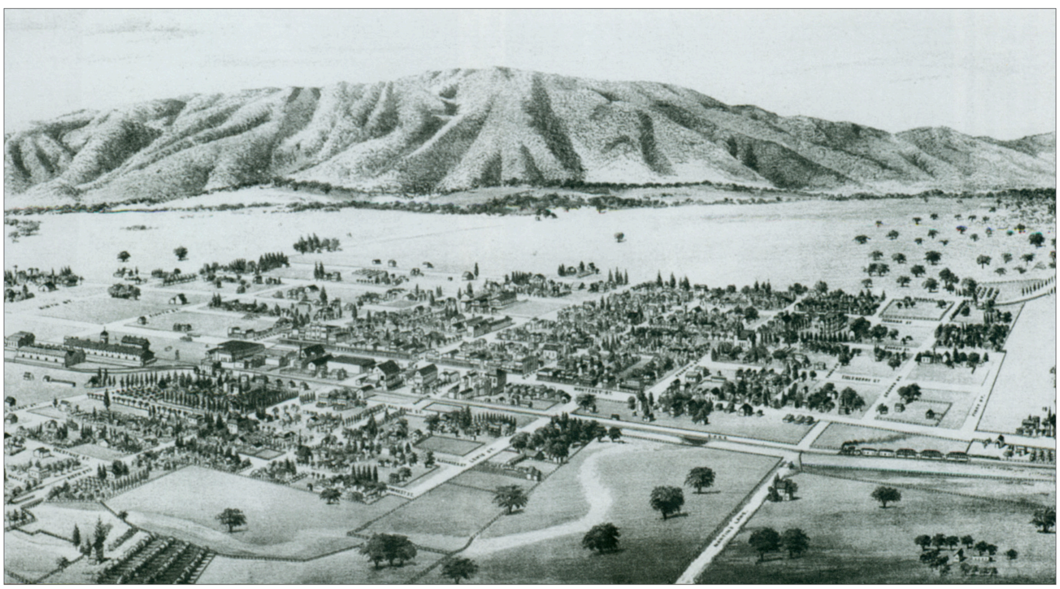


Figure 6.8. The oak grove west of Gilroy shown on this 1885 lithograph was also noted by GLO surveyor Richard Howe, who recorded “left the woodland” in his 1851 field notes. Sherman Day (1854) also noted a “point of timber” close to his survey line in this area. (Blake 1885, courtesy of the Gilroy Museum)

stands dominated by valley oaks. East of Gilroy, Sherman Day (1854) reported “timber is mainly of white oak,” while directly on the other side of the valley he found “white oak, with a few live oaks.” Close to Morgan Hill, he was “amid a grove of white oaks and live oaks.” Despite the low composition percentage, there is evidence that live oaks were the more dominant feature in some locations. In one example, Sherman Day remarks on his entrance into “a grove of tall old live oaks” near the confluence of Tar Creek and the Pajaro River. Such variation in species composition of the oak woodlands and savannas is probably most distinct in and around Morgan Hill, where live oak canopies dominated the landscape immediately around the present-day city. Looking north toward Morgan

Hill from Uvas-Carnadero Creek, travelers saw "beautiful groves of live oak trees" and "many live oaks, some of them very large and beautiful" (Linkins 1874, Manly 1894). Some of these remain today (fig. 6.9). However, further east, valley oaks (such as those illustrated in the Dunne Ranch photograph; fig. see 6.6B) are the dominant oak species. This area was crossed by the GLO surveys, not the west side of the valley at Morgan Hill, which could explain why no live oaks were recorded between Morgan Hill and Gilroy. Other tree species, such as sycamores and willows, were recorded near creeks or rivers.

In south Santa Clara Valley, 84% of the oaks recorded to species level by GLO surveyors were valley oaks.

Table 6.4. Species composition of all GLO trees within the study area. The total differs from density calculation totals because some trees did not have distances recorded and this table includes line trees (those trees with no distance because they fall on the survey line).

Species	# of trees	% of total
Valley Oak	118	65%
Black Oak	17	9%
Live Oak	6	3%
Oak (unspecified)	10	5%
Sycamore	14	8%
Willow	8	4%
Alder	1	1%
Undefined	8	4%
Total	182	

Associations with soils

The soils analysis provides the basis for our mapped habitat units for which GLO data can inform density estimates. We found that several soil types and textures were significant factors explaining the distribution of the 1,976 probable valley oaks digitized from the 1939 aerial photography. To check the relevance of these findings to historical distribution, we confirmed that these correlations also largely reflect the presence and absence patterns of GLO bearing tree data and other sources. We found oak presence significantly correlated (probability >90%) with Pleasanton loam (0-2% slopes), Pleasanton gravelly loam (0-2 and 2-9% slopes), San Ysidro loam (0-2% slopes), and Arbuckle gravelly loam (0-2% slopes). Largely found in association with each other, these soils are located on alluvial fans and described as well

Figure 6.9. Existing heritage oak trees in South Valley are mostly valley oaks, but large live oaks are also relatively common in Morgan Hill, reflecting historical vegetation patterns. This tree was photographed in the winter, when the deciduous valley oaks were leafless.

Table 6.5. Soil type association with density, using 1939 oaks.

Name	Area (ha)	Percent of total area	Observed oaks (1939)	Expected oaks	Percent of total oaks (1939)	Oaks/ha	α = 0.1
ARBUCKLE GRAVELLY LOAM, 0 TO 2 PERCENT SLOPES	1515	7.0%	153	99	10.8%	0.10	+
CAMPBELL SILTY CLAY LOAM	536	2.5%	11	35	0.8%	0.02	-
CAMPBELL SILTY CLAY, MUCK SUBSTRATUM	951	4.4%	29	62	2.0%	0.03	-
CLEAR LAKE CLAY	425	2.0%	6	28	0.4%	0.01	-
CLEAR LAKE CLAY, DRAINED	591	2.7%	15	39	1.1%	0.03	-
CLEAR LAKE CLAY, SALINE	598	2.8%	3	39	0.2%	0.01	-
CROPLEY CLAY, 0 TO 2 PERCENT SLOPES	715	3.3%	21	47	1.5%	0.03	-
CROPLEY CLAY, 2 TO 9 PERCENT SLOPES	329	1.5%	23	22	1.6%	0.07	
HILLGATE SILT LOAM, 2 TO 9 PERCENT SLOPES	814	3.7%	76	53	5.3%	0.09	
HILLGATE SILT LOAM, 9 TO 15 PERCENT SLOPES, ERODED	275	1.3%	29	18	2.0%	0.11	
KEEFERS CLAY LOAM, 0 TO 2 PERCENT SLOPES	266	1.2%	27	17	1.9%	0.10	
KEEFERS CLAY LOAM, 2 TO 9 PERCENT SLOPES, ERODED	754	3.5%	69	49	4.9%	0.09	
LOS ROBLES CLAY LOAM, 0 TO 2 PERCENT SLOPES	382	1.8%	18	25	1.3%	0.05	
PACHECO CLAY LOAM	651	3.0%	20	43	1.4%	0.03	-
PACHECO FINE SANDY LOAM	794	3.7%	27	52	1.9%	0.03	-
PACHECO SILT LOAM, DRAINED	352	1.6%	15	23	1.1%	0.04	
PLEASANTON GRAVELLY LOAM, 0 TO 2 PERCENT SLOPES	665	3.1%	129	44	9.1%	0.19	+
PLEASANTON GRAVELLY LOAM, 2 TO 9 PERCENT SLOPES	505	2.3%	157	33	11.0%	0.31	+
PLEASANTON LOAM, 0 TO 2 PERCENT SLOPES	1707	7.9%	166	112	11.7%	0.10	+
PLEASANTON LOAM, 2 TO 9 PERCENT SLOPES	267	1.2%	27	17	1.9%	0.10	
RINCON CLAY LOAM, 2 TO 9 PERCENT SLOPES, ERODED	269	1.2%	14	18	1.0%	0.05	
RIVERWASH	596	2.7%	28	39	2.0%	0.05	
SAN YSIDRO LOAM, 0 TO 2 PERCENT SLOPES	1228	5.7%	126	80	8.9%	0.10	+
SAN YSIDRO LOAM, ACID VARIANT, 0 TO 2 PERCENT SLOPES	353	1.6%	32	23	2.3%	0.09	
SORRENTO SILT LOAM, 0 TO 2 PERCENT SLOPES	758	3.5%	39	50	2.7%	0.05	
WILLOWS CLAY	2379	11.0%	9	156	0.6%	0.00	-
Willows soils, eroded	387	1.8%	0	25	0.0%	0.00	-
YOLO LOAM, 0 TO 2 PERCENT SLOPES	1082	5.0%	78	71	5.5%	0.07	
YOLO SILTY CLAY LOAM, 0 TO 2 PERCENT SLOPES	423	1.9%	38	28	2.7%	0.09	
ZAMORA CLAY LOAM, 0 TO 2 PERCENT SLOPES	846	3.9%	16	55	1.1%	0.02	-
ZAMORA LOAM, 0 TO 2 PERCENT SLOPES	311	1.4%	21	20	1.5%	0.07	

drained soils with a "deep rooting depth" (USDA [1972] 2007). GLO surveyor Howe (1851) also noted the "gravelly" texture of these alluvial fan soils in the Morgan Hill area. In his study of historic oak distribution in north Santa Clara County, Brown (2005) found that Pleasanton soils, as well as Yolo, Garretson, and Zamora soils were most likely to support oak woodland.

Soils negatively correlated with oaks include Pacheco silt, sandy, and clay loams, Campbell silty clay loams and silty clay with muck substratum, Cropley clay (0-2% slopes), Clear Lake clay, Zamora clay loam, and Willows clay (table 6.5). As might be expected, our analysis of soil textures identified fine-loamy, loamy, and loamy-skeletal textures as positively correlated with valley oak presence, while fine, fine-silty, sandy, landslide, riverwash, and water categories were significantly negatively correlated with valley oaks (table 6.6). Results from the soil texture analysis showed a much larger proportion of the study area (virtually all) falling within either positively or negatively correlated soils. While less selective, we included the soil texture analysis for its more general description and more universal use (figs. 6.10 and 6.11).

Significantly negatively correlated soil types contained only 23% of the expected number of oaks ("expected oaks" based on the number of oaks in the soil type if the 1,976 "probable" oaks are distributed evenly across the study area). Significantly negatively correlated soil textures were less useful predictors of oak absence, containing 58% of the expected oaks. With 11% of the 1939 oaks located in significantly negatively correlated soil types and 33% located in significantly negatively correlated soil textures, it may appear that these are poor indicators of oak distribution. However, these soils both represent stand densities of <0.05 trees per hectare (0.02 trees/ac), or less than 0.5% canopy cover, which

Table 6.6. Soil texture association with oaks density, using 1939 oaks.

Particle Size (texture)	Area (ha)	Percent of total area	Observed oaks	Expected oaks	Percent of total oaks	Oaks/ha	Significant α=0.1
Clayey	193	0.7%	28	15	1.4%	0.145	
Clayey-skeletal	1020	3.8%	96	77	4.8%	0.094	
Fine	9165	34.6%	396	691	19.8%	0.043	-
Fine-silty	4639	17.5%	239	350	12.0%	0.052	-
Fine-loamy	9208	34.7%	1020	695	51.0%	0.111	+
Loamy	116	0.4%	46	9	2.3%	0.395	+
Loamy-skeletal	250	0.9%	44	19	2.2%	0.176	+
Coarse-loamy	841	3.2%	81	63	4.1%	0.096	
Sandy	181	0.7%	1	14	0.1%	0.006	-
Riverwash and water	785	3.0%	32	59	1.6%	0.041	-
not used	114	0.4%	17	9	0.9%	0.149	

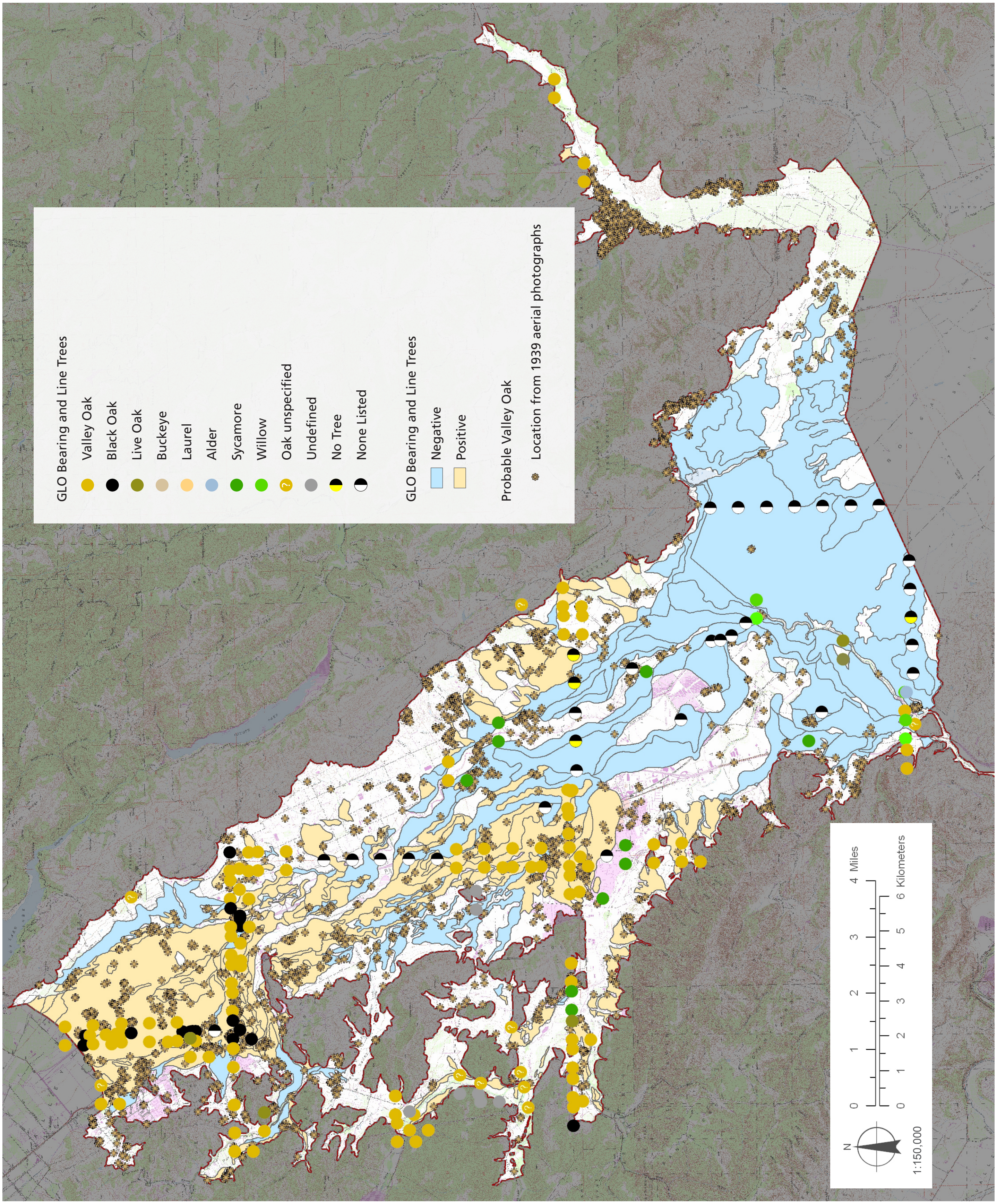


Figure 6.10. Soil types that are positively (yellow) and negatively (blue) associated with oak presence (from 1939 aerial photography) with a significance level <0.1. Areas were left blank for soil types insignificantly correlated with oaks.

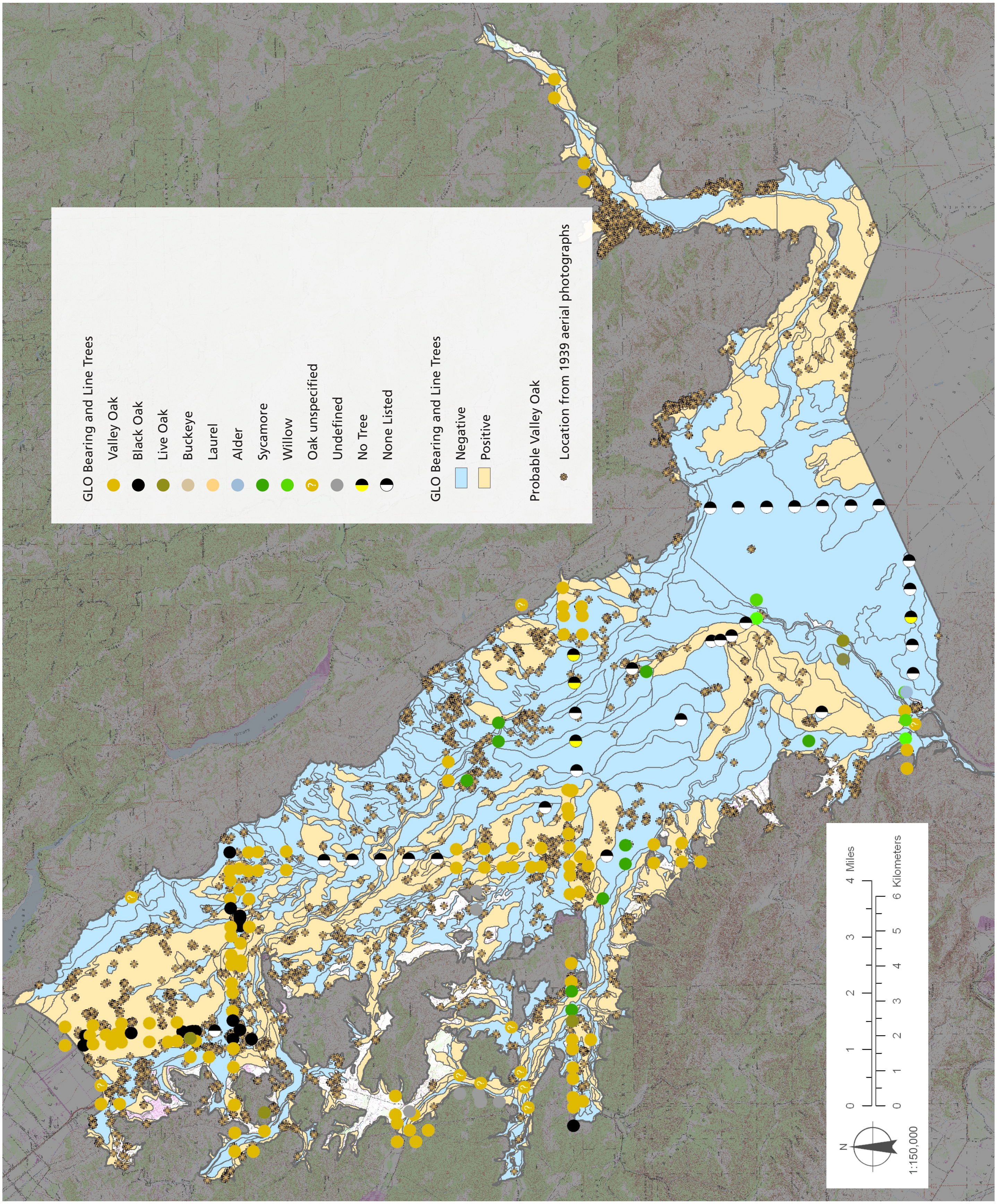


Figure 6.11. Soil textures (based on the soil survey particle size) that are positively (yellow) and negatively (blue) associated with oak presence (from 1939 aerial photography) with a significance level <0.1. Areas were left blank for soil types insignificantly correlated with oaks.

corresponds with maximum possible densities indicated by GLO data points that contain no bearing tree information. By comparison, positively correlated soils are associated with 1939 oak densities of >0.1 trees per hectare (0.04 trees/ac). These levels clearly do not reflect the high historical densities suggested by the GLO data, but the locations of high density in the GLO data match those soils highly correlated with the 1939 "probable" valley oaks.

Narrative sources also illustrate the lack of trees in the Bolsa region, the most distinctive body of negatively correlated soils. Brewer, riding across the Bolsa in 1861, described the treeless region:

> First a ride of eighteen miles across the dead-level plain, tedious and monotonous...To one who has never tried riding on a level plain, no description is adequate to cause a full realization of its tediousness...but at last a belt of scattered oaks is entered. Then we strike up a canyon, on the Pacheco Pass... (Brewer [1930]1974)

Similarly, Broek (1932) described this area as a "treeless plain," affirming the stark differences in tree density found in other parts of the valley.

When comparing these negatively correlated soils to historical soils identified for their wet characteristics with poor growing conditions, such as alkaline, adobe, poorly drained, and seasonally flooded (Grossinger et al. 2007a), the negatively correlated soils largely overlap. Alkaline soils represent 15% of the study area (located in the Bolsa region) but contain only 1% of the total oaks (or only 7% of the expected number of oaks had all oaks been evenly distributed across the study area). These negatively correlated areas correspond closely with the "no tree" points recorded by GLO surveyors. This is not to suggest that oaks cannot grow in these areas; finer-scale micro-topography such as ridges built up from abandoned streams can provide favorable, albeit limited, locations for oak establishment (Cooper 1926).

Change over time

Based on our mapped habitat polygons (see habitat map, inside front cover) and representative average densities from the GLO dataset for points within each habitat type, we estimate that close to 60,000 oaks existed within south Santa Clara Valley during the early settlement period. Using the habitat classification ranges for percent canopy cover, estimates range from 35,000 to 110,000 historic oaks. This is striking when compared to the 1,976 "probable" valley oaks identified in the 1939 aerial photography, and the rough estimate of about 1,000 persisting in 2005 (fig. 6.12).

Based on our approximate density estimates, the average woodland density declined from 13 trees/ha to 0.2 trees/ha (5.3 trees/ac-0.1 trees/ac), while savanna density decreased from 2.9 to 0.1 trees/ha (1.2 trees/ac-0.04 trees/ac). The density decrease between the 1939 digitized trees and those currently standing (as of 2005) is fairly uniform, decreasing by roughly half for both woodland and savanna areas. This means that approximately 97% of the mid-1800s oaks were lost by 1939. Since then, an additional 50% have been lost. These estimates are likely best considered as minimum or low estimates given that the 1939 and 2005 oak populations were based on digitized trees from aerial photography, a method which tends to underestimate density.

For comparison, studies in southern California found losses of approximately 20% between the late 1930s to early 1940s and the late 1980s and 1990s (Sork et al. 2002, Mahall et al. 2005). These studies occurred in areas less impacted by agriculture and urban growth. This difference and the extensive conversion of the south Santa Clara Valley floor to orchards and row crops suggests that the reported losses can largely be attributed to land conversion rather than the lack of regeneration.

The corresponding estimates of historical area are 5700 ha (14,000 ac) of oak savanna and 3,300 ha (8,200 ac) of oak

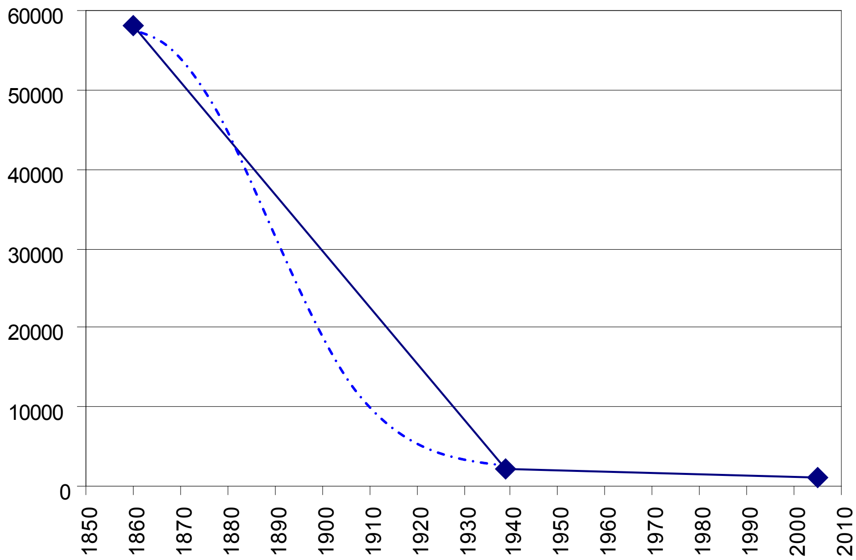


Figure 6.12. Decline in oaks over time based on estimates reflecting the early settlement period, the period after agricultural intensification, and contemporary numbers. Estimated trend based on land use history in dashed blue line.

woodland. Together these habitats represent about 34% of the study area. Recent mapping indicates 164 ha (400 ac) of equivalent habitat ("mixed oak woodland and forest" and "valley oak woodland;" Jones and Stokes 2006) in the Santa Clara County portion of the study, which covers 80% of the study area. Assuming a similar proportion of savanna/woodland for the San Benito County portion of the study area (which is undoubtedly an overestimate given the dominance of wetland soils), the decline is 98%.

Open grasslands have also declined, although not quite as precipitously. We estimate 8,500 ha (21,000 ac) historically, while recent mapping indicates 1,188 ha (2,900 ac) in the Santa Clara County portion of the study area.

DISCUSSION

Historical data intercalibration

Determining the historical extent of valley oak savannas and woodlands involved inter-calibration between quantitative data (GLO nearest neighbor bearing tree distance), historical cartographic depiction, and descriptive terminology. These different styles of data combine to reveal consistent landscape patterns. We found that surveyors and cartographers from a wide range of backgrounds depicted woodland and savanna in similar ways. In general, neither Spanish nor American cartographers show savanna, but each consistently shows groves or woodlands. These visual depictions of groves consistently correlated with spatially explicit GLO surveys that use the terms "grove" or "woodland" as well as the higher densities indicated from bearing tree distances (fig. 6.13). It appears that these dense woodland features were distinct enough to be represented consistently in a range of media. Similarly, we found that the term "scattered trees" was used consistently by surveyors to refer to a more open savanna pattern, based on corresponding bearing tree data. These areas were rarely depicted on early maps. This understanding helped to classify areas into woodland, savanna or grassland, while also refining habitat extents based on soil correlations with the 1939 "probable" valley oaks.

Figure 6.13. GLO surveyor Sherman Day intersected the feature drawn by county surveyor Lewis (1850a) on the right side of this map. Day (1854) noted "Enter timber — white oaks," corresponding with Lewis' representation of a densely wooded area. The distinctive "abra," or opening, is labeled at (a). (Lewis 1850a, courtesy of the Office of the Santa Clara County Surveyor)

Soils associations

Although we used the digitized 1939 oaks rather than oaks from earlier sources to determine soils strongly correlated with the presence or absence of oaks, we expect to only lose significance using this later source and thus underestimate historical extents of woodlands and savannas. It could be that some soils with historically high tree densities were completely cleared of oaks by 1939. However, losses appear relatively evenly distributed across the valley such that the relict oaks of 1939, largely found along roads and at homesites, seem sufficient for determining positively and negatively correlated soils. We would expect losses to occur at a more local level (at the agricultural field level), and thus not affect trends in relative densities across the valley. The valley floor in 1939 was mostly covered in agriculture, and yet these correlations are able to distinguish between different areas within the cultivated region. Our analysis reveals that certain soils could be indicators for potential areas of restoration, or (in the case of the alkali soil type) areas where restoration efforts might have little potential to succeed.

Significantly correlated soil types can suggest potential areas to reintroduce – or not reintroduce – oak populations

Stand densities

Our estimates of historical stand densities appear to fall within the range of those reported in other studies, although no quantified estimates of density were found prior to the 1930s. Sork et al. (2002) reported an average 1944 density of 1.48 valley oaks per hectare (0.6 oaks/ac) located on the Sedgwick Reserve in Santa Ynez, California. Davis et al. (2000) found a valley oak density of 1.7 trees/ha (0.7 trees/ac; using 22,647 canopy-sized valley oaks on 44,000 ha (108,700 ac), derived from polygons that contained valley oaks). Also on Sedgwick Reserve, a 2005 report found overall 1943 oak densities of 13.5 trees/ha (5.5 trees/ac) based on 20 oak woodland stands identified in 1943 aerial photography (Mahall et al. 2005).

Oak patterns and land use history

Findings suggesting that the majority of oaks were lost prior to World War II is supported by the history of land use in the valley. Local history also indicates that the GLO surveys, upon which we base our estimates of historical oak densities, occurred at the cusp of rapid settlement and cultivation in the valleys and thus largely reflect pre-modification conditions. It appears that large scale removal of trees had not yet occurred by the 1850s and 1860s, even though Spanish colonization in the region began in the late 1700s. Most of the South Valley land passed through by GLO surveyors was described as open plains with only occasional cultivated fields. Land uses into the late 1860s focused on grazing and the production of hay and grain, which did not directly conflict with the presence of oaks (see fig. 3.1). Cattle ranchers considered oaks a benefit to rangeland, since they provided shade for stock (Jepson 1910, Bartlett 1928), and 19th-century photographs and lithographs frequently show cows under oak trees (e.g., Thompson and West 1876, Shortridge [1896]1986). Accounts that “everywhere scattered in the fields and rising above the surrounding fruit trees are large live oaks with widespreading crowns” (Broek 1932) or that trees were “not so close together as to render it necessary to cut away to prepare the land for cultivation” (1850s, in Bartlett 1965) suggested that oaks and agriculture were not mutually exclusive. Descriptions and photographs indicate that oaks were usually left intact within 19th-century hay and grain fields, so that by the 1890s the remaining grain farms in the county were noted for their preservation of “the grand old oaks in all their original beauty” (Shortridge [1896]1986).

Equally important, valley oak wood is too soft for building purposes (Jepson 1910), and did not receive the same pressures as the redwoods in the nearby Santa Cruz Mountains, which were the preferred source of lumber during the early settlement period. While some trees were undoubtedly removed in the immediate vicinity of settlements or used for firewood and even occasionally as fence posts during this early transition period (Jepson 1910, Brown 2002), these factors did not drive significant clearing until the large-scale planting of orchards. Consequently, we expect our estimate of historical oak coverage is an accurate approximation of conditions at the time of European contact.

> Oak trees did not directly conflict with Mexican-era and early American agricultural practices. Oak mortality was greatest during the late 19th century, with gradual attrition since that time.

It should also be considered whether baseline levels assumed from the 1850 picture were affected by the rapid decline in the fire regime practiced by indigenous land management (Barbour et al. 2007). However, intensive ranching almost immediately followed European contact and likely would have overwhelmed any effects of a reduced fire regime toward producing denser stands (Keeler-Wolf pers. comm.). If anything, it is likely that the valley vegetation was more restricted following European settlement. The oak woodlands and savannas are distinctive and stable features in the earliest maps and accounts, suggesting that these stands were well established before Spanish contact. Also, research shows that oak pollen remained steady in the periods leading up to European contact and was followed by a sharp decrease in levels in the early settlement period (Barbour et al. 2007). In South Valley, subregional variation shown in the historical sources is reflective of persistent controls such as soils, topography, and groundwater.

After surviving the first century of Euro-American presence relatively intact, oak trees found themselves in direct conflict with fruit and nut orchards in the last decades of the 19th century. Oaks competed for sunlight and space within the dense tree spacing of orchards, so settlers no longer desired the large spreading canopies of the oaks, at least not in their cultivated fields. For example, prunes were typically spaced 20 ft apart, at densities of 108 trees/ha (44 trees/ac; Shortridge [1896]1986), making a large oak a significant impediment. It was during these decades – 1870s-1910s – that widespread clearing took place as grain fields and pastureland were converted to orchards. The value of the trees for firewood was an additional but secondary benefit to large-scale clearing:

> The land is being cleared as opportunity offers. Stove wood commands such a good price, however, that the work is done at a profit. (Shortridge [1896]1986)

> The wood secured in clearing the land was quite an object, as live oak stove wood commanded $6.50 per cord, on the ground, and white oak $5.50. (Shortridge [1896]1986)

The conversion to orchards resulted in a dramatic loss of valley oaks during this period. By the beginning of the 20th century, in most of the former oak lands only scattered trees remained along orchard margins or as remnant stands within homesteads or small pastures (fig. 6.14). Fortunately, several large ranches, such as the Dunne Ranch in the Morgan Hill-San Martin area, were subdivided relatively late (Harrison ca. 1888, Sharma 2005), allowing them to be documented in landscape photography of the 1890s (see fig. 6.6). Given this rapid transition, it is not surprising that our estimate of relict valley oaks in 1939 is just 3% of our estimate for oaks present in the 1850s.

During the post-World War II era, the expansion of urban and suburban areas has further impacted oaks, although at an overall slower rate. These added pressures, plus the natural mortality of oaks, appear to have decreased the 1939 abundance by approximately 50%. With low recruitment rates of valley oaks and intensive local land use, few young oaks have grown up to replace those that have died. It also remains to be seen whether young oaks will be able to survive in many of highly urbanized or irrigated regions where relict oaks exist today. Today's remnant mature stands are largely confined to the valley margins, areas less desirable for agriculture and development.

Fine scale variation in spatial pattern

Our mapping attempts to capture the larger-scale patterns and likely distribution of oaks. Evidence of density variations and spacing patterns within savannas and woodlands created a structural complexity largely lost in the contemporary landscape that should be considered in restoration planning. Density distribution is scale dependent, such that small groupings or patches of denser "groves" fit within a broader savanna setting (Grossinger and Beller in press). Only the larger and better documented of these are likely shown in our map. This finer scale spatial distribution of trees is a potentially important factor when considering an overall density measurement. Factors contributing to local variations in density may include finer-scale physical conditions (e.g., alluvial ridges from historic channels, clay soil intrusions, groundwater levels), which we were not able to recognize in the mapping process. While the local variations in density are difficult to distinguish spatially from the historical record, illustrative quotes and historical images indicate that densities varied at many spatial scales. It is therefore important to consider local scale

Figure 6.14. In the 1935 image (A), orchards cover most of the formerly wooded Morgan Hill area. Remnant isolated trees are mostly associated with farm homesteads. In the far right background, and in the picture below, groups of oaks can be seen in remnant pasturelands. (A: Unknown 1935, courtesy of the Santa Clara Valley Water District; B: Unknown ca. 1923, courtesy of the Gilroy Museum)

oak distribution patterns as well as general landscape density variation in any restoration plan.

Current remnant distribution

Despite their relatively sparse coverage in terms of percent canopy cover, oaks have a comparatively dominating presence in the landscape. While their numbers have declined dramatically since the 1860s, the majestic oaks of the valley have been much appreciated through the history of south Santa Clara Valley and remain well-recognized today. Remnant trees of the former savannas and woodlands are carefully preserved in yards, parks, housing developments, and even warehouse districts (fig. 6.15). A few larger stands can still be found in agricultural fields (see fig. 6.17) and on parcels of undeveloped land on the valley margins.

Social and ecological value of remnant oaks

The oaks represent a significant part of the cultural and natural heritage of the region. Some modern land uses, including residential housing, pose less direct conflict with oaks than do orchards. While oak trees compete with orchard trees for sunlight, oaks can function as shade trees and aesthetic features within urban and residential settings. Valley oaks and live oaks are recognized as suitable street trees in a number of California cities (e.g., Los Angeles, Davis, Morgan Hill) and, because of their size, are particularly effective for medians, yards, and parks. The city of Morgan Hill has successfully planted live oaks in medians for a number of years because of the trees' tolerance of drought and high temperatures (Beale pers. comm.; fig. 6.16). The utility and cultural appeal of the oaks have been noted for over a century:

> [Gilroy] was formerly covered with groves of magnificent oak trees, many of which yet remain, giving to the locality a natural park like appearance… (Shortridge [1896]1986)

Ecologically, establishment of general historical oak land densities in parts of south Santa Clara Valley could have significant benefits. As trees mature, they would rapidly begin to provide habitat for a number of oak-associated species. Achieving close to historical densities may help support birds such as acorn woodpecker, which were historically common in the valley but are now rarely seen in valley floor areas lacking oaks (Rottenborn pers. comm.). Other species associated with valley oak ecosystems include white-breasted nuthatch and the oak titmouse. Benefits include available nesting and granary sites and linkages to adjacent hills and creeks, although some of these needs can be served by other tree species and/or artificial sites (Bousman 2007).

Valley oaks are also important to the Pacific pallid bat, a non-migratory species that typically occupies valley oak savanna habitat. This special status bat utilizes tree cavities and crevices created by the exfoliating bark of valley oaks and other large trees for day roosting habitat (Johnston et al. 2006). Pallid bats forage primarily on terrestrial invertebrates (e.g., Jerusalem crickets, centipedes, and darkling ground beetles) found among the fallen decaying branches under the oaks and in the surrounding grassland habitats (Johnston and Fenton 2001). Coastal pallid bat populations have continued to decline since the California Department of Fish and Game designated the species as a species of special concern in 1986 (Johnston and Stokes 2007). The restoration of valley oak lands and their ecosystem functions, along with stewardship of adjacent grassland and riparian habitats, could have significant benefits for the Pacific pallid bat by providing reliable roosts and foraging areas. As with oak-associated birds, planning for the preservation of old limbs and understory litter where possible, including leaves and fallen branches, will increase the effective habitat value.

Threats to remnant oaks

Despite general appreciation and some preservation, local oak populations continue to decline. Many trees persist as relicts of the past in agricultural fields, parking lots, or around manicured parks and homes, where natural recruitment of young trees is difficult, if not

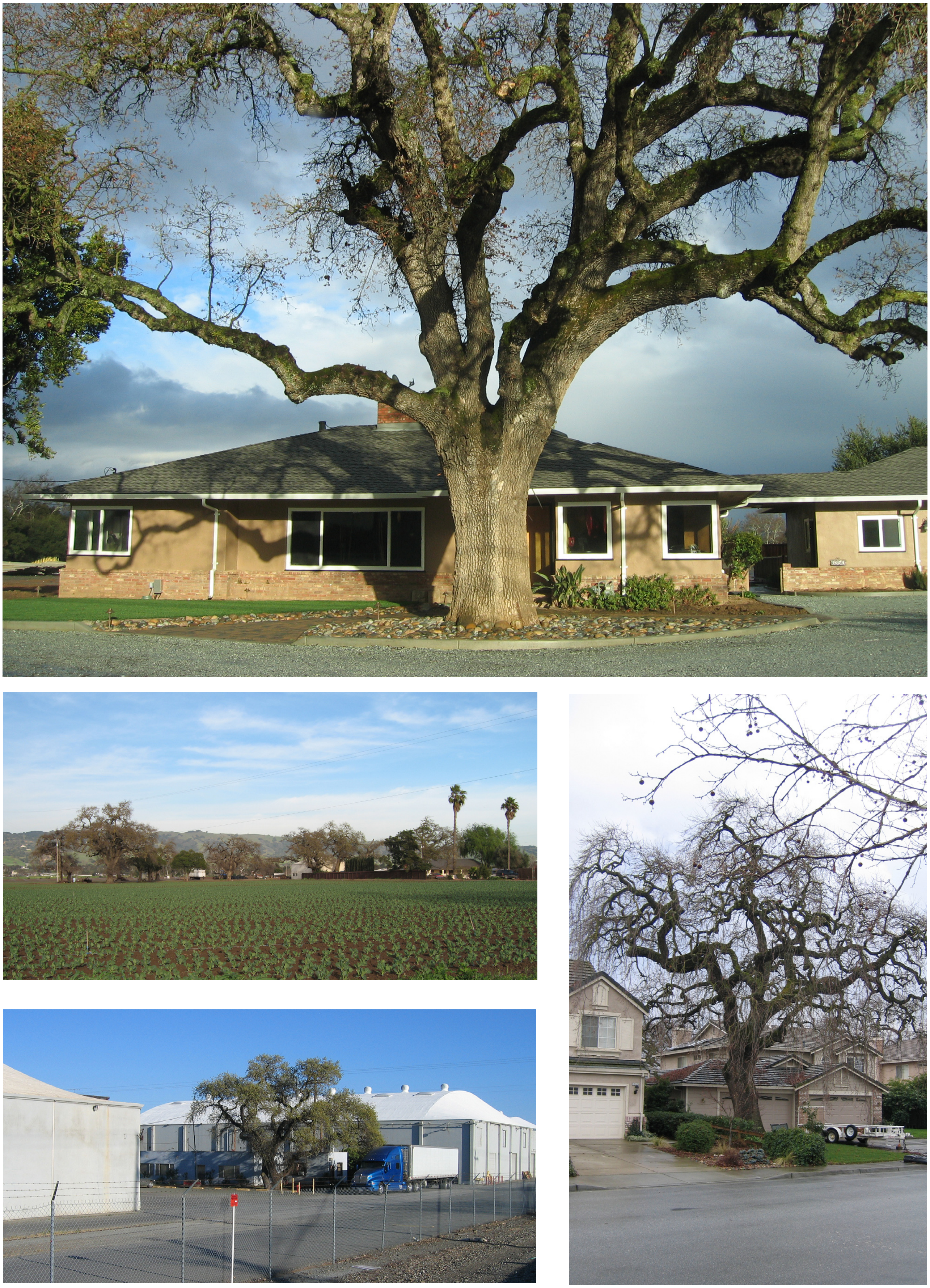


Figure 6.15. Valley oaks in the contemporary landscape.

Figure 6.16. Street medians in Morgan Hill are frequently planted with live oaks because of their ability to tolerate the harsh site conditions.

impossible. The trend towards more intensive summer irrigation in parts of the valley is likely to have negative effects on existing oak populations (fig 6.17). Development pressures also threaten existing trees. Without active stewardship to recruit new trees and conservation measures for those that exist, valley oaks are likely to disappear almost completely from the valley floor in coming decades as older trees die naturally or are removed.

Increasing oak density in the valley is important for maintaining the genetic viability of local valley oak populations. In addition to the direct loss of trees, declining genetic diversity and the possibility of reproductive isolation of the now highly scattered valley oak trees may limit successful seed production and the fitness of seedlings (Sork et al. 2002). Although relatively little is known of the regional and local genetic variation and its significance for adaptation, genetic diversity may prove to be a significant factor determining valley oak persistence into the future, and further efforts should be made to learn more. The average

Figure 6.17. This rare group of valley oak trees east of Gilroy has been preserved through a century or more of agricultural land use. However, there is no evidence of recruitment and more intensive irrigation practices may be deleterious to the continued persistence of existing trees.

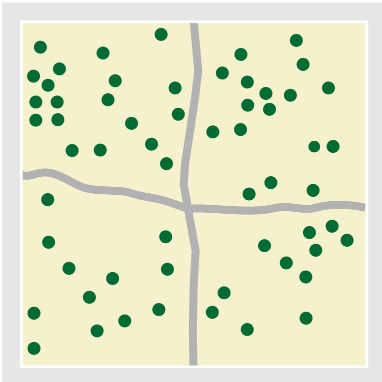
Figure 6.18. While these valley oaks in a Morgan Hill residential community have been well preserved and are fortunate to have some immediate neighbors, the lack of younger trees suggests that the future of the local valley oak population is uncertain.

spacing we observed of approximately 30 m (100 ft) from historical GLO data is consistent with healthy neighborhood sizes, given estimates of average pollen dispersal distance for the species of 65 m (210 ft; Sork et al. 2002). Reintegrating valley oaks within present-day south Santa Clara Valley could help support local populations in their resiliency to climate change and other environmental trends.

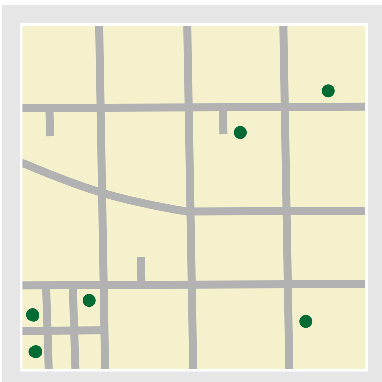
Opportunities for restoration and improved management

Despite their aesthetic and ecological significance, however, valley oaks occupy little of the actual land area. The density and distribution patterns associated with the native woodlands and savannas could be strategically re-introduced within the urban and suburban landscape, where oaks can serve as shade trees. Valley oaks are particularly effective in this function, casting a “high shade” in the summer and allowing light through in the winter months as they drop their leaves. Under suitable conditions, the trees grow rapidly, often reaching a height of 12 m (40 ft) in 25 years (Bornstein et al. 2006). Within agricultural areas, oaks can be placed along roadsides, fence lines, and occasionally within fields (fig. 6.15). Less dense savannas with canopy cover between 10% and 25% (approximately 3 to 6 trees per hectare/1.2 to 2.4 trees per acre) could be interspersed between denser woodlands or groves located in parks or areas of open land (fig. 6.18 and 6.19). Such densities could fit within many contemporary landscape patterns (Grossinger et al. 2007a). Although simply increasing tree density would not address broader goals of conservation and restoration of valley oak or mixed oak ecosystems, such efforts could provide for specific species' needs as well as help ensure oaks continued presence in the landscape. A program for reintroducing urban oak trees would involve consideration by arborists and ecologists of horticultural factors such as infrastructure constraints, appropriate watering regimes, and maintenance.

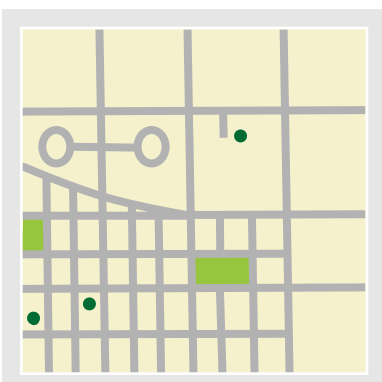
While oak patterns are greatly diminished in the present-day landscape, several significant oak groves still remain along the valley margins. These features, which have been preserved by local and private stewardship, would be worthy of long-term conservation attention as part of a regional plan to restore, not just individual trees, but also valley oak and mixed oak ecosystems. Remnant groves such as those along Highway 152 (near San Felipe Lake and along Pacheco Creek, see figs. 6.4C and 6.4D) represent the best remaining local examples of these habitat types. In contrast to oaks within an urban environment, such areas have added ecosystem benefits with the associated understory vegetation as well as other components such as riparian areas and connections to upland habitats. These features can serve as reference systems for regional restoration efforts and may also be reservoirs of local genetic diversity, with larger genetic neighborhoods and connection to upland populations. Facilitating oak seedling recruitment in these areas (e.g., through enclosures, grazing management) could aid their long-term persistence.



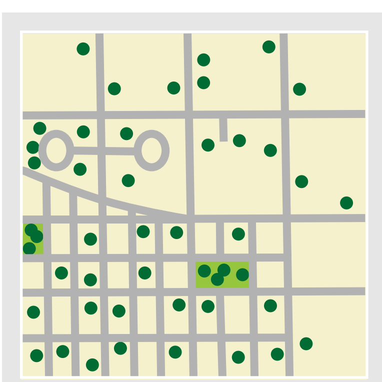
Circa 1800: Valley oaks occur in varying densities. Visitors identify dense groves, areas of "scattered" trees, and open "glades." Dirt roads go around trees and, for the most part, so do ranching and early agricultural activities.



Pre-World War II: Most of the valley floor has been cleared for orchards, but a few trees remain in pasturelands, along roadsides, and as a shade trees in town and on farms.



2008: Despite some preservation of existing trees, oak decline continues. Residential and commercial development expands into former orchards.



Conceptual restoration model: Similar densities and patterns to historical conditions could be achieved through strategic planting and stewardship along roads, in parks and yards, and other areas.

Figure 6.19. Oak savanna and woodland: conceptual model of landscape trajectory