The Dangermond Preserve:
INTEGRATING HISTORICAL CHANGE AND FUTURE PROJECTIONS TO GUIDE CONSERVATION

University of California, Santa Barbara

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Date

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Abstract

California's coastal habitats face increasing threats from climate change and development. The newly created Dangermond Preserve, located in western Santa Barbara County and managed by The Nature Conservancy, remains largely undeveloped but was managed as a cattle ranch for over a century. Our project aimed to inform conservation planning at the preserve by studying the property's history and anticipating its future. This combined approach is important because, given our increasing awareness of climate change, conservation that focuses on recreating past conditions or maintaining current conditions may not be ideal or possible. We had four objectives: 1) identify changes in area and structure of natural habitats over time, 2) predict plant distribution changes under future climate scenarios, 3) investigate the impact of ranching infrastructure on the threatened California red-legged frog distribution, and 4) prioritize conservation actions. An analysis of historic aerial imagery and vegetation maps showed that grassland area at the preserve has declined since the 1930s, whereas woodland and shrubland areas have increased. Ground surveys of coast live oak indicated, however, that oak recruitment has possibly declined over the same time period. Climate forecasting showed that some northern plant species and locally endemic species might decline at the preserve, while southern species that prefer warmer temperatures could expand. Finally, an analysis of streams and water features indicated that the preserve's red-legged frog population may be supported by ranching stock ponds. In light of these results, we made recommendations for conservation, monitoring, and future research priorities.

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EXECUTIVE SUMMARY

The Dangermond Preserve was established by our project client, The Nature Conservancy (TNC), in 2017. The preserve, located at Point Conception in western Santa Barbara County, was previously known as the Bixby Ranch and the Cojo-Jalama Ranch. Within its 24,000 acres, the preserve protects large swaths of important native California habitats and hundreds of plant and animal species.

The purpose of this project is to inform conservation planning at the Dangermond Preserve by studying the property's history and anticipating its future. Comparing the extent and structure of habitats today to those in the past is the first step in conservation planning — it can reveal if habitats have been degraded over time and if they may need restoration. However, an analysis of historical change is not sufficient on its own. Given our increasing awareness of climate change and species range shifts, conservation planning that focuses on recreating past conditions or maintaining current conditions may not be ideal or even possible. Therefore, our project integrates historical change with future projections in conservation prioritization.

Our first objective was to identify changes in the extent and structure of terrestrial habitat types on the property since the 1930s using historical ecology. Historical ecology is an interdisciplinary field that uses a variety of historical data sources to understand what ecosystems looked like in the past and how they have changed over time. At the Dangermond Preserve, we have three different sources of vegetation data going back to the 1930s: aerial photographs, vegetation maps, and vegetation field surveys. The photographs and maps allowed us to track broad habitat types (grassland, shrubland, and woodland), while the field surveys allowed us to track individual species.

We used aerial photographs from 1938, 1978, and 2012 and vegetation maps from 1931 and 2015 to assess changes in area of the habitat types and calculate transition rates between habitat types. We also used the vegetation maps to model the effects of topography and fire on the likelihood of habitat conversions between grassland and shrubland. We found that grassland area has decreased, while shrubland and woodland area have increased. Grassland to shrubland transition was common, and its likelihood increased with time since last fire. Shrubland to woodland transition was also common. We suspect that wildfire suppression may be a driver of this woody plant encroachment.

In 2018, we repeated historical field surveys from 1931 to assess changes in coast live oak woodland structure (density and diameter distribution) and changes in brush community composition at the preserve. Interestingly, though the aerial photographs and vegetation maps show that woodland area increased, the field surveys indicate that the density of trees within that area decreased, and there are fewer small trees today than there were in the 1930s. These results suggest an aging oak population with low recruitment. We suspect that cattle grazing and competition with exotic annual grasses for water may be contributing to low oak recruitment. We did not observe any obvious directional changes in brush species composition among or between plots across survey years.

Our second objective was to assess the impact of ranching infrastructure on the distribution of California red-legged frogs (CRLF) at the preserve. Now that the property is a nature preserve, some might advocate that TNC restore the land to a ‘natural’ state by removing anthropogenic disturbances to the greatest extent possible, including ranching infrastructure and cattle. However, the most ‘natural’ state of an ecosystem is not necessarily the most biodiverse. To illustrate this point, we investigated if stock ponds and cattle troughs could be expanding functional habitat for CRLF beyond the preserve’s stream network. First, we created a hydrological model that predicts which streams on the preserve have year-round flow, constituting appropriate habitat for CRLF. Then, we compared CRLF presence points from a recent survey to our hydrological model and to locations of stock ponds and cattle troughs. Some CRLF presence points are associated with stock ponds and troughs, even in the upper reaches of sub-watersheds where stream flow is unlikely. It seems that stock ponds and troughs may be increasing habitat connectivity for CRLF between sub-watersheds of the preserve.

Our third objective was to predict changes in the distribution of sensitive plant species under two climate warming scenarios: warm/wet and hot/dry. We used Maxent to model future climate suitability for four species at the preserve: two trees, coast live oak and tanoak, and two shrubs, lemonade berry and La Purisima manzanita. Maxent evaluates relationships between species presence data and environmental variables within a defined area, and then returns the most randomly distributed model of species presence probabilities that exists within those environmental constraints. Three environmental variables were used: maximum summer temperature, minimum winter temperature, and climatic water deficit. We trained the models under historic climate conditions and then projected them to the end of this century (2070-2099). We found that coast live oak is stable under the warm/wet scenario, with decreased suitability under the hot/dry scenario. Tanoak, a more northern tree species, is less suitable under the warm/wet scenario and excluded from the preserve under the hot/dry scenario. Lemonade berry, a southern shrub species, sees increased suitability under both climate projections. La Purisima manzanita, a local endemic shrub, has less suitability under the warm/wet scenario and is excluded from the preserve under the hot/dry scenario.

Lastly, our fourth objective was to integrate findings from our historical analyses and future projections to recommend conservation priorities and future research questions. Our major recommendations are as follows:

1. **Monitor native grasslands for evidence of shrub encroachment:** Grassland area has decreased since the 1930s, and grassland to shrubland conversion was common. We were unable to differentiate native grasses from exotic annual grasses in our photograph and map analyses, but we know that very little grassland at the preserve today is native. To conserve herbaceous biodiversity, TNC should monitor patches of native grassland, especially where they are surrounded by shrubland.

2. **Plant and protect coast live oak to improve recruitment:** The tree surveys suggest that there are fewer small trees on the preserve today than there were in the 1930s. This indicates that the oak population may be aging, and there may be a lack of oak recruitment. Further investigation is needed to confirm this, as our survey included only nine tree survey plots. If oak recruitment failure is confirmed, we recommend that TNC

prioritize oak acorn and seedling planting immediately, given the fact that rainfall in the first year after planting is a crucial factor in oak seedling survival, and climate change may bring more drought to the preserve in the future. Planted oak acorns and seedlings should be protected from cattle and wild herbivores including deer and rodents.

3. **Anticipate climate change and species range shifts:** Some sensitive species of conservation concern, like tanoak and La Purisima manzanita, may not have suitable climatic conditions at the preserve in the future. TNC should anticipate the potential loss of these species from the preserve and prioritize conservation of species that are more likely to thrive in the future. On the other hand, lemonade berry, a more southern shrub species, sees increased suitability at the preserve under both climate projections. Thus, TNC should consider how incoming southern plant species will affect the preserve.

4. **Conduct a detailed investigation into California red-legged frog habitat at the preserve, including the importance of stock ponds and cattle troughs:** We recommend Jalama Creek as a priority for CRLF habitat conservation because it is predicted to have year-round flow, and most CRLF observations were concentrated along this stream. With that said, our hydrological model is theoretical (based on topography), so we recommend that TNC install and monitor stream gauges for a more complete understanding of aquatic habitat. More research is needed to assess the importance of stock ponds and cattle troughs for CRLF habitat, but we recommend that TNC consider maintaining and regularly filling these artificial structures, even if cattle are permanently removed from the property.

5. **Incorporate adaptive management and use our analyses as a foundation for ongoing monitoring:** TNC will face a lot of uncertainty in their management of the Dangermond Preserve, especially in planning for climate change. Therefore, we recommend adaptive management — an iterative process of improving management by repeatedly learning from the outcomes of management decisions and adjusting them. Monitoring is at the core of adaptive management, and our findings in this report can serve as a foundation for ongoing monitoring at the preserve.

1. PROJECT OVERVIEW

1.1 Purpose and Objectives

The Dangermond Preserve was recently established by our project client, The Nature Conservancy (TNC), on 24,000 acres of land that had previously been managed as a cattle ranch. The purpose of this project is to inform conservation planning at the Dangermond Preserve by studying the property's history and anticipating its future.

A thorough understanding of the property's history can provide important context for TNC as they assess the present-day state of the preserve. By comparing the extent and structure of natural habitats today to those in the past, we investigate if any broad habitat types have been degraded and may need restoration. The property's historical land use is also relevant to wildlife conservation. Accordingly, we present a case study on the effects of ranching infrastructure on the distribution of California red-legged frogs at the preserve. Finally, effective conservation planning also requires the consideration and prediction of likely future conditions. Anticipating the effects of climate change on the distribution of species is necessary for setting realistic conservation goals. Therefore, we model the future habitat suitability for four sensitive plant species at the preserve under two climate warming scenarios.

Objectives

1. Identify trends in the extent and structure of terrestrial habitat types on the property since the 1930s.
2. Assess the impact of ranching infrastructure on the California red-legged frog distribution at the preserve.
3. Predict changes in the distribution of sensitive plant species under climate warming scenarios.
4. Recommend conservation priorities and future research questions.

1.2 Significance

The world's five Mediterranean climate regions, including California, are known for their high biodiversity and numbers of endemic species. However, compared to other climate regions, the Mediterranean regions are expected to undergo the biggest proportional decrease in biodiversity by the year 2100, largely due to land use change (Sala et al. 2000). In California, some of the worst threats to biodiversity are urban development and increasing population density (Underwood et al. 2009). Therefore, one important way to preserve biodiversity is to create large nature reserves that are protected from development.

The Dangermond Preserve offers The Nature Conservancy (TNC) a fantastic opportunity to protect biodiversity. The preserve is one of the last large, undeveloped coastal properties in southern California, and it has been referred to as the "last perfect place" (Herold and Harder 2007) and "the crown of the coast" (Borrell 2018). Within its 24,000 acres, the preserve protects large swaths of important native California habitats. With 6,000 acres of coast live oak woodland, the preserve stands out amidst large statewide loss of this habitat type — studies estimate that at least 3 million acres of California's oak woodlands have been lost due to rangeland and agricultural land conversion, as well as urban development (Tyler et al. 2006). Furthermore, studies of the structure of California oak woodlands have demonstrated a lack of oak recruitment in some locations, where small, young oaks are rare (Tyler et al. 2006). This is problematic because an oak population will decline if new oak establishment does not make up for adult mortality. Our project focuses on oak woodlands because, as the most abundant tree species at the Dangermond Preserve, coast live oak is a keystone species that provides habitat for many animals (WRA Environmental Consultants 2017). Oak woodlands also hold cultural value for Californians and are one of the state's most beautiful and iconic landscapes.

In addition to oak woodlands, the preserve has 10,000 acres of chaparral and scrub and 7,000 acres of grassland. As a result of this habitat diversity, the preserve supports hundreds of plant and animal species, including 13 that are threatened or endangered (WRA Environmental Consultants 2017). In fact, the preserve exists within one of 25 global biodiversity hotspots — areas with high endemic species richness that have experienced large losses of natural habitat (Myers et al. 2000).

In the face of climate change, protected areas like the Dangermond Preserve can be important tools for protecting biodiversity. By acting as 'stepping stones,' large tracts of natural habitat can allow species to track their preferred climate more easily (Hannah 2014). Furthermore, landscapes containing a high diversity of topography, geology, and soils, such as the Dangermond Preserve, are expected to remain biodiverse even as the climate changes (Hunter et al. 1988, Beier and Brost 2009).

For all of these reasons, the Dangermond Preserve represents an opportunity to be a model of conservation science and management for California. TNC and the Dangermonds intend to create one of the world's most studied and monitored nature preserves — a state-of-the-art research station focusing on how conservation strategies should be adapted in the face of a changing climate. Our project is one of the first steps, and we hope to inform future study questions for subsequent collaboration between TNC and researchers at UC Santa Barbara.

1.3 Introduction to the Jack and Laura Dangermond Preserve

Description

In December 2017, TNC acquired the 24,364-acre Cojo-Jalama Ranch using funds donated by Jack and Laura Dangermond, the co-founders of the geographic information system company Esri. The newly-named Dangermond Preserve is located at Point Conception in Santa Barbara County and contains over 8 miles of undeveloped coastline (Figure 1-1). The property is bordered by Vandenberg Air Force Base to the north and west, Hollister Ranch to the east, and the Point Conception State Marine Reserve offshore.

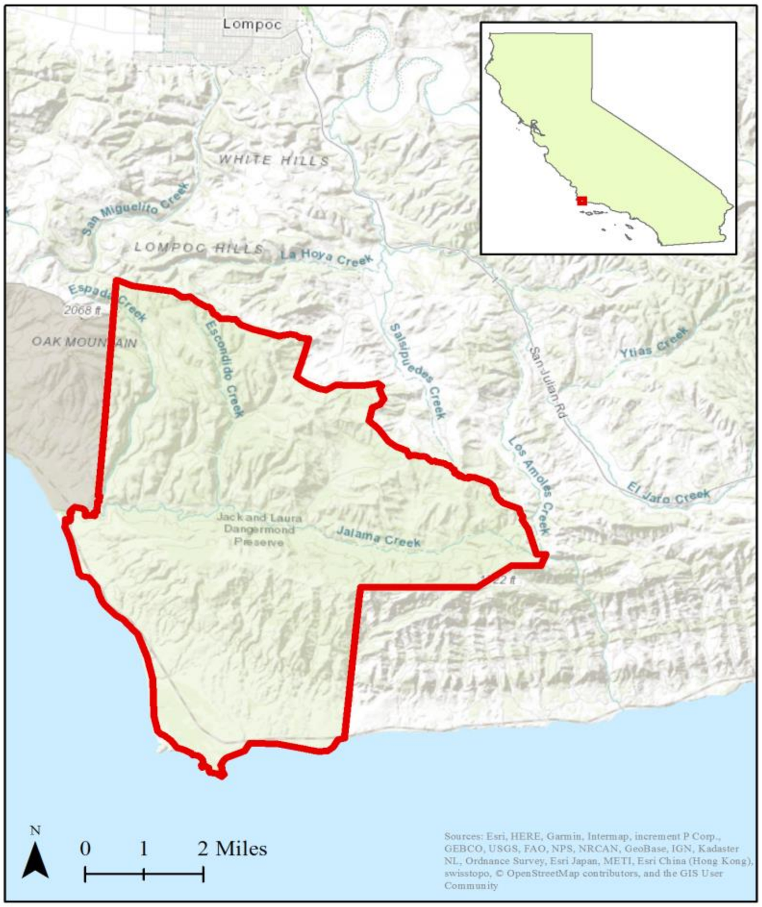

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Figure 1-1. The Jack and Laura Dangermond Preserve. The 24,000-acre preserve, outlined in red, is located at Point Conception in western Santa Barbara County.

The region exhibits a Mediterranean climate with mild, wet winters and warm, dry summers. Mean annual temperature is 59°F and mean annual precipitation is 17.98 inches (WRA Environmental Consultants 2017). Interestingly, the property is located at a climatic boundary between cooler, wetter northern conditions and warmer, drier southern conditions. These climatic conditions, combined with hilly topography ranging from sea level to 1,900 feet, support diverse plant and wildlife communities.

Over 600 plant and animal species occur on the property, and 58 of these have a special conservation status — including 13 that are threatened or endangered (WRA Environmental Consultants 2017). Fifty different natural vegetation communities exist within the preserve, of which 20 are considered sensitive by the California Department of Fish and Wildlife (WRA Environmental Consultants 2017). A comprehensive survey of biological resources at the preserve was conducted by WRA Environmental Consultants from 2012 to 2017.

Although many natural California habitats are now protected at the Dangermond Preserve, those habitats have been affected by both direct and indirect human influences in the past, including ranching activities, road and infrastructure development, fire, and climate change. Appropriate conservation planning at the preserve will be contingent upon an understanding of the dynamics and lasting effects of human influences on key habitats and species. Our project took the first steps in collecting, synthesizing, and analyzing the implications of these dynamics at the preserve.

Ranching

The Dangermond Preserve has a long history of cattle ranching and was formerly known as the Bixby Ranch or the Cojo-Jalama Ranch. Ranching on the property dates back to at least 1837, when the Mexican government granted the land to Anastacio Carillo, who once had 1,700 head of cattle (Palmer 1999). The land was later owned by Fred H. Bixby, who purchased Cojo Ranch in 1913 and the adjacent Jalama Ranch in the 1940s (PHR Associates 1990). The Bixby family used the land for crop agriculture as well as cattle ranching. TNC intends to keep cattle on the preserve for the foreseeable future. A detailed history of ranching and agriculture on the property is provided in Appendix 1, including cattle herd estimates from the 1940s to 2018 (Figure A1-1).

Development

In 2007, the Bixby family sold the ranch to The Baupost Group, a Boston-based investment firm. These owners built dozens of roads and wells without permits, prompting intervention by the California Coastal Commission. Now that TNC owns the property, they have inherited obligations to restore 200 acres of oak and 300 acres of beach and grassland (Hamm 2017). In preparation for oak restoration, TNC is collecting acorns and growing 3,000 seedlings at the ranch nursery (Borrell 2018).

Fire

Fire regimes in the region have been anthropogenically influenced for centuries. The Chumash people who lived there centuries ago intentionally set fires to improve cherry and elderberry harvests (Hardwick 2015), and records show several prescribed burns on the property from 1981 to 2000 (California Department of Forestry and Fire Protection 2017). In addition to controlled burns, there were three recorded wildfires at the preserve from 1981 to 2004 (Figure 1-2). Wildfire suppression was likely practiced during the Bixby years in order to protect crops and livestock, while prescribed burns were likely used as a tool to clear shrublands and increase grasslands. In 1945, the California State Legislature authorized range improvement activities through the California Division of Forestry, which included permits to burn in order to improve rangelands. This led to the founding of the Santa Barbara County Range Improvement Association in 1955, whose goal was to use controlled burning to reduce the threat of wildfire while also limiting brush growth (Callahan et al. n.d.). We have yet to find permits that confirm such burns were conducted at the Cojo-Jalama Ranch.

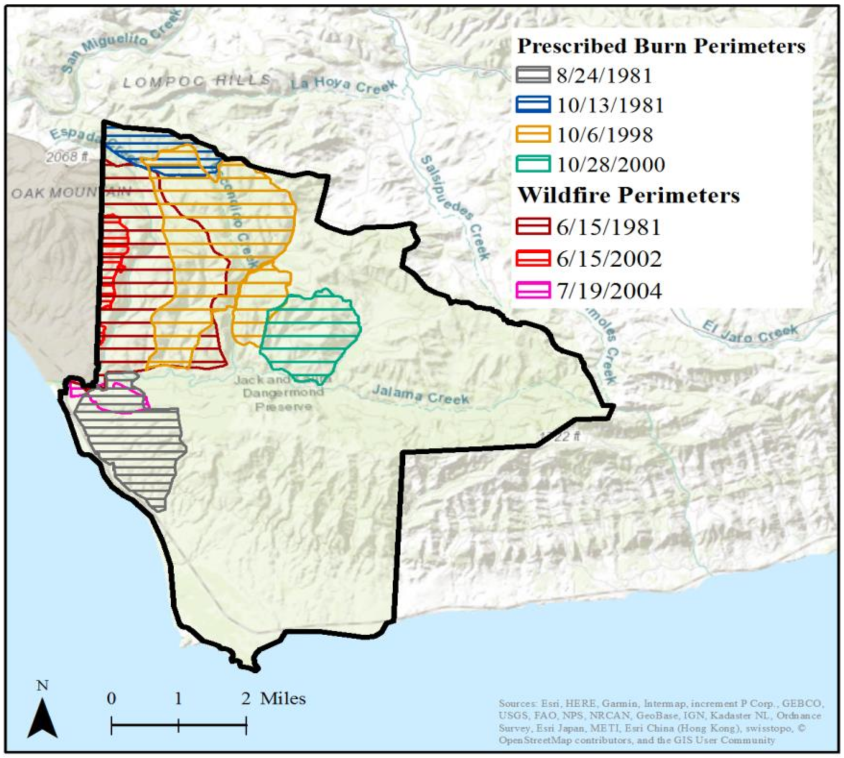

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Figure 1-2. Prescribed burns and wildfires at the Dangermond Preserve. Fire perimeters, clipped to the preserve boundary, are from the Fire and Resource Assessment Program (FRAP) (California Department of Forestry and Fire Protection 2017).

Climate Change

High resolution paleoclimate reconstructions from the Santa Barbara channel show a climate history marked by droughts and extreme precipitation effects (Hendy et al. 2015). The past 30 years of rainfall data also shows frequent wet and dry years, but rarely 'average' years (Figure 1-3). Paleoclimate reconstructions indicate that the 2012-2014 drought in California was the most severe in the last 1,200 years (Griffin and Anchukaitis 2014).

Climate change is predicted to bring warmer temperatures (Figure 1-4) and, thus, more severe drought. These more extreme conditions will stress the existing vegetation at the Dangermond Preserve. For example, oak seedling establishment is an important process that occurs during windows of ample precipitation and mild temperatures, and a study done in southern California mountains predicts that oak establishment windows will decrease by 50-95% by the end of this century and move to higher elevations and north-facing slopes (Davis et al. 2016). Climate change represents a major threat to oak woodland systems, but other plants at the preserve will be stressed as well, and shifting species ranges are inevitable.

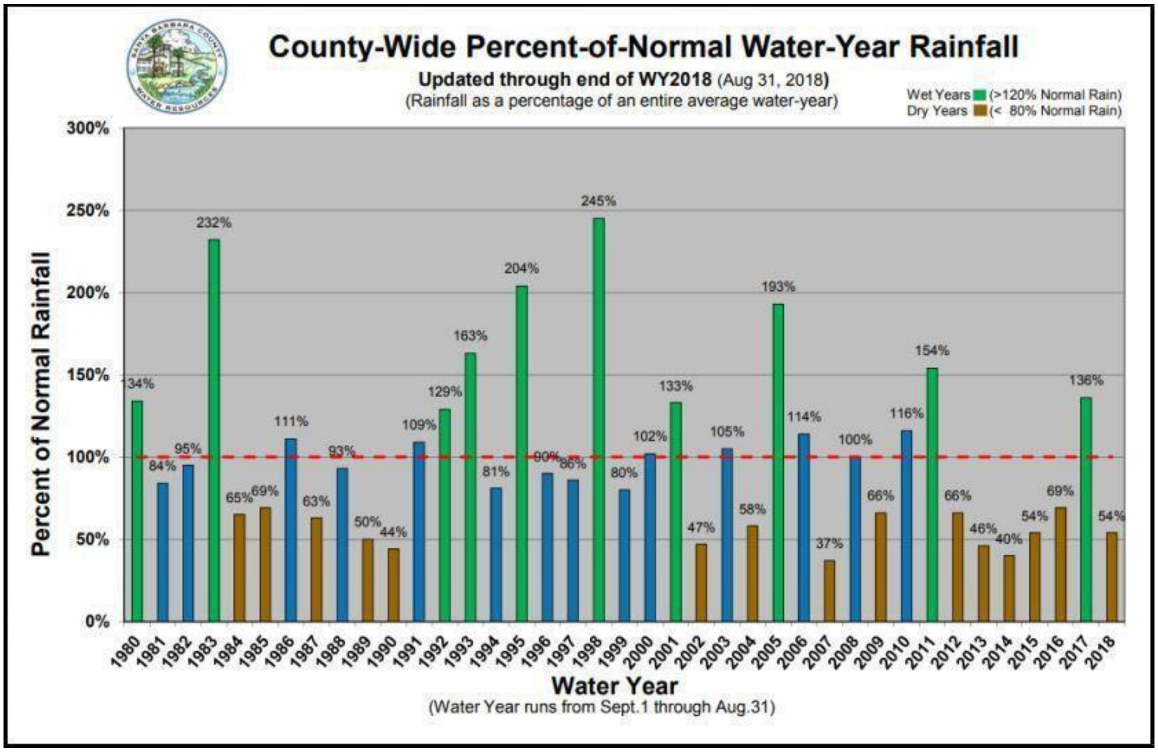


Figure 1-3. Annual precipitation in Santa Barbara County since 1980 as percentage of average water-year. Source: Santa Barbara County.

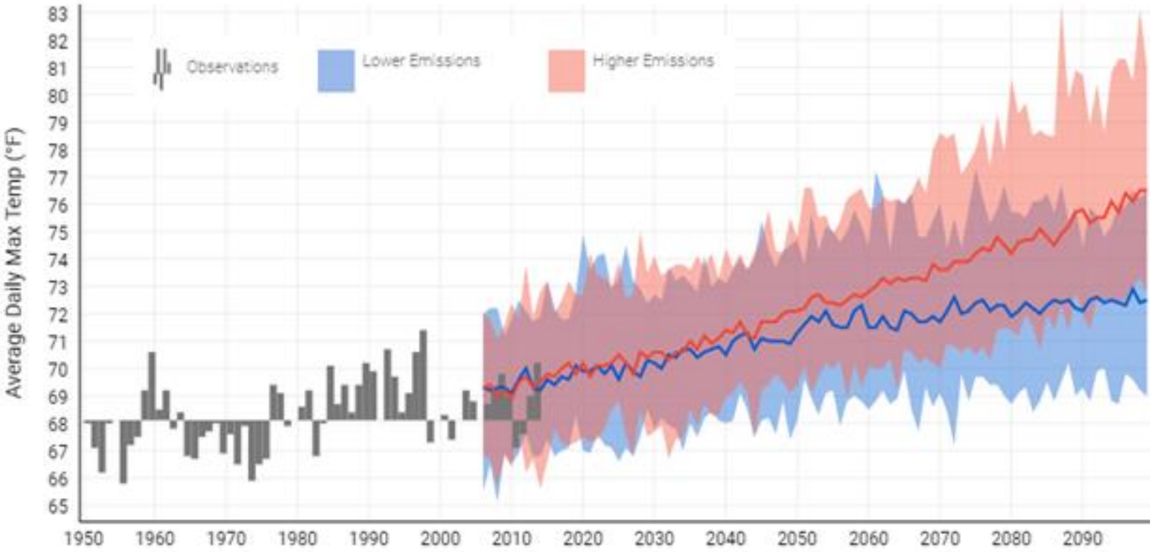


Figure 1-4. Historic and modeled future maximum daily temperature for Santa Barbara County. Lower emissions pathway is an ensemble of 19 RCP 4.5 models. Higher emissions pathway is an ensemble of 20 RCP 8.5 models. Source. U.S. Climate Resilience Toolkit 2018.

1.5 Report Overview

The next four chapters address our four project objectives. In Chapter 2, we use a variety of historical data sources to identify trends in the extent and structure of terrestrial habitat types on the property since the 1930s. In Chapter 3, we investigate the historical legacy of ranching infrastructure on a threatened species, the California red-legged frog. In Chapter 4, we predict changes in the distribution of four sensitive plant species under two different future climate warming scenarios. In each of these chapters, we describe the data and methods associated with each objective, followed by an interpretation of the results. Finally, in chapter 5, we summarize our findings to make management recommendations and suggest future research questions for TNC.

2. HISTORICAL ECOLOGY:
HABITAT CHANGE OVER 80 YEARS

2.1 Introduction

In order for TNC to effectively plan for conservation and restoration at the Dangermond Preserve, they need to understand how the property's vegetation communities have changed over time. In this regard, historical ecology can be used to inform restoration targets and conservation priorities. Historical ecology is a broad interdisciplinary field that uses historical data to understand the form and function of ecosystems in the past (Safran et al. 2017). Data sources can include historical biological surveys (Kelly et al. 2005, McIntyre et al. 2015), aerial photography (Whipple et al. 2011, Allen 1989), landscape photography (Swenson et al. 2012, Zier and Baker 2006), dendrochronology (Swetnam et al. 1999), maps, diaries (Whipple et al. 2011), and interviews (Swenson et al. 2012).

Burgi and Gimmi (2007) identify three objectives of historical ecology: preserving culture, understanding ecosystem patterns and processes, and informing restoration targets. When selecting restoration targets, knowing what the landscape looked like in the past is not sufficient; we need to know if and how ecosystem processes have changed in order to determine if a return to a previous state is achievable or desirable (Safford et al. 2012). This necessity is exemplified in the case of TNC's riparian restoration of the Cosumnes River (Swenson et al. 2012). In an effort to restore agricultural land to valley oak forest, TNC hand-planted oak acorns and seedlings. This was cost-intensive and ultimately ineffective. A breakthrough occurred when they found a photograph from 1985 that showed an oak forest growing in a location where the river had breached its levee. From interviews and further study of historical information, they realized that flooding had deposited sand in the riparian zone, which promoted recruitment of valley oaks. This information prompted TNC to switch from a species-based restoration approach to a process-based approach, which involved intentional levee breaches.

As the Cosumnes River case demonstrates, historical data can change the way we perceive current ecosystems and our strategies for managing them. Another example concerns a historical study of tree invasion in New Mexico. In this case, aerial photography demonstrated that an ancient, native grassland had been recently invaded by ponderosa pine and Douglas-fir trees. Using other historical information, including dendrochronology, climate data, and fire and land use history, the invasion was attributed to livestock grazing and fire suppression (Allen 1989). Prior to this historical study, land managers perceived the region as a forest with an unusually dense understory, rather than the invaded grassland it truly was. This discovery prompted grassland restoration efforts by the National Park Service in accordance with their mandate to preserve natural communities (Swetnam et al. 1999).

A thorough understanding of the property's history can provide important context for TNC as they assess the present-day state of the preserve. By comparing the extent and structure of natural habitats today to those in the past, we can determine if any broad habitat types have been degraded and may need restoration. Our project uses three forms of historical data to track vegetation change at the Dangermond Preserve since the 1930s:

1. Aerial photographs from 1938, 1978, and 2012 to investigate which habitat types (woodland, shrubland, and grassland) have become more or less common at the preserve.
2. Vegetation maps from 1931 and 2015 to investigate:
    a. Which habitat types (woodland, shrubland, and grassland) have increased or decreased in extent at the preserve
    b. The effects of topography and fire on the likelihood of habitat type transitions
3. Repeat on-the-ground vegetation surveys from 1931 to assess:
    a. Changes in brush community composition
    b. Changes in coast live oak woodland structure (density, basal area, and diameter distribution)

Time series of aerial photographs can be used to track changes in the extent of vegetation (Callaway and Davis 1993). High quality aerial and satellite imagery has become easier and cheaper to produce (Morgan et al. 2010), and the photographs are often freely and publicly available to download. It should be noted, however, that aerial photography analyses have limitations and biases in interpretation. For example, early camera lenses can distort or shift the image from its true spatial position (Swetnam et al. 1999). Furthermore, vegetation identification to the species level is often challenging, especially with black and white images. Nonetheless, many aerial photographs of the preserve were taken since the 1920s, and they provide a long spatiotemporal record of the landscape.

Vegetation maps and field surveys are also useful sources of historical data to track vegetation change over time — particularly in California, where over a third of the state's vegetation was mapped and surveyed during the 1930s. These data, known as the Wieslander Vegetation Type Mapping (VTM) project, offer a comprehensive, detailed look at California's vegetation in the early twentieth century. The VTM vegetation maps display dominant vegetation types classified by overstory canopy dominance as seen from observation points located on peaks and ridges (Wieslander 1935a, Wieslander 1935b). The VTM field surveys identified tree species composition and size data, percent cover of dominant herb and shrub species, and site characteristics including exposure, slope, year of last burn, and soil type within vegetation plots (Kelly et al. 2005, Wieslander 1935a). The VTM data were digitized by scientists at UC Berkeley and are available online (Kelly et al. 2005). Some studies have resurveyed VTM plots (Dolanc et al. 2013) as we have done in this project, while others have compared VTM data to modern surveys like the Forest Inventory Analysis (McIntyre et al. 2015, Fellows and Goulden 2008).

2.2 Aerial Photographs

We used a time series of aerial photographs to investigate how the amount of grassland, woodland, and shrubland habitat has changed on the Dangermond Preserve since the 1930s. In this analysis, we also investigated transition rates between these habitat types.

2.2.1 Methods

Selection of Sample Years and Preparation of Aerial Photographs

We used aerial photographs from 1938, 1978, and 2012 (Figure 2-1). These years were selected because they have enough aerial photographs to cover the entire preserve, and 1938 is the earliest such year. Eleven photographs were used for 1938, five photographs were used for 1978, and ten photographs were used for 2012. The 1938 and 1978 photographs were obtained from the FrameFinder website, publicly available from the UC Santa Barbara's Special Collections Library (Fairchild Aerial Surveys 1938, Pacific Aerial Surveys 1978). The 1938 images are black and white, and they were taken around January 1938 by Fairchild Aerial Surveys under contract to Santa Barbara County. The 1978 images are in false color/color infrared, and they were taken around January 1978 by Pacific Aerial Surveys under contract to the USDA. The 2012 images were obtained from the EarthExplorer website, publicly available from the USGS (USDA-FSA-APFO 2012). These four-band color images were taken in May 2012 for the USDA National Agriculture Imagery Program (NAIP).

The 2012 photographs had previously been georeferenced and orthorectified; they were encoded with a NAD83 datum and projected in Universal Transverse Mercator (UTM) Zone 10. The 1938 and 1978 photographs were plain images and required georeferencing, the process of assigning real-world coordinates to a raster image. We used the Georeferencing toolbar in ArcGIS version 10.6.1. Image correction (orthorectification) was not performed on these images since we did not have sufficient time or technical experience to do so.

Georeferencing uses ground control points (GCPs) to align the unreferenced images with known locations in the 2012 images. Features that have not changed over the selected time period are the best candidates for GCPs — typically anthropogenic structures are most useful, though topographic features can also be used. For the Dangermond Preserve, GCPs included buildings, intersections between roads and/or creeks, and ridgelines. A total of 10 to 69 GCPs were chosen for each image; a higher number of GCPs were selected for images that lacked human-built features. Georeferencing was completed with a second-order transformation to minimize root mean square (RMS) error of actual GCP location. The second-order transformation shifts, bends, and/or curves the raster data (Esri 2018), and it can compensate for original image capture issues (such as camera tilt). After second-order transformation, the largest RMS error associated with any of the 11 images from 1938 is 78 meters, and the largest RMS error associated with the five images from 1978 was 64 meters.

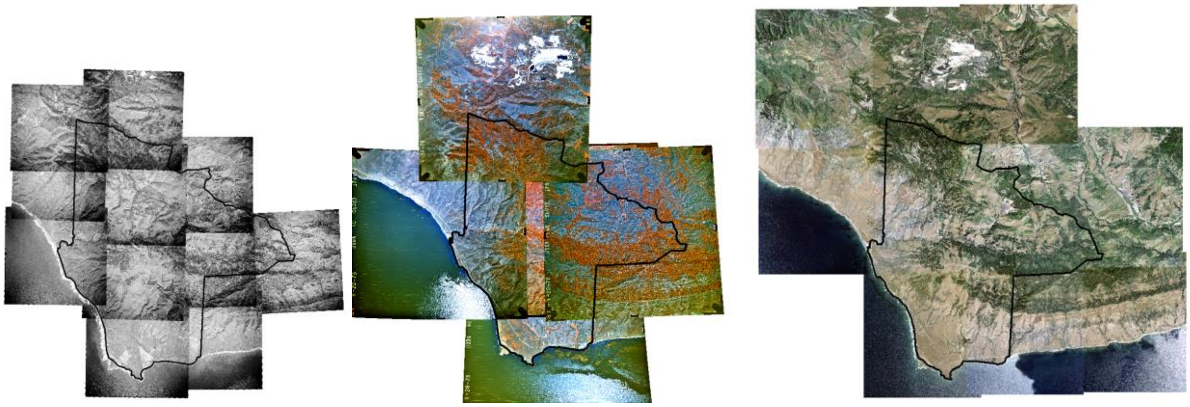


Figure 2-1. Aerial photographs used to identify habitat types at the Dangermond Preserve. Left**:** 11 photographs from 1938, taken by Fairchild Aerial Surveys. Middle**:** 5 photographs from 1978, taken by Pacific Aerial Surveys. Right**:** 10 photographs from 2012, taken for the USDA National Agriculture Imagery Program.

Experimental Design

In order to quantify change in major habitat types at the preserve between 1938 and 2012, we first identified habitat types at random sample locations within the preserve. We used the same sample points in all three sets of photos because our goal was to compare habitat types at paired locations between years. However, due to georeferencing error, images from different years do not always perfectly align. This means that the habitat type identified at a sample point can change from 1938 to 2012 simply because the 1938 image is inaccurately placed. To account for this issue, we created a buffer zone around each random sample point.

To buffer our sample points, we created five by five grids centered on each point and identified habitat type within each grid cell. The dominant habitat type at a sample point is the type that occupies the greatest proportion of the grid. The distance from a sample point, centered in the grid, to the side of its grid is 80 meters. This size was chosen because the largest RMS error from georeferencing was 78 meters. Therefore, the grids are 160 by 160 meters, and each cell within a grid is 32 by 32 meters (Figure 2-2).

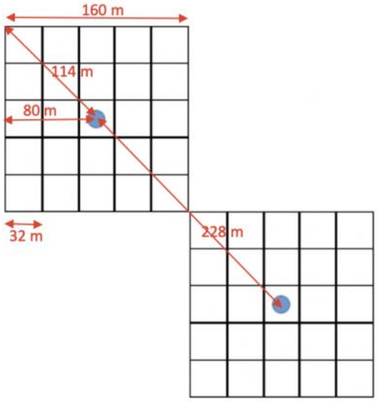
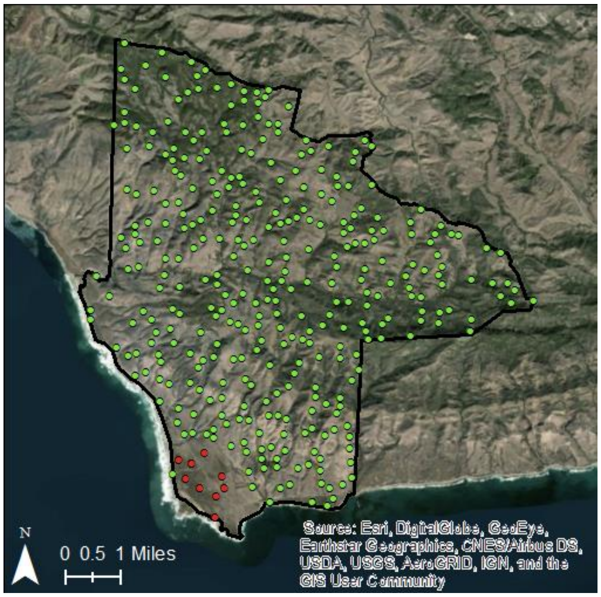


Figure 2-2. Diagram of sample grids centered on randomly generated sample points. The distance from a sample point to a vertex of its grid is 114 meters, so the minimum allowable distance between sample points was set to 226 meters to avoid grid overlap.

Sample points were generated using the Create Random Points tool in ArcGIS version 10.6.1. Sample grids were drawn around these points using a toolbox created by Dilts and Hornsby (2016). In order to have independent random samples, we did not allow grids to overlap. Given that the distance from the sample point to a vertex of its grid is 114 meters (Figure 2-2), we set the minimum allowed distance between sample points to 226 meters. In restricting overlap, only 352 points were generated. Later, 12 points were excluded, leaving 340 total sample points. Three points were excluded because they were on the beach. Nine points, all concentrated in the southwest corner of the preserve (Figure 2-3), were excluded because they appear to have ice plant, a common invasive species at the preserve. We feel that our methods for identifying vegetation do not adequately address ice plant because 1) it is much easier to see ice plant in the 2012 color photographs, and 2) as a succulent, ice plant does not fall neatly in our three vegetation categories (see below).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-3. Random sample points at the Dangermond Preserve for aerial photograph analysis. Green points (n = 340) were retained for the analysis. Red points (n = 9) were excluded because they have ice plant in 2012, but it is difficult to ascertain if ice plant was present in 1938.

Habitat Type Identification

We identified habitat to three main categories: woodland, shrubland, and grassland. Where the image showed bare ground, rocky cliffs, roads, or train tracks, we identified cover as “other.” Woodland areas are dominated by coast live oak (*Quercus agrifolia*), as it is the most prevalent tree at the preserve (WRA Environmental Consultants 2017). Shrubland includes both scrub and chaparral because we could not reliably distinguish the two in our visual interpretation of the photographs. Table A2-1 (Appendix 2) illustrates the guidelines used for classification and provides example photographs.

At every sample grid and for each year, we identified one dominant (largest proportion of cover) habitat type in each of the 25 grid cells. The dominant habitat type at a sample point is the type that occupies the greatest proportion of the grid cells surrounding that point. For example, if nine cells are woodland, four cells are shrubland, and 12 cells are grassland, the dominant type at that point is grassland. Where multiple habitat types were equally dominant, we recorded the dominant type as "tie."

Data Analysis

We used a Pearson's chi-squared test to determine if the relative frequencies of dominant habitat types changed from 1938 to 1978 and from 1978 to 2012. The "other" and "tie" categories were left out of this test because they do not satisfy the chi-squared test assumption that the expected values are greater than 5. Results of the chi-squared test were evaluated at significance level α=0.05.

We calculated transition rates between habitat types using paired data of a point's dominant habitat in an earlier year and its dominant habitat in a later year. For example, the transition rate from habitat type X in 1938 to habitat type Y in 1978 is calculated as:

$$\text{Transition (\%)} = 100 \times \frac{\text{Number of X-dominated points in 1938 that became Y-dominated in 1978}}{\text{Total number of points that were X-dominated in 1938}}$$

2.2.2 Results

The proportion of woodland-, shrubland-, and grassland-dominated sample points has changed significantly from 1938 to 2012 ($\chi^2(2) = 22.88$, $p < 0.001$). This result is driven largely by a decrease in grassland-dominated points and an increase in shrubland-dominated points (Figure 2-4). In 2012, these three habitat types are more evenly represented than in 1938, when grassland was the most common. Most of this change happened from 1978 to 2012 ($\chi^2(2) = 9.75$, $p < 0.01$), whereas the proportions of habitat types did not change significantly from 1938 to 1978 ($\chi^2(2) = 3.60$, $p = 0.17$).

The largest transition rates are observed between grassland and shrubland. Interestingly, grassland to shrubland transitions occurred more often from 1978 to 2012 than they did from 1938 to 1978 (Figure 2-5). For shrubland to grassland transitions, we see the opposite trend. Shrubland to grassland transitions became less common after 1978 (Figure 2-5). Tables A2-2 and A2-3 (Appendix 2) provide transition rates between all observed combinations of dominant habitat type.

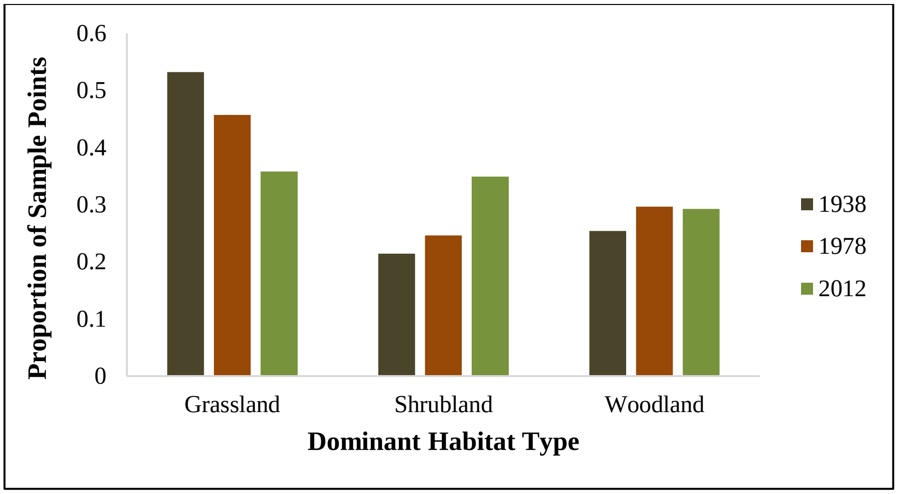


Figure 2-4. Proportion of sample points dominated by grassland, shrubland, and woodland in 1938, 1978, and 2012. Sample points dominated by "other" or "tie" were excluded, leaving 327 points in 1938, 317 points in 1978, and 335 points in 2012.

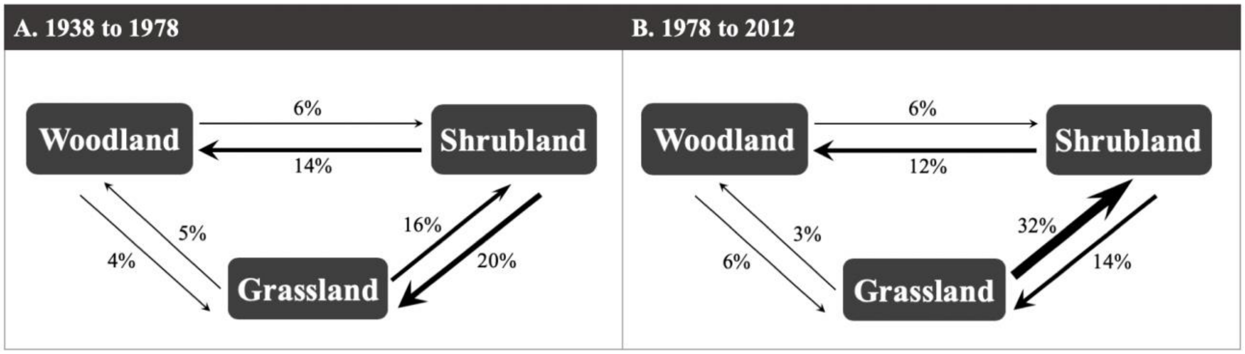


Figure 2-5. Transition rates between woodland, shrubland, and grassland from 1938 to 1978 (panel A) and 1978 to 2012 (panel B) according to aerial photographs. The transition rate between any two habitat types, X and Y, was calculated as the percentage of sample points that converted from X-type to Y-type, divided by the starting number of X-type points.

2.2.3 Limitations

A major limitation of our analysis is that we did not orthorectify the 1938 aerial photographs. Orthorectification is a process that improves georeferencing accuracy by adjusting the image for camera tilt, lens distortion, and topographic relief. This likely contributed to our georeferencing error (the largest root mean square error was 78 meters). Although we incorporated the grids around our sample points to act as a buffer for georeferencing error, it is still possible that the dominant habitat type identified at a given sample point changed between two years because the images do not spatially align well, rather than because the vegetation at that location has truly changed. With that said, this is only a limitation for our habitat type transition calculations, which required that sample points be paired across the two years. Our results demonstrating that the proportion of grassland-dominated sample points has decreased, while shrubland and woodland points have increased, were not calculated by pairing the data — therefore, this result is robust to georeferencing error.

2.3 Vegetation Maps

To confirm and support the habitat type trends we observed in the aerial photograph analysis, we used vegetation maps to investigate changes in habitat type extents. Our map analysis has two components:

1. Calculate the overall gain or loss in area of habitat types on the preserve since the 1930s.
2. Stack historical and modern vegetation maps to identify where habitats were gained or lost and what habitats they transitioned to, and model the effects of fire and topography on the probability of habitat type transition.

2.3.1 Methods

Map Selection and Habitat Classification

Two maps were used to identify trends in the extent and locations of habitat types at the preserve since the 1930s: a historic Wieslander VTM vegetation map from 1931 (Kelly et al. 2016) and a modern-day Fire and Resource Assessment Program (FRAP) vegetation map from 2015 (California Department of Forestry and Fire Protection 2015). The VTM map has eight vegetation types within the preserve boundary, while the FRAP map has 13. To facilitate comparison with the results of our aerial photograph analysis, we aggregated these mapped vegetation types to three broad categories: woodland, shrubland, and grassland (Tables 2-1 and 2-2). Four habitat types (barren, urban, lacustrine, and deciduous orchard) were omitted from our map analyses as they did not correspond to any of these categories.

Table 2-1. Vegetation types occurring at the Dangermond Preserve in 1931 according to the Wieslander VTM map (Wieslander et al. 1933, Kelly et al. 2016). Wildlife Habitat Relationship (WHR) vegetation types were aggregated to three main habitat types of interest: grassland, shrubland, and woodland.

Grassland	Shrubland	Woodland
Annual grassland	Coastal scrub	Coast oak woodland
Cropland	Chamise-redshank chaparral	Montane hardwood
	Mixed chaparral	Valley foothill riparian

Table 2-2. Vegetation types occurring at the Dangermond Preserve in 2015 according the FRAP map (California Department of Forestry and Fire Protection 2015). Wildlife Habitat Relationship (WHR) vegetation types were aggregated to three main habitat types of interest: grassland, shrubland, and woodland.

Grassland	Shrubland	Woodland
Annual grassland	Coastal scrub	Coast oak woodland
Pasture	Mixed chaparral	Montane hardwood
		Montane hardwood conifer
		Closed-cone pine cypress
		Valley foothill riparian

Map Preparation

Before comparing the two maps, we had to improve the alignment of the recently digitized VTM map. When recording the locations of habitat types, the VTM surveyors used a different base map (NAD 27, Clarke's spheroid of 1866) than the FRAP map. To account for this, we re-projected both maps in NAD 83 Teale Albers and shifted the VTM base map 45 meters east and 150 meters north to improve its alignment with the coast line and roads, using the locations of road intersections on the VTM base map and a modern road map as a guide. Based on 31 ground control points at road intersections, the root mean square (RMS) error prior to shifting was 172 meters, and the RMS error after shifting was 57 meters, indicating a better fit. Then, the VTM vegetation polygon map was shifted in the same way as the VTM base map. Map alignment methods are described in detail in Appendix 3. ArcGIS Pro version 2.2 was used for map alignment and manipulation.

Change in Area of Habitat Types

We converted the vegetation maps to raster format at 30-meter resolution. As described earlier, mapped vegetation types were aggregated into three broad habitat types: woodland, shrubland, and grassland (Tables 2-1 and 2-2). We calculated the total area of each habitat type on each map and then calculated the percent change in area from 1931 to 2015.

Habitat Type Transitions

We assessed habitat type transitions by stacking the 1931 VTM map and the 2015 FRAP map to see where habitat types changed or stayed the same over time. For this analysis, we converted the vegetation maps to raster format at 60-meter resolution to account for the 57-meter RMS error in VTM map alignment. The transition rate between any two habitat types, X-type and Y-type, was calculated as the percentage of raster cells that converted from X-type in 1931 to Y-type in 2015 divided by the total number of X-type raster cells in 1931.

We modeled the probability of grassland to coastal sage scrub and coastal sage scrub to grassland transitions using binomial logistic regression in R version 1.0153. We trained our regression models on areas of the preserve that we know have burned (California Department of Forestry and Fire Protection 2017). For these areas, we included time since last fire as a predictor variable, in addition to slope, elevation, and aspect. Then, we ran another regression trained on the burned areas but excluding year since last burn as a predictor. This regression allows us to make inferences about the effects of slope, elevation, and aspect on transition in other areas of the preserve if a fire is to occur. We chose to focus on grassland-shrubland transitions in this preliminary analysis because they are among the most common transitions we observed, but we do recommend that this process be repeated for the other habitat type transitions.

2.3.2 Results

Change in Area of Habitat Types

According to the vegetation maps, grassland area decreased by 26%, shrubland area increased by 32%, and woodland area increased by 16% from 1931 to 2015 (Table 2-3, Figure 2-6). These trends are consistent with the results of our aerial photograph analysis (see section 2.2.2).

Table 2-3. Percent change in area of woodland, shrubland, and grassland habitats from 1931 to 2015. Area was calculated using the 1931 VTM vegetation map (Wieslander 1931, Kelly et al. 2016) and the 2015 FRAP vegetation map (California Department of Forestry and Fire Protection 2015) at 30-meter resolution.

Habitat Type	1931 VTM Area (ha)	2015 FRAP Area (ha)	Percent Change
Woodland	2594	3017	+ 16%
Shrubland	2388	3163	+ 32%
Grassland	4963	3687	- 26%

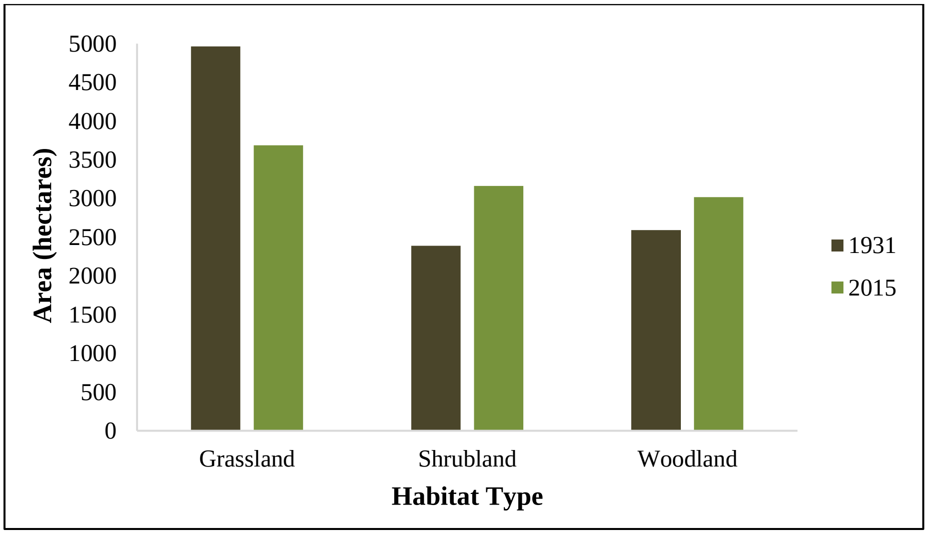


Figure 2-6. Area of grassland, shrubland, and woodland at the Dangermond Preserve in 1931 and 2015. Area was calculated using the 1931 VTM vegetation map (Wieslander 1931, Kelly et al. 2016) and the 2015 FRAP vegetation map (California Department of Forestry and Fire Protection 2015) at 30-meter resolution.

Habitat Type Transitions

Areas where each habitat type was gained or lost from 1931 to 2015 are displayed in Figure 2-7. Grassland to shrubland and shrubland to woodland transitions were the most common (Figure 2-8 and Table A3-1, Appendix 3) consistent with the results of our aerial photograph analysis (see section 2.2.2).

With more time since last burn, grassland to coastal sage scrub transitions become more likely to occur, and coastal sage scrub to grassland transitions also become more likely to occur, according to the binomial logistic regression models (Table A3-3, Appendix 3). In areas that have burned, grassland to coastal sage scrub transitions are most likely to occur on north-facing slopes at higher elevations, while coastal sage scrub to grassland transitions are most likely to occur on south-facing slopes at lower elevations (Figure 2-9). Coastal sage scrub to grassland transitions are also less likely to occur on steep slopes, while grassland to coastal sage scrub transitions are not significantly predicted by slope.

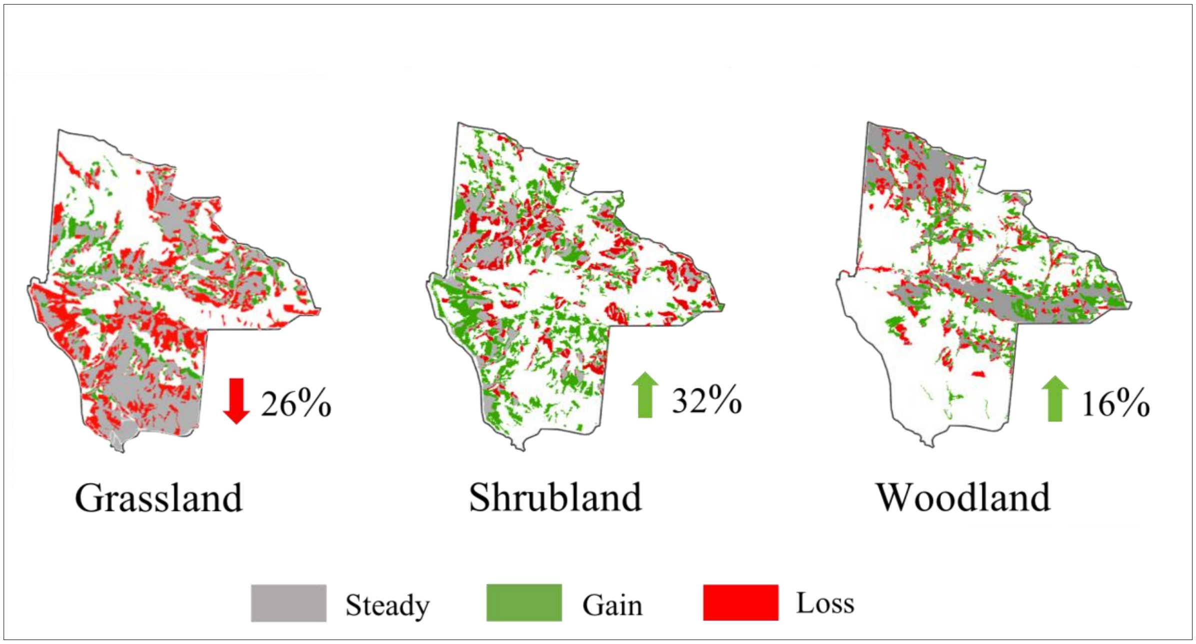


Figure 2-7. Locations where grassland, shrubland, and woodland habitat have been lost (red), gained (green), or remained steady (grey) from 1931 to 2015. We stacked the 1931 VTM vegetation map (Wieslander 1931, Kelly et al. 2016) and the 2015 FRAP vegetation map (California Department of Forestry and Fire Protection 2015) to generate this output. Percent change was calculated as the net gain or loss of habitat.

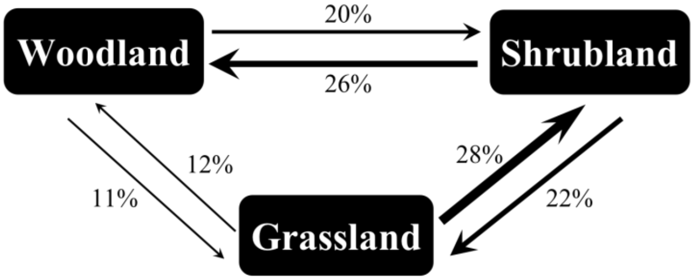


Figure 2-8. Transition rates between woodland, shrubland, and grassland from 1931 to 2015 according to vegetation maps. The transition rate between any two habitat types, X and Y, was calculated as the percentage of raster cells that converted from X-type in 1931 to Y-type in 2015 divided by the total number of X-type raster cells in 1931. We used the 1931 VTM map (Wieslander 1931, Kelly et al. 2016) and the 2015 FRAP map (California Department of Forestry and Fire Protection 2015) at 60-meter resolution.

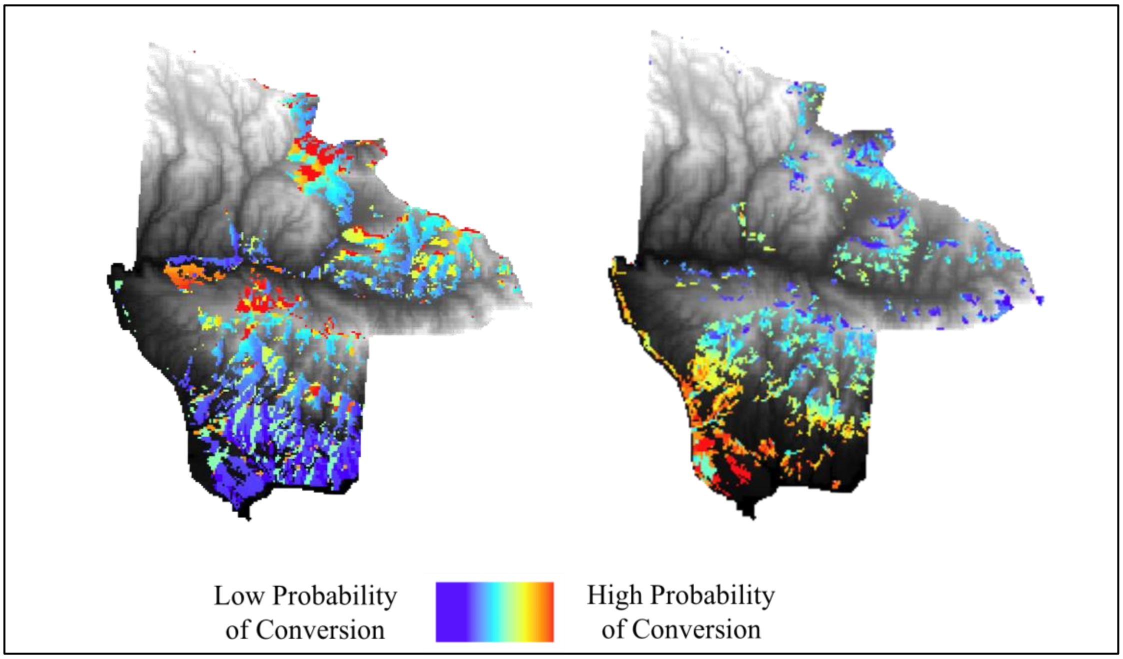


Figure 2-9. Probability of post-fire vegetation transition based on binomial logistic regression. Grassland to coastal sage scrub conversion (left) and coastal sage scrub to grassland conversion (right). Elevation is scaled from black (low) to white (high). The regression models predict the effects of elevation, aspect, and slope on conversion and were trained on areas of the preserve that we know have burned since the 1980s.

2.3.3 Limitations

According to Thorne et al. (2008), three sources of error were introduced when the historic VTM maps were digitized. These sources of error include cross-walking VTM vegetation types to modern classifications, registering the vegetation polygon tiles to the historic base map, and the resulting alignment of the historic base map with modern topography. The largest potential source of error for this analysis is the alignment of the historic VTM map with the modern-day FRAP map, which has a different topographic base map. As mentioned in section 2.3.1, we took multiple steps to improve the alignment of the VTM map (discussed in detail in Appendix 3). Spatial alignment of these maps is necessary to accurately identify areas at the preserve where each habitat type has been gained or lost since 1931 and to determine transition rates between vegetation types. However, spatial alignment is not necessary to calculate the overall area of each habitat type on each map and the percent change in area since 1931, which was the primary goal of the map analysis.

Another potential limitation is that the VTM maps, which were drawn by hand, may have mapped vegetation at a lower resolution than the FRAP map, which uses satellite imagery. Map error of this kind can be reduced by comparing the maps at higher resolution. Therefore, we calculated the area of each habitat type at 30-, 60-, and 160-meter resolutions and had nearly identical results for all three scenarios (Appendix 3). Thus, we chose to present the habitat area results calculated at 30-meter resolution.

2.4 Repeat Vegetation Survey

In the previous two sections, we demonstrated that grassland area has decreased since the 1930s, while shrubland and woodland area have increased. The photographs and maps allow us to investigate how these habitat types have changed in extent, but they do not provide information about the composition and structure of these habitats. In this section, we repeat historical field surveys to assess changes in brush community richness and diversity, as well as changes in the density and size distribution of coast live oak woodlands.

2.4.1 Methods

Plot Relocation

We relocated and resampled 17 historic VTM plots within the Dangermond Preserve. Plot relocation is difficult because their precise location and boundaries were never recorded (Dolanc et al. 2013). Instead, the plots were only generally marked on USGS quadrangle maps with a numbered stamp (Figure A4-4, Appendix 4). To address this issue, some researchers using the same dataset have taken multiple replicates within the general vicinity of a historical plot (Minnich et al. 1995). Following Dolanc et al. (2013), and with guidance from our faculty advisor Kelly Caylor, we chose to conduct only one resample plot for each of the 17 historic plots. In order to place our plot markers as close to the presumed original location as possible, we used historically recorded plot attributes to locate possible site locations ahead of time in ArcGIS Online. Given the large amount of uncertainty in location of the historic plots, we sited our plots within a 247-meter error buffer around a calculated GPS point for each VTM plot, similar to Kelly et al. (2005). In plot relocation, we attempted to match the 1931 recorded elevation (+/-50m), slope (+/-10%), and aspect (+/-45°). We also compared aerial images from 1938 to modern aerial images of the plot location to ensure that we were correctly placing plots in areas having the same general vegetation type as the original data. Once a plot was located, we entered the location coordinates in Collector for ArcGIS and placed orange rebar stakes at the beginning and end of the survey area. Full details on plot relocation can be found in Appendix 4.

Brush and Ground Cover Plots

At each location, we set up brush and ground cover plots using the same methods as the historical VTM survey (Appendix 4). These plots were 33 feet wide by 132 feet long and were subdivided into 100 squares (with square lengths of 6.6 feet). For each square within the plot, we recorded the dominant brush species if vegetation covered 50% or more of the square. If vegetation covered less than 50% of the square, we recorded the dominant ground cover (litter, rock, barren ground, or tree trunk). We calculated percent cover for each brush species as the percentage of squares within the plot where that species was dominant.

Species richness and diversity were calculated for all brush and ground cover plots. Richness was calculated as the number of different brush species observed in a plot. Simpson's Diversity Index was chosen as a metric for diversity because it takes species evenness into account (relative spread of abundances within a sample). The equation used for Simpson's Diversity is:

$$DI = 1 - \frac{\Sigma\, n(n\text{-}1)}{N(N\text{-}1)}$$

where n is the number of individuals of a particular species, and N is the total number of individuals of all species. Simpson's Diversity Index can range from 0 and 1, with higher values indicating a more evenly distributed sample of species abundance. Due to the low sample size and non-normal data distribution, Wilcoxon signed-rank tests were used to compare brush richness and diversity between 1931 and 2018. The Wilcoxon signed-rank test is comparable to the parametric paired t-test, where two samples of repeated observations are compared across time.

For species richness and diversity estimates, calculations for percent ground cover (including bare ground, litter, and trunk) were not included, since these measurements did not represent any brush species of interest. However, these three ground cover categories were included in the community clustering analysis (discussed below), to better identify trends or patterns in the actual plot vegetation composition.

A hierarchical clustering analysis was performed to identify patterns in brush community composition in each plot. We chose the average linkage method (Borcard et al. 2011) to determine the average degree of similarity among plots, based on the relative percent cover of each species observed. Total percent cover of each species in each plot was used as a standardization metric in the clustering analysis. We calculated the total percent cover per species as:

$$\textit{Total \% Cover (Species A in Plot X)} = \frac{\textit{Relative \% Cover in Plot X}}{\textit{Total \% Cover of all Species (1700)}}$$

where the relative percent cover equals the percentage of species cover in a given plot (from 0-100%), and total cover across all 17 plots for each year adds to 1700%.

All statistical analyses were completed in R, Version 3.5.1. Packages used included: "tidyverse" (used for data manipulation and plotting), "vegan" (used for diversity calculations and clustering distance calculations), "ggdendro" (used to graph hierarchical clustering), and function "hclust" within R base packages (for additional hierarchical clustering calculations).

Tree Tally Plots

Where trees were present, a tree tally plot was placed around the brush and ground cover plot. Tree tally plots were 66 feet wide by 132 feet long (Appendix 4). Trees with a diameter at breast height (DBH) of at least 4 inches were counted and measured. The 1931 surveyors binned trees into three DBH classes: 4-11 inches, 12-23 inches, and 24-35 inches. The exact DBH of trees in 1931 are not available. Our 2018 surveys recorded the exact DBH and height for trees over 4 inches tall in VTM plots, but for ease of comparison with the historical survey, we have also binned our data.

Combining all trees recorded across the 17 plots, we used a Pearson's chi-squared test to determine if the proportions of small (4-11" DBH), medium (12-23"), and large (24-35") trees have changed from 1931 to 2018. Results of the chi-squared test were evaluated at significance level α = 0.05. We also calculated the basal area for each individual tree (m^2) and plot (m^2/hectare) using the DBH measurements. We calculated the plot's tree density as the number of trees per hectare. Then we calculated the average tree density across these plots.

2.4.2 Results

Brush and Ground Cover Plots

A total of 28 brush species were observed over both years. Twenty-five species were recorded in 1931, and 23 species were recorded in 2018 (Table A5-1, Appendix 5). Species recorded in 1931 but not 2018 include *Polystichum spp.* (sword fern), *Prunus ilicifolia* (holly-leafed cherry), *Pteris aquilina lanuginosa* (bory hook), *Ribes malvaceum* (chaparral currant), and *Ribes sanguineum* (red flowering currant). Species observed in 2018 but not 1931 include *Lonicera hispidula* var. *californica* (pink honeysuckle), *Carpobrotus edulis* (ice plant), and *Salvia spathacea* (hummingbird sage). All of these species, with the exception of *Pteris aquilina lanuginosa*, were also observed during a recent comprehensive biological survey of the preserve (WRA Environmental Consultants 2017). These species appear to be rarer or more localized to specific habitat types that were not found in the VTM surveys. For example, the sword fern species (*Polystichum*) was observed by WRA in tanoak forest, and tanoaks were not found in any of our plots. It may be possible that tanoak (and/or the sword fern) was more common in 1931, or the surveyor's original plot was not aligned with our repeated survey. Of note, ice plant is currently widespread along the southwest coast of the preserve and in the bordering Point Conception lighthouse property. Based on the lack of ice plant noted in the previous survey, the invasion of ice plant may have occurred after 1931.

Some of the species names have been updated over time, but the older classifications were used for analysis to keep consistency with 1931 identifications. Species with outdated nomenclature are outlined in Table A5-1 (Appendix 5). Additionally, we changed *Arctostaphylos andersonii* (Aan) to *Arctostaphylos species* (ArXX) in the original 1931 survey data because we believe that the VTM surveyors misidentified this species. According to Calflora, the *andersonii* species, also known as Santa Cruz manzanita, is mainly found around the San Francisco and Monterey Bays and Santa Cruz Mountains (Calflora 2018). Its southern range is too far north of Point Conception.

The average plot species richness for 1931 and 2018 were 4.12 and 4.76, respectively (Figure A5-1, Appendix 5). Both years had a median richness of 4, and there was no significant difference in medians from 1931 to 2018 for individual plots (Wilcoxon signed-rank, V = 43, p = 0.57). The average plot diversity for 1931 and 2018 were both approximately 0.44. The median diversity for 1931 and 2018 were 0.57 and 0.43, respectively; however, there was no significant difference in medians for individual plots (Wilcoxon signed-rank, V = 69, p = 0.98).

Hierarchical clustering of all VTM plots did not indicate any clear patterns in ground cover composition over time (Figure A5-2, Appendix 5). Plots with similar cover (in species and/or ground cover concentrations) are located near each other in the branches; conversely, dissimilar plots are located further away from each other in the clustering tree. If vegetation composition changed over time, then plots from 1931 would be more similar to each other than to their corresponding plots from 2018. If vegetation composition did not change over time, then we would expect a plot in 1931 to be most similar to that same plot in 2018. We did not observe either of these patterns on a consistent basis in our clustering analysis. Therefore, there are no obvious directional changes in species composition among or between plots across years.

Tree Tally Plots

Of the 17 VTM plots, six plots contained trees in 1931 and nine plots contained trees in 2018. All trees were coast live oak (*Quercus agrifolia*). The total number of trees across all plots was 221 in 1931 and 107 in 2018 (Figure 2-10). The proportion of small-diameter trees decreased from 1931 to 2018, while the proportion of medium and large diameter trees increased ($\chi^2(2) = 48.07$, $p < 0.001$) (Figure 2-11). Average basal area across all plots showed a slight decline from 25 m^2/hectare in 1931 to 22 m^2/hectare in 2018. Average plot tree density declined by 50% from 1931 to 2018 (Table 2-4).

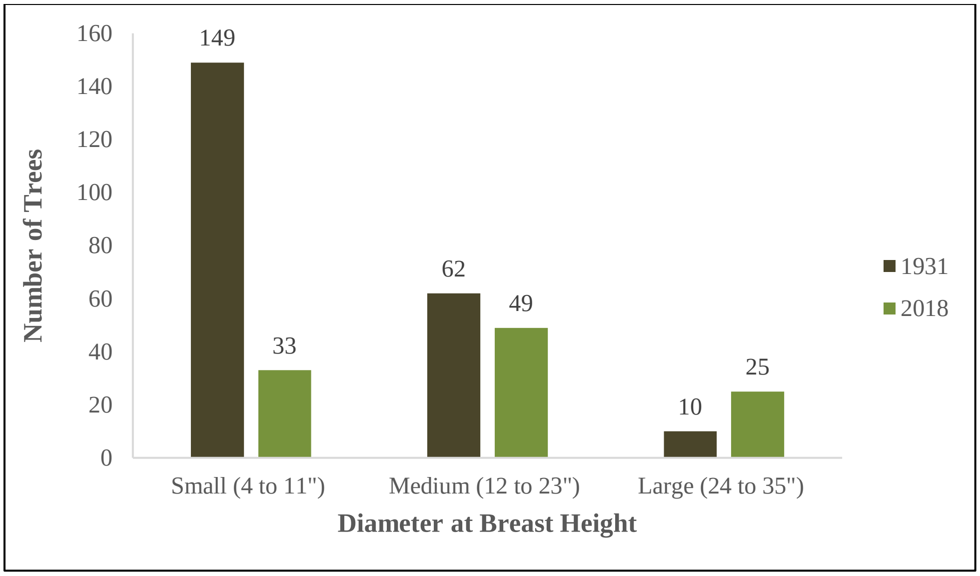


Figure 2-10. Number of coast live oak trees recorded across 17 VTM tree tally plots in 1931 and 2018. Trees are binned in three diameter at breast height (DBH) categories.

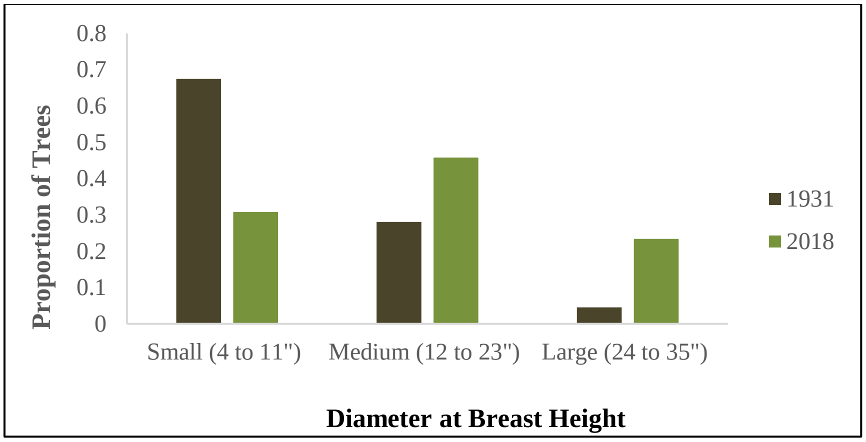


Figure 2-11. Proportion of surveyed coast live oak trees having small (4-11”), medium (12-23”), and large (24-35”) diameter at breast height (DBH) in 1931 and 2018.

Table 2-4. Adult tree density and basal area at the Dangermond Preserve compared to other coast live oak woodland studies in California.

Study	Maximum Tree Density (per hectare)	Mean Tree Density (per hectare)	Maximum Basal Area (m^2/hectare)	Mean Basal Area (m^2)
Dangermond Preserve 1931	725	303	60	25
Dangermond Preserve 2018	381	146	40	22
Pillsbury et al. 1991	1750	750	56	35
Davis et al. 2016	N/A	20-50	59	9-23

2.4.3 Limitations

A major limitation to our study is that the original VTM plot locations were not accurately recorded. The VTM surveyors marked their plot locations with a large stamp on old topographic maps and did not leave plot markers in the field (Figure A4-4, Appendix 4). This introduces error in plot relocation. Keeley (2004) argues that this is more problematic than most VTM resurvey efforts acknowledge. He measured shrub densities in plots spaced 30 meters apart and found that — even over this short distance — shrub density varied a lot. Plot relocation error can be addressed by sampling multiple plots in the vicinity of the historic plot or by resurveying a large number of sites (Keeley 2004). Ultimately, we chose to conduct only one re-sample plot for each historic VTM plot at the preserve — and there were only 17. With that said, other researchers disagree that this is a major problem. For example, Dolanc et al. (2013) resampled VTM plots in the Sierra Nevada and noted that, although it was likely their plots fell outside of the exact footprint of the original VTM plot, they were confident that the new plots were located within the same forest stand. Following Dolanc et al.’s methods, and with guidance from our faculty advisor Kelly Caylor, we chose to conduct a single, well-placed resample plot for historic plot. Details on our efforts to accurately relocate plots are provided in Appendix 4. We cannot know how accurate our resample locations are, but following the reasoning of Dolanc et al., we are confident they are in the same stand of vegetation as the original.

2.5 Discussion

Grassland Lost, Shrubland and Woodland Gained

Our comparison of historical and modern aerial photographs and vegetation maps revealed interesting trends in the relative frequencies of different habitat types over time. Since the 1930s, grassland extent has decreased, while shrubland and woodland extent have increased on the property. Two of the most frequent habitat type transitions were from grassland to shrubland and shrubland to woodland. These trends are consistent with other studies in Santa Barbara County. On the Burton Mesa, just north of the preserve, chaparral is considered a seral stage in succession to oak woodlands (Davis and Dozier 1990, Davis et al. 1988). In nearby Gaviota State Park, a comparison of aerial photos from 1947 and 1989 revealed that grassland to coastal sage scrub and coastal sage scrub to oak woodland transitions were the most common (in plots that had not burned since 1929) (Callaway and Davis 1993). Our results are also consistent with the global phenomenon of "woody plant encroachment" — an increase in woody vegetation in grassland and savanna rangelands over the past two centuries, observed in North and South America, Australia, and southern Africa (Archer et al. 2017). Woody plant encroachment is a concern for ranch managers because it decreases available forage for livestock. In response, aggressive brush management techniques, including prescribed burning or mechanically clearing woody plants, started to become popular in the 1940s (Archer et al. 2017). Therefore, the woody plant encroachment at the preserve, particularly after 1978, appears to suggest that the previous ranch managers did not aggressively remove woody plants or prevent their spread. Indeed, there are only four records of prescribed burns on the property, and they were all concentrated in the northwest region (Figure 1-2) (California Department of Forestry and Fire Protection 2017).

Wildfire suppression and declines in grazing pressure are potential drivers of woody plant encroachment. A study of Gaviota State Park in Santa Barbara County found that unburned plots with livestock excluded had higher transitions from grassland to coastal sage scrub and from coastal sage scrub to oak woodland compared to burned plots and to plots with livestock (Callaway and Davis 1993). In the same study, burned plots with livestock excluded had a much higher transition rate from coastal sage scrub to grassland than unburned plots. Our regression results align with this study when considering grassland to coastal sage scrub transition, as we found that the likelihood of this transition increased with time since last fire. However, our regression results seem to contradict this study when considering scrub to grassland transition. In contrast to Callaway and Davis (1993), we found that the likelihood of scrub to grassland transition also increased with time since last fire. Our regressions were a preliminary analysis, and further steps should incorporate other aspects of fire such as fire interval. Some scrub and chaparral species are fire-adapted but become prone to habitat type conversion when fire interval is very short (Lippitt et al. 2013).

Wildfire suppression is also a likely driver of the increase in woodland extent that we observed. Research on the Burton Mesa in Santa Barbara County demonstrated that coast live oak canopy cover increases with time since last fire (Davis et al. 1988). Furthermore, pollen records indicate that the amount of oak pollen in the Santa Barbara region remained stable from the 1400s to 1870, when it began to steadily increase, suggesting an increase in oak cover and/or density (Mensing 1998). Mensing (1998) speculates that this is a result of a changing fire regime, because the shift coincides with European settlement in Santa Barbara. Prior to Spanish colonization, the native Chumash frequently set fires to improve their harvests; today, fire protection and suppression are common practices.

Compared to fire effects, evidence for grazing effects on woody plant encroachment is more mixed. At the Hastings Reservation in central coastal California, scientists observed succession in a field that had historically been used for pasture and growing barley. Thirty years after protecting the field from grazing and stopping agriculture, there was very minimal woody plant encroachment (White 1966). A review by Archer et al. (2017) found that, over 149 papers, grazing was not a significant predictor of changes in shrub cover over time. Some studies suggest that grazing promotes shrub expansion by clearing grasses and dispersing shrub seeds, while other studies demonstrate that grazing can inhibit shrub expansion (Naito and Cairns 2011). The latter result is more likely when the shrub is palatable to the grazers (Naito and Cairns 2011, Archer et al. 2017).

Given the similarity of our findings to other studies in the Santa Barbara region, we suspect that wildfire suppression and declines in grazing pressure are likely contributing to the trends we have observed at the Dangermond Preserve since the 1930s, though we lack sufficient data on fire and grazing to confirm our hypothesis. The temporal record of cattle stocking numbers is sparse (Appendix 1), and we also lack spatial data for where grazing was concentrated on the property. The fire record is incomplete, with the earliest recorded fire on the property occurring in 1981 (Figure 1-2), but we believe it is reasonable to assume that wildfire suppression was practiced by the previous ranch managers in order to protect livestock and infrastructure.

In light of the decrease in grassland cover at the preserve over the past 80 years, we recommend that TNC monitor grasslands on the property. Grasslands provide crucial habitat for many bird species at the preserve, including the burrowing owl, which is a U.S. Fish and Wildlife Service bird of conservation concern (WRA Environmental Consultants 2017). Maintaining sufficient, healthy grassland habitat at the preserve is important given the fact that grassland birds have declined more rapidly than any other birds in North America over the past 30 years (Archer et al. 2017). Although grassland is still one of the most abundant habitat types at the preserve — covering 7,000 acres — very little of that is native grassland. A recent biological survey of the preserve found only 172 acres of native purple needlegrass patches, and they were commonly intergraded with coastal sage scrub (WRA Environmental Consultants 2017). Given the high frequency of grassland to shrubland conversion we have observed, TNC should closely monitor these patches of native grassland to preserve herbaceous biodiversity. Monitoring should be focused on patches of native grassland that are surrounded by shrubland (we have identified these areas in Appendix 3, Figure A3-3). Post- fire vegetation transition models additionally indicate there is an increased probability of conversion from grassland to coastal sage scrub at high elevations and on north-facing slopes — in the event of fire, it is recommended that restoration efforts focus on these areas as they are at greater risk of converting to shrubland. Furthermore, given that TNC intends to keep cattle on the preserve, they should investigate prescription grazing as a means to facilitate the growth of native grasses. Research has demonstrated that early spring cattle grazing can increase purple needlegrass growth by reducing shading and competition from exotic annual grasses (George et al. 2013).

Signs of Oak Recruitment Failure

Although the aerial photographs and vegetation maps indicate that oak woodland cover has increased at the preserve since the 1930s, the VTM tree plots reveal that the number and proportion of large trees have increased, and the number and proportion of small trees have decreased. Overall, tree density and basal area have decreased. Hence, our results suggest changes in both the extent and structure of coast live oak woodlands at the preserve.

Our results at the Dangermond Preserve stand in contrast to forest structure trends in the broader region. McIntyre et al. (2015) compared historical VTM data to contemporary US Forest Service data for the south and central coast of California, and they found that large tree density has decreased, medium tree density has decreased, and small tree density has not significantly changed. This discrepancy may be due to the fact that McIntyre et al. studied all kinds of forests, while the Dangermond Preserve is dominated by coast live oak woodlands. The trends observed at the preserve are more consistent with a study of valley oaks in coastal central California. In this study, Whipple et al. (2011) used aerial photographs and historical tree records to reconstruct valley oak density in the Santa Clara Valley, and they found that density has decreased since the mid-1800s. We should note that, although oak density and basal area have apparently decreased at the preserve since the 1930s, the current values still fall within the wide range of densities and basal areas reported for other oak woodlands in California (Table 2-4). Moreover, it is important to keep in mind the relatively short time period of our study. Pollen studies of the Santa Barbara region actually suggest that oak density today is much higher than it was prior to 1870 (Mensing 1998).

Our results — particularly the decline in small trees — suggest that there has been limited coast live oak recruitment on the property since the 1930s. If this is the case, recruitment of seedlings and saplings may not be sufficient to balance adult mortality, and the population may decline in the future (albeit slowly, as coast live oak is a long-lived species). Lack of oak recruitment at the preserve may be driven partly by wildfire suppression. Oaks are typically considered shade-intolerant, and disturbances such as fire can create openings in the oak canopy that stimulate new oak growth (Aldrich et al. 2005). However, coast live oak is actually quite shade-tolerant relative to other oak species in California (Callaway 1992). Therefore, we suspect that oak recruitment at the preserve is more likely limited by grazing and competition with annual grasses.

Various studies have demonstrated that cattle grazing and wildlife herbivory can be detrimental for oak seedlings and saplings. Lopez-Sanchez et al. (2014) studied coast live oak recruitment at eight ranches in northern California, some which still have cattle and some which have not had cattle for 40 years. They found that the presence of cattle reduced seedling and sapling density by 50%, while adult tree density was not affected. Furthermore, oaks exposed to cattle had a higher probability and intensity of herbivory than oaks exposed to wildlife grazers. Davis et al. (2011) created a matrix population model for valley oaks at the Sedgwick Reserve in Santa Barbara County. According to their model, this population declines when exposed to cattle, deer, and rodents; the population grows when protected from cattle but still exposed to deer and rodents; and the population grows most rapidly when protected from all three grazers. Cattle can also indirectly inhibit oak recruitment by 1) causing soil compaction and reducing soil organic matter, making it more difficult for oak roots to grow (Welker and Menke 1987), and 2) facilitating the dispersal (Chuong et al. 2016) and establishment (Maun 2009) of exotic grasses, which outcompete oaks for water (Tyler et al. 2006).

Competition with exotic annual grasses is another likely cause of the apparent lack of oak recruitment at the preserve. Exotic annual grasses have shallow, dense root systems that deplete soil moisture early in the growing season, while native perennial grasses do not monopolize soil moisture to the same degree (Tyler et al. 2006). A review of various oak recruitment studies found consistent evidence that oak seedlings surrounded by annual grasses have lower rates of emergence, growth, and survival than oaks surrounded by perennial grasses (Tyler et al. 2006). Therefore, the prevalence of exotic annual grasses at the Dangermond Preserve (WRA Environmental Consultants 2017) is likely detrimental for oak recruitment on the property.

We recommend that TNC further investigate oak recruitment at the Dangermond Preserve. They should conduct an age structure analysis of the oak population using tree cores, which would be an improvement to using stem size as a proxy for age. Stem size is an imperfect indicator of age, particularly in species like oaks that can re-sprout after disturbance (Larsen et al. 1997). Furthermore, our tree tally methods could be improved in the future by sampling more than 17 plots and by recording oaks of all sizes, rather than limiting the survey to trees with a diameter at breast height above 4 inches. If oak recruitment failure is confirmed, we recommend that TNC prioritize oak acorn and seedling planting immediately, given the risk that climate change may bring less precipitation and more drought to the preserve in the future. Rainfall in the first year after planting is a crucial factor in oak seedling survival (Tyler et al. 2006), and less precipitation could exacerbate competition with exotic annual grasses. We also recommend that young oaks be protected from cattle, as well as wild herbivores including deer and rodents.

2.6 Conclusion

Our objective in this chapter was to identify trends in the extent and structure of major habitat types at the preserve since the 1930s. Using multiple historical ecology methods, we were able to show that grassland extent has decreased, while shrubland and woodland extent have increased. Interestingly, however, repeating historical tree surveys revealed that, although coast live oak woodland area has increased over time, the density of trees within that area has likely declined. That, in combination with our finding that there are relatively fewer small trees today than there were in the 1930s, suggests that the coast live oak population is aging. These findings have important implications for management at the preserve. First, the small amount of native grasslands remaining at the preserve should be monitored closely given their susceptibility to shrubland encroachment. Second, coast live oak planting and sapling protection may be needed to prevent population decline.

3. LEGACY OF HISTORIC LAND USE ON BIODIVERSITY: A CASE STUDY OF CALIFORNIA RED-LEGGED FROGS

3.1 Introduction

The land now known as the Dangermond Preserve has been influenced by humans for centuries. The property functioned as a cattle ranch since at least 1837 (Palmer 1999), although Spanish Mission records indicate that ranching in the general vicinity began around 1770 (Dartt-Newton and Erlandson 2006). As discussed in Chapter 2, we believe this history of cattle ranching has affected vegetation on the property and may have contributed to a lack of oak recruitment. Now that the property is a nature preserve, some might advocate that TNC restore the land to a ‘natural’ state by removing anthropogenic disturbances to the greatest extent possible, including ranching infrastructure and cattle. However, depending on TNC’s conservation goals, entirely eliminating ranching may not be the ideal choice.

The most ‘natural’ state of an ecosystem is not necessarily the most biodiverse. In some cases, historic land use practices have been shown to indirectly increase biodiversity. For example, studies in Central Europe have linked a decline in forest plant biodiversity to the cessation of litter collecting, a historical practice where humans collected leaves from the forest floor to fill their mattresses (Burgi and Gimmi 2007). When litter collecting stopped and more biomass was left to decay, the forest soils became richer in nutrients (Dzwonko and Gawronski 2002). As a result, the forest became denser, and many shade-intolerant species disappeared. This decline in biodiversity alarmed conservationists in Switzerland, and in the canton of Zurich, the state office for nature protection has implemented a plan to restore ‘light forests’ with more open canopies. The reintroduction of litter collecting has been proposed as one means to achieve this (Burgi et al. 2010).

In a similar way, we suspect that cessation of cattle ranching at the Dangermond Preserve could have indirect implications for biodiversity. To illustrate this point, we present a case study on the effects of ranching infrastructure on the distribution of California red-legged frogs at the preserve.

The California red-legged frog (CRLF), *Rana draytonii*, is one of the federally threatened species occurring at the Dangermond Preserve. In 2006, the U.S. Fish and Wildlife Service (USFWS) designated critical habitat for CRLF throughout the entire state, including area within the Dangermond Preserve boundaries. These measures were a direct response to the contraction of CRLF populations to 30% of their former range as a result of habitat loss and degradation, predation by invasive bullfrogs (Doubledee et al. 2003), and an invasive chytrid fungus (*Batrachochytrium dendrobatidis*) (USFWS 2006). Given the threats to CRLF survival nationwide, conservation of this species is a priority at the Dangermond Preserve.

California red-legged frogs are highly dependent on aquatic habitats for breeding, foraging, and shelter (WRA Environmental Consultants 2017). Therefore, conservation of this species should focus on protecting streams with year-round water. However, CRLF at the Dangermond Preserve have also been detected in stock ponds and cattle troughs, suggesting that these anthropogenic features could be increasing CRLF habitat. In this section, our objectives are to:

1. Develop a hydrological model to predict which streams at the Dangermond Preserve are likely to have year-round flow, constituting appropriate CRLF habitat.
2. Investigate if ranching infrastructure (stock ponds and cattle troughs) could be expanding functional habitat for CRLF beyond these perennial streams.

3.2 Methods

We created a hydrological model of the Dangermond Preserve using a digital elevation model (DEM) of the preserve’s topography and the Hydrology toolset in ArcGIS. First, we used the Fill tool to remove imperfections in the DEM, where some pixels are lower or higher in elevation than all surrounding pixels and thereby disrupt flow. Then we used the Flow Direction and Flow Accumulation tools to model which steams drained into other stream channels in hierarchical order. Lastly, we set a threshold for flow accumulation to delineate which streams are likely to have year-round flow. Detailed methods are provided in Appendix 6. To investigate if stock ponds could be facilitating CRLF range expansion beyond these streams, we mapped the hydrology model output, locations of stock ponds and cattle troughs, and CRLF presence points from a recent comprehensive survey (WRA Environmental Consultants 2017).

3.3 Results

According to the hydrology model, Jalama Creek — the main east-west stream at the preserve — likely has year-round water (Figure 3-1). Most of the CRLF presence points are located along Jalama Creek. The model also predicts year-round flow in some of the streams in the southern portion of the preserve, though there are relatively few CRLF presence points along these streams. Interestingly, there is only one CRLF presence point in the northwest region of the preserve, despite the fact that the model predicts year-round flow in three north-south tributaries there (Gaspar, Espada, and Escondido Creeks). This single CRLF presence point in the northwest region is at a cattle trough. The lack of CRLF in the northwest region, despite predicted perennial flow there, casts some doubt on the validity of our hydrology model, and, in fact, field observations indicate that these some of these streams are currently dry, even during this very wet winter (personal communication with Kelly Caylor). It should also be noted that these three north-south tributaries and the single CRLF presence point in the upper northwest region are located within USFWS-designated critical habitat for the species.

Some CRLF presence points occur in areas of the preserve that are not predicted to have year-round stream flow, and 10 of these presence points appear to be associated with the locations of stock ponds and cattle troughs (Figure 3-1).

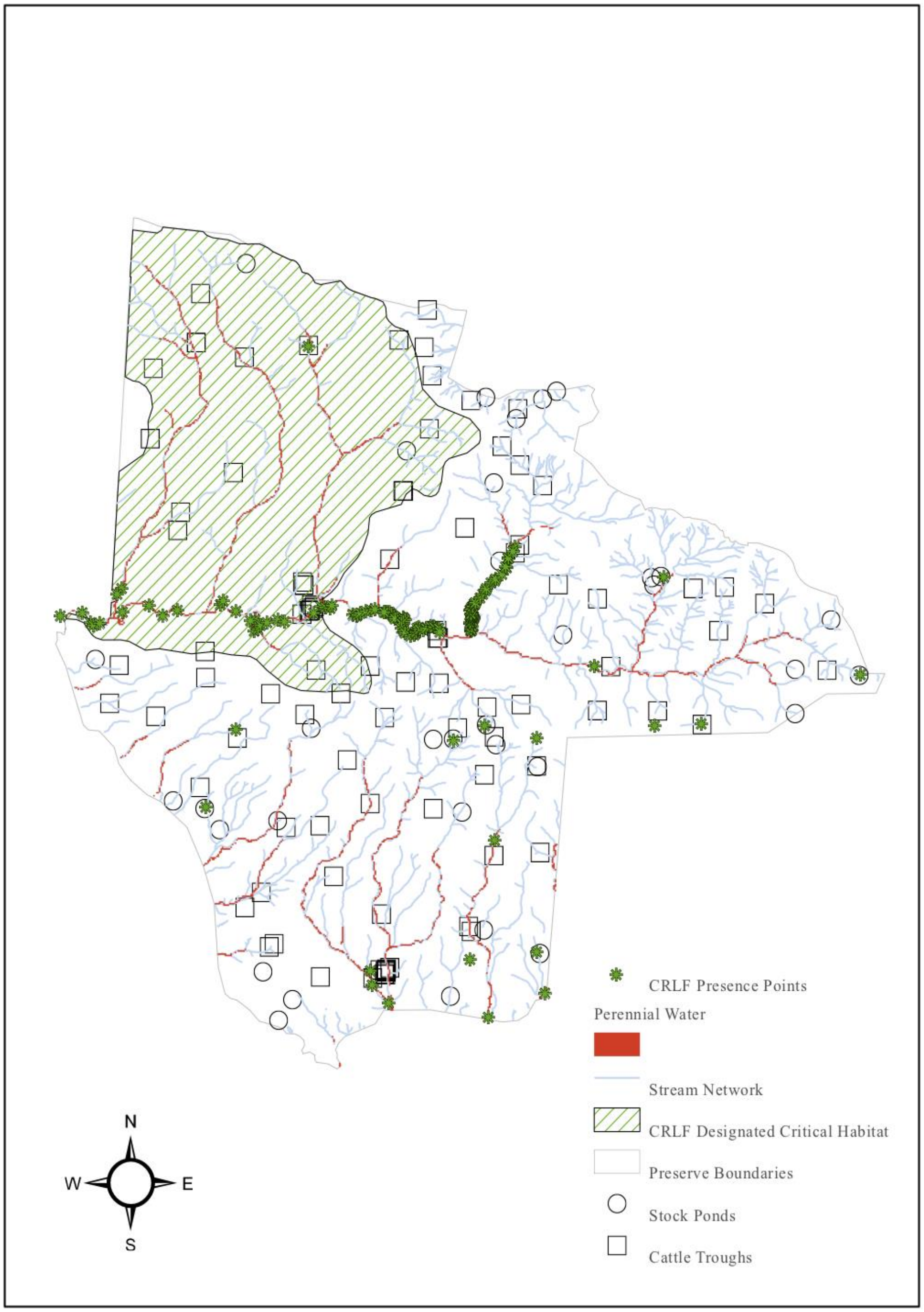


Figure 3-1. California red-legged frog presence points and predicted perennial streams. The entire stream network is shown in blue, while the streams predicted to have perennial flow are shown in red. USFWS-designated critical habitat is the green-hashed area. Locations of CRLF presence points (green stars), stock ponds (circles), and cattle troughs (squares) were provided by WRA Environmental Consultants (2017).

3.4 Limitations

A major limitation to this analysis is that we modeled perennial water using topographic features alone because there are no stream gauges on the preserve. Measurements of flow rates, stream depth, bank depth, water temperature, and riparian corridor width would provide a more accurate and complete picture of habitat suitability for CRLF. Another limitation is that, while we know where stock ponds and cattle troughs are located, we do not know how often they are filled. This information would allow us to make stronger conclusions about the effects of ranching infrastructure on CRLF distribution. Furthermore, we lack information about temporal trends in the CRLF population at the preserve, and, therefore, we cannot prove that the creation of stock ponds and cattle troughs increased CRLF habitat beyond its historical range.

3.5 Discussion

Our first objective in this chapter was to predict which streams at the Dangermond Preserve are likely to have year-round flow, as these streams should be prioritized for CRLF habitat conservation. Our analysis suggests that Jalama Creek is a priority for conservation because it is predicted to have year-round flow, and most of the CRLF presence points are concentrated along this stream. Interestingly, only a portion of Jalama Creek is included within USFWS-designated critical habitat for CRLF, and many CRLF presence points are located outside of this designated area. Therefore, conservation planning for CRLF at the preserve should not be limited to USFWS critical habitat.

Our second objective was to investigate if stock ponds and cattle troughs could be expanding functional habitat for CRLF beyond perennial streams. Though we have not conducted a formal analysis, it is apparent that some CRLF presence points are associated with stock ponds and troughs, even in the upper reaches of sub-watersheds where perennial flow is unlikely. It seems that stock ponds and troughs may be increasing connectivity for CRLF between tributaries of Jalama Creek and south-flowing creeks in the southern region of the preserve, though more in-depth analyses are needed to confirm this. Therefore, to conserve the federally threatened CRLF, we recommend that TNC consider maintaining and regularly filling these stock ponds and troughs, even if cattle are permanently removed from the property.

With that said, our recommendation to maintain troughs and stock ponds is contingent upon the exclusion of bullfrogs from the preserve. Bullfrogs are not native to California, and they prey on larval and juvenile CRLF, constituting a major threat to the species. Because bullfrogs and CRLF are both known to occupy ponds, draining stock ponds can be an effective strategy to reduce bullfrog populations without significantly reducing CRLF numbers (Doubledee et al. 2003). There are no historical records of bullfrogs at the Dangermond Preserve, and a recent biological survey of the property did not record any there (WRA Environmental Consultants 2017). However, two of our team members believe they saw a bullfrog on the property in the summer of 2018. TNC should investigate this further, and if bullfrogs have invaded the preserve, an eradication program should be implemented immediately.

Our hydrological model is only an initial step in understanding aquatic habitat for CRLF at the Dangermond Preserve. Because it was based solely on the preserve’s topography, it is a purely abiotic model. Our understanding of aquatic habitat quality would be improved by considering biotic aspects of the stream network like the presence of predatory bullfrogs, riparian vegetation and corridor width, and waterborne infectious diseases. One such disease is chytridiomycosis, an infection caused by the waterborne fungus *Batrachochytrium dendrobatidis* (Bd) (O'Hanlon et al. 2018). We do not currently know if Bd has been introduced to the CRLF population at the Dangermond Preserve, although we suspect that the CRLF population may be somewhat protected from Bd invasion because our hydrological model indicates that nearly all streams running through the preserve originate within the property. Further research is needed to assess possible paths of Bd ingression.

3.6 Conclusion

In this chapter, we conducted a preliminary investigation of the effects of ranching infrastructure on CRLF distribution at the Dangermond Preserve. These frogs have been observed at cattle troughs and stock ponds on the property where our model does not predict perennial stream flow, suggesting that these artificial impoundments are expanding functional habitat for CRLF and increasing connectivity between watersheds at the preserve. Now that the property is managed as a nature preserve, rather than a for-profit cattle ranch, TNC may be tempted to remove cattle and all ranching infrastructure to achieve a more 'natural' landscape. However, we recommend that TNC consider maintaining and filling troughs and ponds in the future, even if they remove all cattle from the preserve. Keeping this infrastructure — a legacy of historic human land use at the property — could be an important tool to support the federally threatened CRLF population at the preserve and, thus, conserve biodiversity.

4. SENSITIVE PLANT DISTRIBUTIONS UNDER FUTURE CLIMATE CHANGE

4.1 Introduction

Our use of historical ecology methods in Chapter 2 revealed how major vegetation communities have become more or less common at the preserve since the 1930s. Here, we explore how four sensitive plant species might become more or less common at the preserve in the future. Climate change will introduce novel conditions at the preserve; thus, it is critical to explore how sensitive plant species will respond to different future climate scenarios. Decisions to restore a specific habitat type or conserve a particular species at the preserve should be informed by the probability that the preserve will continue to offer suitable conditions for that habitat type or species in the future. Otherwise, land managers should attempt to preserve ecosystem function and biodiversity, rather than specific communities (Safford et al. 2012).

In the face of climate change, protected areas like the Dangermond Preserve are essential for protecting biodiversity. Studies suggest that climate change will commit 3 to 16% of species to extinction by 2050 (Urban 2015). By acting as ‘stepping stones,’ large tracts of natural habitat can allow species to track their preferred climate more easily (Hannah 2014). Furthermore, landscapes containing a high diversity of topography, geology, and soils, such as the Dangermond Preserve, are expected to remain biodiverse even with climate change (Hunter et al. 1988, Beier and Brost 2009).

In this component of the project, we use species distribution models to predict suitability for important and sensitive plant species at the preserve in the future. Our objectives are to:

1. Model changes in climate suitability for four sensitive plant species at the Dangermond Preserve.
2. Recommend management actions to maintain biodiversity and ecosystem function under uncertain climate futures.

We analyzed four plant species at the Dangermond Preserve that are listed as sensitive by the California Department of Fish and Wildlife: coast live oak (*Quercus agrifolia*), tanoak (*Notholithocarpus densiflora*), lemonade berry (*Rhus integrifolia*), and La Purisima manzanita (*Arctostaphylos purissima*), each representing a broad species category of relevance for conservation managers. Coast live oak is a keystone species and the dominant tree at the preserve. Tanoak is a more northern tree species that is at the southern extent of its range at the preserve. Lemonade berry is a frost-sensitive shrub more commonly found in southern California; it is at the northern extent of its range at the preserve. Finally, La Purisima manzanita is a chaparral shrub that is rare, range-limited, and endemic to western Santa Barbara County.

This analysis modeled the current climatic suitability for these species and then forecasted future suitability under two different climate warming scenarios. By predicting how climate will affect these plants’ distributions, we can identify species and locations on which to focus restoration and management resources.

4.2 Methods

To explore projected shifts due to climate for these four species, we chose a species distribution modeling method called maximum entropy, or Maxent (Maxent v3.3.3k modeling software, Philips et al. 2011). Maxent uses species occurrence data and environmental variables to produce a map of the probability of a species' presence across a landscape of interest. Maxent is supported in the literature as a well-performing species distribution model when using presence-only data (Elith et al. 2006) and has been shown to perform equally well under current, past, and future climates (Hijmans and Graham 2006).

Species Occurrence Points

The current distribution of the four species were retrieved as individual presence locations from the Consortium of California Herbaria, hosted by UC Berkeley's Jepson Herbarium (Markos et al. 2016). The consortium brings together over 2.2 million plant specimen records from 36 California institutions, offering latitude-longitude locational data for many of its specimens. The presence locations for our species of interest were filtered for recording dates between 1950 and 2018 in order to match the historic climate data time frame (Table 4-1).

Maxent evaluates relationships between these species presence data and environmental variables within a defined background domain, and then returns the most randomly distributed model of probabilities of species presence (the maximum entropy) that exists within those environmental constraints.

Table 4-1. Number of species occurrence points for training the Maxent model. Occurrence points are from the Consortium of California Herbaria.

Species	Number of Occurrence Points
Coast live oak (*Q. agrifolia*)	739
Tanoak (*N. densiflora*)	189
Lemonade berry (*R. integrifolia*)	335
La Purisima manzanita (*A. purissima*)	71

Environmental Variables

The initial environmental predictor variables included nine climate variables from the Basin Characterization Model (BCM) at 270-meter resolution (Flint et al. 2015), with elevation data from the USGS at 1/3 arc second resolution (approximately 10 meters), and six soil variables from the Soil Survey Geographic Database (Natural Resources Conservation Service 2018). The BCM data consists of 30-year climate averages. We used historic BCM data (1951–1981) to train the model and chose end-of-century climate predictions (2070–2099) for our suitability forecasts.

To reduce collinearity among the environmental predictor variables, we calculated correlation coefficients in R version 3.4.1 (R Development Core Team 2014) using the Raster package (Hijmans and van Etten 2012), and with jackknife results from Maxent, which excludes each variable one at a time to observe how important it is to the overall model. To maximize predictive ability of the model, the original 18 environmental variables (Appendix 7, Table A7-1) were narrowed down to three BCM variables: climatic water deficit, maximum summer temperature, and minimum winter temperature. The selection of climatic water deficit (CWD) is supported by research showing that it is strongly associated with tree distributions in California and their response to climate change (Stephenson 1998, Lutz et al. 2010, Anderegg et al. 2015, Davis et al. 2016). Climatic water deficit is calculated as the difference between potential evapotranspiration and actual evapotranspiration (Stephenson 1998). This term combines the effects of solar radiation, evapotranspiration, air temperature, and soil moisture retention capabilities, which results in an estimate of the drought stress on plants (Ackerly et al. 2015). Maxent parameters settings are described in Appendix 7, Figure A7-1.

Background points were generated by randomly sampling 10,000 points across the state of California. We used k-fold cross validation with 10 replicates to split the occurrence points into training and test data. We then used the AUC (area under curve) statistic to assess model performance, which compares true positive species occurrences with false positives between the training and test data. An AUC value of less than 0.5 signifies that the model performs worse than random chance, while an AUC value greater than 0.5 indicates the model has predictive powers greater than chance. Model performance metrics are available in Table A7-2 and Table A7-3 (Appendix 7).

Future Climate Projections

After training the Maxent model on the distribution of the four species under historic climate conditions (1951–1981), we forecasted their suitability for end-of-century conditions under two different climate scenarios: warm-wet (MPI RCP 4.5) and hot-dry (MIROC RCP 8.5). The RCP (representative concentration pathway) is a greenhouse gas concentration trajectory created by the Intergovernmental Panel on Climate Change's fifth report from 2014 (Pachauri et al. 2014). We chose these two models as they represent the reasonable high and low bounds of emission futures and have been used previously when modeling oak distributions in California (Davis et al. 2016). The MPI RCP 4.5 model represents emission stabilizing by mid-century. The MIROC RCP 8.5 model represents the continued increase of emissions through the end of the century (Van Vuuren et al. 2011).

We then compared historic and future models within the boundaries of the preserve. For all species and climate models, we calculated the mean suitability score over the entire preserve, as well as the percentage of the preserve suitable for that species. Binary suitability threshold selection can be subjective, and there are a variety of methods available. We chose to use the maximum sensitivity plus specificity threshold (Appendix 7) because it was recommended by evaluations of prediction methods using presence-only data (Liu et al. 2013) and has previously been used to model California plant distributions and, specifically, oak trees (Kelly et al. 2016).

Suitable Areas for Coast Live Oak and Tanoak Seedling Recruitment

The species distribution models used here assess the habitat suitability for mature, established individuals of these species. They do not account for the fact that seedlings are typically more sensitive to climate conditions (Grubb 1977) and are more likely to establish in cooler, wetter areas (Davis et al. 2016). To address this issue, we identified specific areas of the preserve that are most likely to support natural, unassisted coast live oak and tanoak seedling establishment in the future.

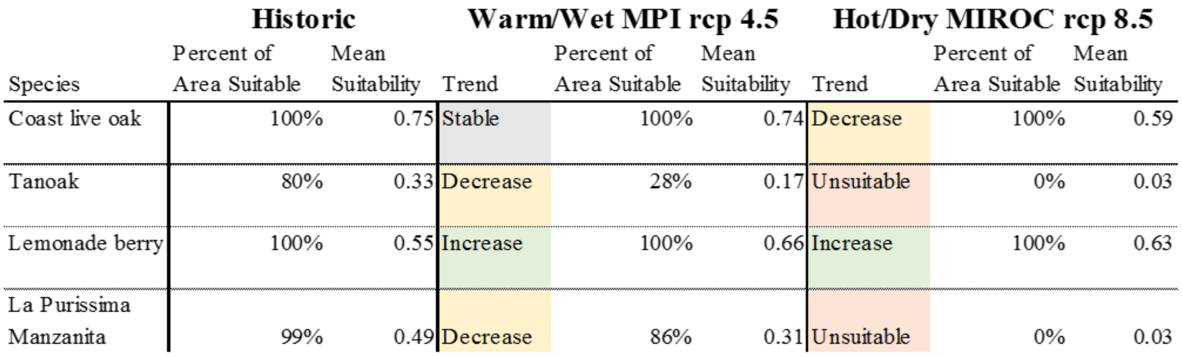
To do this, we assigned each cell within the preserve a maximum summer temperature and a climatic water deficit score under both of the future climate scenarios. We reclassified projected maximum summer temperature and climatic water deficit into 10 equal classes (given values 1-10). Scores for the two variables were weighted equally and summed for each cell. Areas with relatively low maximum summer temperature and low climatic water deficit are the cooler, wetter areas of the preserve where seedlings have a higher chance of establishment success.

4.3 Results

Species Distributions under Hot/Dry and Warm/Wet Scenarios

The predicted future suitability for coast live oak, tanoak, and La Purisima manzanita are all reduced to different degrees under both climate scenarios, with coast live oak (Figure 4-1) being much more resilient to warming than tanoak (Figure 4-2) and La Purisima manzanita (Appendix 7, Figure A7-5). In contrast, lemonade berry experiences increased suitability at the preserve under both climate scenarios, with decreased suitability in its current range between Los Angeles and San Diego (Appendix 7, Figure A7-4). The amount of suitable area for each species at the Dangermond Preserve is provided in Table 4-2. It is important to remember that this model is based on the current distribution of *adult* individuals; thus, seedlings would probably have smaller windows of suitability.

Table 4-2. Suitability for coast live oak, tanoak, lemonade berry, and La Purisima manzanita at the Dangermond Preserve under historic (left) and projected future warm-wet (center) and hot-dry (right) climates. The percent of area suitable was calculated as the percent of the preserve above each individual species' binary suitability threshold, defined by the 'maximum training sensitivity plus specificity' threshold in Maxent (Appendix 7). Mean suitability was averaged across the extent of the preserve.



	Historic		**Warm/Wet MPI rcp 4.5**			**Hot/Dry MIROC rcp 8.5**		
Species	Percent of Area Suitable	Mean Suitability	Trend	Percent of Area Suitable	Mean Suitability	Trend	Percent of Area Suitable	Mean Suitability
Coast live oak	100%	0.75	Stable	100%	0.74	Decrease	100%	0.59
Tanoak	80%	0.33	Decrease	28%	0.17	Unsuitable	0%	0.03
Lemonade berry	100%	0.55	Increase	100%	0.66	Increase	100%	0.63
La Purissima Manzanita	99%	0.49	Decrease	86%	0.31	Unsuitable	0%	0.03

Warm/Wet MPI RCP 4.5 Scenario

Under the warm/wet MPI RCP 4.5 scenario, suitable areas remain in the preserve for all species, with coast live oak's suitability remaining relatively stable — dropping from a mean suitability of 0.75 to 0.74 (Figure 4-1). The suitability for tanoak decreases from 0.33 to 0.17, with the suitable area decreasing from 80% to 28% of the preserve. La Purisima manzanita also sees a decrease in suitability, from 0.49 to 0.31. Lemonade berry, the southern shrub, sees an increase in mean suitability from 0.55 to 0.66 (Table 4-2).

Hot/Dry MIROC RCP 8.5 Scenario

In the business-as-usual, hot/dry MIROC RCP 8.5 scenario, the situation is more severe. Coast live oak still finds suitable conditions throughout the preserve. While 100% of the preserve is still suitable for coast live oak, the mean suitability index drops from 0.75 to 0.59. Tanoak (Figure 4-2) and La Purisima manzanita both have no suitability. However, under this more severe scenario, lemonade berry suitability increases from 0.55 to 0.63 (Figure 4-4). Interestingly, this is actually a slight drop in suitability from the warm/wet scenario for lemonade berry, suggesting this scenario marks a potential tipping point for the species. Suitability maps for all species and scenarios are available in Appendix 7.

Suitable Areas for Coast Live Oak and Tanoak Seedling Recruitment

The suitability ranking analysis revealed that the most suitable areas for coast live oak and tanoak seedling establishment at the preserve occur along Jalama Creek (Figure 4-3). The highest suitability occurs within an approximately 6 km^2 area along Jalama Creek, across from the Jalama Ranch Headquarters. This is interesting because many studies predict plant species will move to higher elevations (Lenoir et al. 2008), but our analysis suggests that mid- and lower-elevation sites may be more suitable for tanoak and coast live oak. This may be because climatic water deficit is more restrictive than temperature for these species, which may actually result in some species tracking their preferred climate downslope (Crimmins et al. 2011)

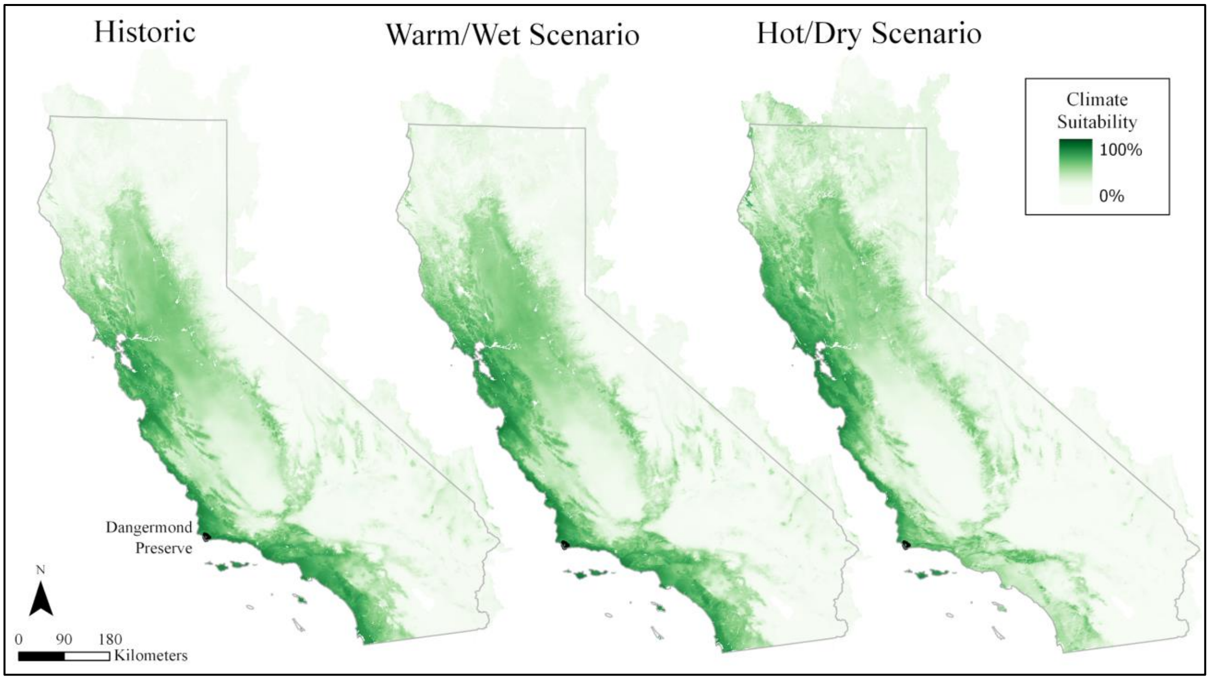


Figure 4-1. Coast live oak suitability shift under end-of-century climate change scenarios. The historic climate suitability (left) is based on herbarium presence locations (1950–2019) and historic maximum summer temperature, minimum winter temperature, and climatic water deficit (1951–1981). The warm/wet scenario (middle) forecasts the climate suitability to the end-of-century (2070–2099) under the MPI RCP 4.5 climate projection that predicts a ~10% increase in precipitation and ~2.5°C increase in temperature. The hot/dry scenario (right) forecasts the climate suitability to the end-of-century (2070–2099) under the MIROC RCP 8.5 climate projection that predicts a ~25% decrease in precipitation and ~6.5°C increase in temperature.

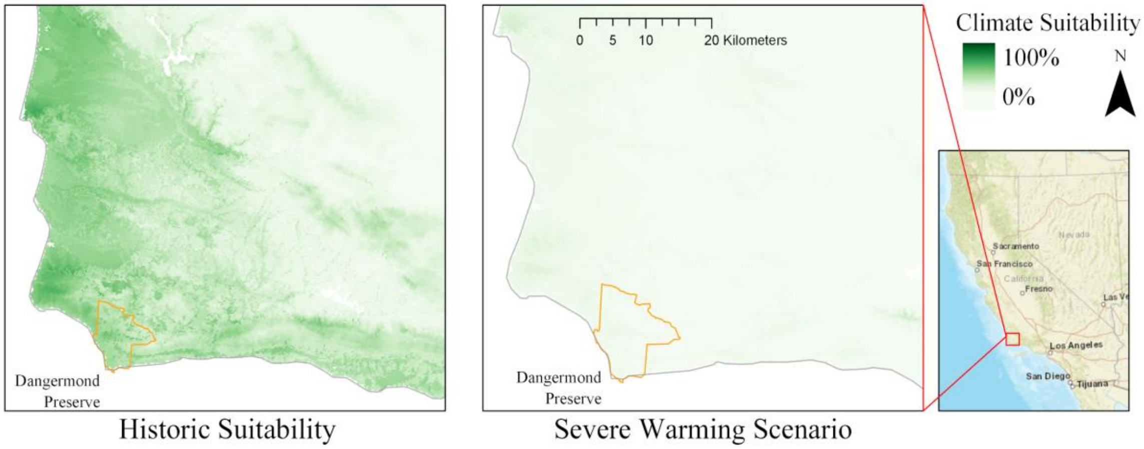
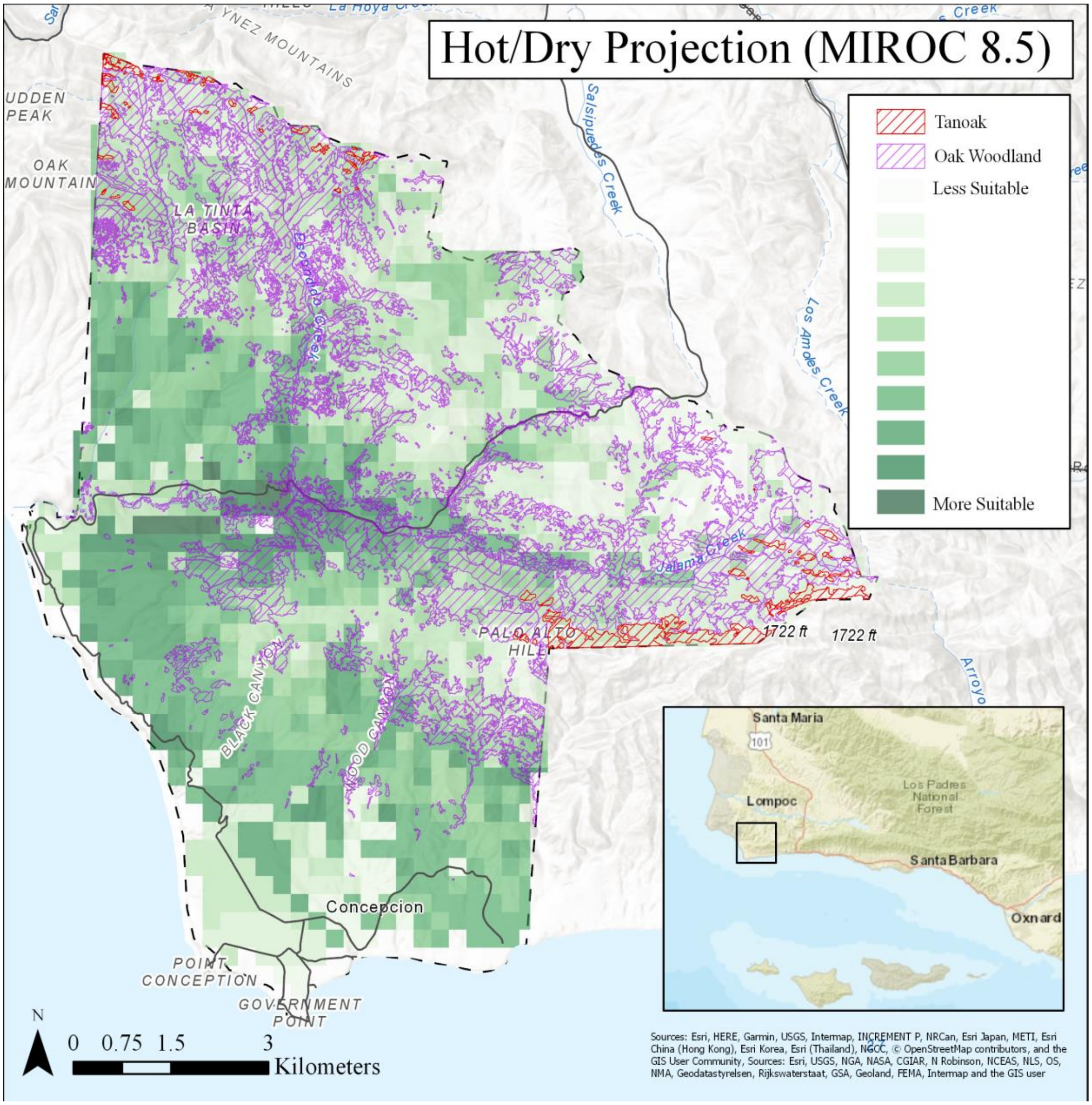


Figure 4-2. Climate projections show no future suitability for tanoak at the Dangermond Preserve under the hot/dry scenario. The MIROC RCP 8.5 climate projection predicts a ~25% decrease in precipitation and ~6.5°C increase in temperature.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community, Sources: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user

Figure 4-3. Most suitable areas for coast live oak and tanoak establishment. Darker green represents areas of lower maximum summer temperature and lower climatic water deficit, and thus areas most suitable for seedling establishment. Current oak woodland distribution is purple-hashed. Current tanoak distribution is red-hashed.

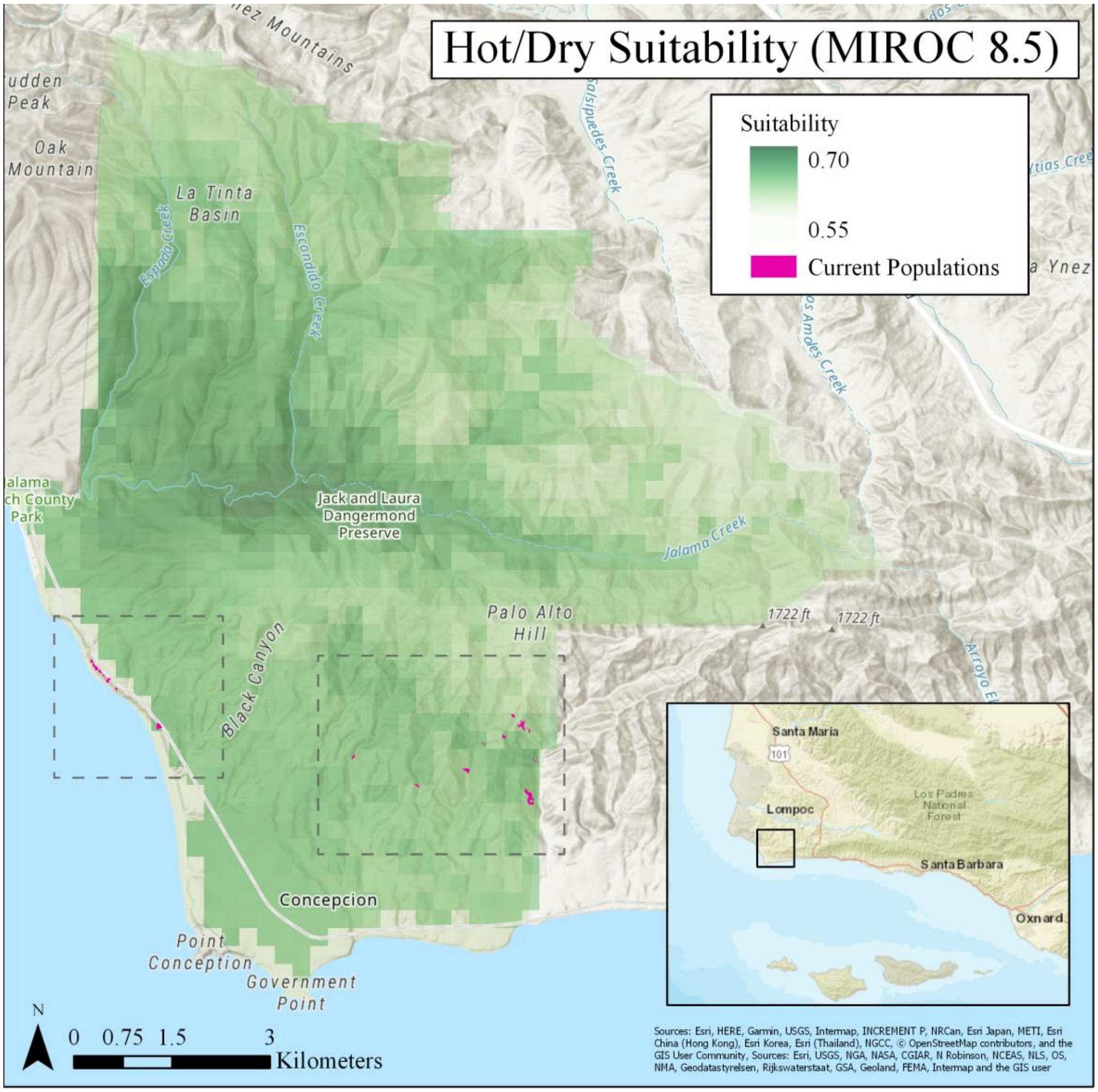


Figure 4-4. Existing populations of lemonade berry and projected suitability under the hot/dry scenario. The pink areas represent existing lemonade berry patches. Lemonade berry is a frost-sensitive shrub species currently at the northern extent of its range at the Dangermond Preserve. The MIROC RCP 8.5 climate projection predicts a ~25% decrease in precipitation and ~6.5°C increase in temperature.

4.4 Limitations

Presence-Only Species Distribution Models

Although Maxent is frequently used for species distribution modeling method in the scientific literature (Elith et al. 2006, Hijmans and Graham 2006), presence-only modeling techniques have a few fundamental limitations. First, it is not possible to determine the proportion of occupied sites over a landscape of interest because we do not have absence data (Ward et al. 2009). Second, some areas of the landscape may have been sampled more intensively than others, which can lead to inaccurate modeling (Phillips et al. 2009). This can be addressed by using a 'bias layer.' We chose not to include a bias layer because: 1) the presence points from the majority of herbaria throughout California since 1950 are the most comprehensive data available, and 2) it would be inaccurate to create a bias layer for presence points that are aggregated from 36 institutions, all with differing sampling methodologies over many surveys and years.

Species Climate Thresholds Change Through Their Life History

The presence points represent only mature individuals of each species, and we assume their current distribution accurately represents their preferred climate. Therefore, a model's output may not accurately represent the suitability for all life stages of a species. Furthermore, climate models predict temperature at two meters above the ground surface, and research has shown that the near-surface temperature, where seedlings grow, can be 10°C warmer (Dingman et al. 2013). We attempted to address this with a post-hoc analysis of climate suitability for seedlings.

Climate Projection Model Uncertainty

Unfortunately, there are considerable uncertainties in all climate projection models. Not only are there different possible emissions futures, but different global circulation models from different research groups present differing views of future climate (Raper and Giorgi 2005). When given the challenging task to successfully simulate the large climatic shifts documented during the last 100,000 years of glacial oscillations, these sophisticated models performed poorly (Beier and Brost 2010). Due to this, and because these models have been shown to perform no better than chance (Beale et al. 2008), Overpeck et al. (2005) urge conservationists to use them cautiously when designing management strategies. Despite this caveat, we attempted to bound our predictions through our choice of two climate projections representing contrasting futures (warm/wet and hot/dry). Since our predictions for the four species were similar across these projections, we are confident in the results presented.

270-meter Resolution

We restricted this analysis to the input variable with the coarsest resolution — the 270-meter Basin Characterization Model dataset, which itself is a statistically downscaled model from 4-kilometer spatial resolution PRISM climate data (PRISM Climate Group 2019). At this spatial resolution it is not possible to accurately represent microclimates that are important to many plant species at the preserve.

Exclusion of Many Environmental Variables in Maxent Model

It is important to note that our projections are based on climate suitability alone, and do not take into account other abiotic (i.e, fire, erosion) or biotic factors (i.e., herbivory from browsers or competition for water, nutrients, light, and dispersal ability) that can affect plant distribution (McClaran 1986). This was done to create a simpler model with less interacting and correlated factors. Future modeling efforts at the preserve could further investigate the impact of other environmental variables on the results presented here.

4.5 Discussion

The climate analysis results show that some species may be lost at the preserve over time (tanoak and La Purisima manzanita), while some species may benefit under future climates (lemonade berry). Species in the middle of their range, like coast live oak, will see increased stress from climate warming, but still find suitable habitat at the preserve.

Maintaining Ecosystem Function

TNC should consider likely vegetation trends when allocating conservation resources. Given that tanoak and La Purisima manzanita may lack suitable climate at the preserve in the future, it may be futile to allocate resources to conserve them. Instead, TNC can focus on maintaining ecosystem function (Safford et al. 2012) and biodiversity by planning for the inflow of southern species like lemonade berry (Figure 4-4). Facilitating the replacement of species with others that are functionally similar can be an important way to ensure ecosystem health under changing environmental conditions (Walker et al. 1999). One example of this would be to investigate if lemonade berry could fill the functional role of La Purisima manzanita or other shrub species that may decline at the preserve in the future.

Climate Change Will Outpace Rate of Natural Plant Dispersal

The rate of climate change will likely outpace plant species' ability to track their preferred climates. Managers may be able to mitigate this issue by using a mixture of local and nonlocal genotypes in restoration projects. Though some studies show that nonlocal genotypes are harmful to local population fitness (Hufford and Mazer 2011), strategically utilizing genotypes from southern populations of the same species may increase climate tolerance and increase gene flow across its distribution, as was the case in a study investigating the adaptive plasticity of California sagebrush (Pratt and Mooney 2013). This strategy would not work well for tanoak or La Purisima manzanita, as no populations exist further to the south, but it could be investigated for coast live oak or other species in the middle of their range at the preserve.

Assisted migration is another controversial tool that is being considered to help extremely at-risk species track their preferred climates. This method relocates plants or animals from their current or native location to a distant location in order to better match future climate (Sgro et al. 2011). Transplanting existing populations of species in the preserve to more suitable areas in the preserve could be explored, but looking at the regional scale or larger could help plants overcome dispersal limitations and maintain biodiversity. However, the ecological impacts of this are not well understood and costs might outweigh benefits (Bucharova 2017).

Early Life Stages of Plants are More Sensitive to Climate

We must also consider the life stages of plants when planning for the future. The narrow establishment window of some of these species means that these early stages are the time in the plant's life cycle where management resources can make the most difference. Oak seedling establishment is an important process that occurs during windows of ample precipitation and mild temperatures (Mahall et al. 2009). A study done in southern California mountains predicts that oak establishment windows will decrease by 50–95% by the end of this century and move to higher elevations and north-facing slopes (Davis et al. 2016). Therefore, it is important that TNC protect and plant oak acorns and seedlings now and in the near future, before climate suitability decreases.

Climate change represents a major threat to oak seedling establishment, but grazing is another stressor that must be considered when protecting and planting oaks. We recommend that TNC use fenced enclosures to exclude cattle — and other browsers and rodents, if possible — from the most suitable seedling establishment areas. Research also shows that coast live oak recruitment is higher in shrub understory than herbaceous understory because shrubs provide protection against herbivores (Callaway and Davis 1998). Thus, managing for increased shrubland may result in increased oak recruitment. Additionally, controlling or reducing invasive grasses would benefit oak recruitment because these grasses can outcompete the oaks for water (Tyler et al. 2006). Therefore, we recommend that TNC explore prescription grazing to control invasive grasses.

4.6 Conclusion

Our objective in this chapter was to predict changes in the distribution of sensitive plant species under climate warming scenarios. This is an important goal because anticipating the effects of climate change on the distribution of species is necessary for setting realistic conservation goals. Our climate suitability analysis can help TNC conceptualize possible futures at the preserve and plan accordingly. If species are predicted to lose suitable climate at the preserve, TNC should attempt to conserve other species that might fill the same functional role. For example, TNC should prioritize the conservation of coast live oak over tanoak, since the latter is unlikely to have suitable climatic conditions at the preserve in the future. Furthermore, coast live oak planting to prevent an aging population, as discussed in Chapter 2, should be implemented quickly — before the climate becomes warmer and, thus, less suitable for oak seedlings and saplings — and in the locations we have identified as having the coolest, wettest conditions. In terms of shrubs, TNC should investigate the potential of lemonade berry to fill the functional role of La Purisima manzanita, as the former is predicted to thrive under warmer climates, while the latter is expected to decline at the preserve. Further research is needed to investigate the potential value of assisted migration and of using non-local genotypes in restoration. Looking forward, monitoring and adaptive management should be used to revisit the problem of species range shifts and reassess objectives as we learn more about the future.

5. SUMMARY OF FINDINGS AND RECOMMENDATIONS

5.1 Summary of Findings

The purpose of this project is to inform conservation planning at the Dangermond Preserve by integrating information about the property's history with projections of its future. The first piece, looking to the past to investigate how habitat has changed over time, is a major component of traditional restoration efforts. By comparing the extent and structure of habitats today to those in the past, we investigated if any broad habitat types have been changed and may need restoration. Indeed, one of our most interesting findings was that there are fewer small oak trees on the property today than there were in the 1930s, indicating that cattle grazing and/or wildlife herbivory may have reduced oak recruitment. Therefore, we recommend that TNC plant oak acorns and seedlings to ensure that new oak recruitment balances adult mortality, thereby preventing population decline.

Though an analysis of historical change is undeniably important in conservation and restoration planning, it is not sufficient on its own. According to Safford et al. (2012), "[o]ne of the time-honored fundamentals of restoration ecology and resource management has been the implicit assumption that the historical range of variation…represents a reasonable set of bounds within which contemporary ecosystems should be managed" — but this is an outdated assumption. Given our increasing awareness of climate change and species range shifts, conservation planning that focuses on recreating past conditions or maintaining current conditions may not be ideal or even possible. Instead of focusing on recreating or maintaining certain species assemblages, management should attempt to conserve ecosystem structure and function (Safford et al. 2012). To illustrate this point, we modeled future climate suitability for four sensitive plant species at the preserve: two trees, coast live oak and tanoak, and two shrubs, lemonade berry and La Purisima manzanita. Coast live oak and lemonade berry are predicted to have suitable climatic conditions at the preserve under both of the warming scenarios we explored, while tanoak and La Purisima manzanita are predicted to have much less suitable conditions. Thus, we recommend that TNC prioritize conservation of coast live oak and lemonade berry and investigate how well these species might fill the functional roles of species that may be lost. This analysis could be repeated for other important plant species at the preserve.

By integrating our historical analysis with future projections, we were able to make stronger and more useful recommendations for TNC. For example, our historical analysis demonstrated a lack of oak recruitment at the preserve, which led us to recommend planting acorns and seedlings and protecting them from herbivory. Then, our projected distribution models for coast live oak allowed us to refine this recommendation: plant and protect oaks in the coolest, wettest areas of the preserve where conditions will most likely remain suitable for the species in the future.

As we have demonstrated, conservation planning should not necessarily aim to restore historic conditions or maintain current conditions. We also argued in this report that conservation planning should not necessarily focus on achieving the most 'natural' conditions. Now that the property is managed as a nature preserve, rather than a for-profit cattle ranch, TNC may be tempted to remove cattle and all ranching infrastructure to achieve a more ‘natural’ landscape. However, our analysis of California red-legged frog (CRLF) distribution suggests that this federally threatened species may benefit from ranching infrastructure on the property. It seems that stock ponds and cattle troughs may be increasing habitat connectivity for the frogs between different sub-watersheds of the preserve, and we recommend that TNC consider maintaining and regularly filling these artificial structures, even if cattle are permanently removed from the property. Keeping this infrastructure — a legacy of historic human land use — could be an important tool to support the CRLF population and, thus, conserve biodiversity.

Our integrated approach spanned multiple ecological scales, from the species-level analyses of coast live oak woodland structure and CRLF distribution to the landscape-level analyses of habitat type extents. We also looked at the preserve over multiple time scales: past, present, and future. Combined, these multi-level level analyses improved our understanding of the preserve and strengthened our ability to make conservation recommendations.

5.2 Recommendations for Conservation Planning and Future Research

Recommendation 1: Monitor native grasslands for evidence of shrub encroachment

Our aerial photograph and vegetation map analyses indicated that grassland extent at the preserve has decreased since the 1930s (Chapter 2). Grassland to shrubland conversion was the most common habitat transition according to both aerial photographs and vegetation maps. Unfortunately, we were unable to differentiate between exotic annual grasslands and sensitive native grasslands with these methods. However, we know that very little grassland at the preserve today is native. A recent biological survey of the preserve found only 172 acres of native purple needlegrass patches (compared to 7,000 total acres of grasslands), and they were commonly integrated with coastal sage scrub (WRA Environmental Consultants 2017). Given the high frequency of grassland to shrubland conversion we have observed, TNC should closely monitor native grasslands to conserve herbaceous biodiversity. Monitoring should be focused on patches of native grassland that are surrounded by shrubland (we have identified these areas in Figure A3-3, Appendix 3).

Given that TNC intends to keep some cattle on the preserve, they should investigate prescription grazing as a means to facilitate the growth of native grasses. Prescription grazing is the practice of managing the livestock grazing season, intensity, and/or duration to meet vegetation or landscape management goals (Frost and Launchbaugh 2003). Research has demonstrated that early spring cattle grazing can increase purple needlegrass growth by reducing shading and competition from exotic annual grasses (George et al. 2013). However, any type of grazing regime will require careful planning to avoid herbivory of sensitive species (e.g. see recommendations below for oak recruitment).

Recommendation 2: Plant and protect coast live oak to improve recruitment

Although our aerial photograph and vegetation map analyses demonstrated that woodland area has increased, our on-the-ground surveys suggest that the density of trees within that area has decreased and that there are fewer small trees today than there were in the 1930s (Chapter 2).

This suggests that the oak population may be aging, and there may be a lack of oak recruitment. With that said, we had a small sample size (nine survey plots), so further investigation is needed to confirm if this pattern is consistent across the entire preserve. Furthermore, we are using diameter at breast height as a proxy for age, but stem size is an imperfect indicator of age in species that can re-sprout after disturbance, like oaks (Larsen et al. 1997). Therefore, we recommend a more in-depth age structure analysis using other methods like tree coring.

If oak recruitment failure is confirmed, we recommend that TNC prioritize oak acorn and seedling planting immediately, given the risk that climate change may bring more variable precipitation and drought to the preserve in the future (Chapter 4). Rainfall in the first year after planting is a crucial factor in oak seedling survival, and less precipitation could exacerbate competition with exotic annual grasses (Tyler et al. 2006). To increase the likelihood of planting success now and into the future, the coolest, wettest areas of the preserve should be prioritized (Figure 4-3). If TNC is interested in a long-term, larger-scale oak restoration plan, a more detailed study of existing oak woodlands and predicted climate trends will be required.

We also recommend that TNC protect any planted oaks from cattle, as well as wild herbivores including deer and rodents. TNC should also protect areas of the preserve that have high rates of unassisted oak recruitment. The amount of herbivory from cattle, deer, and rodents has been shown to be an important factor for *Quercus agrifolia* seedling survival at the nearby Sedgwick Reserve — increased herbivory can have as much, if not more, of an influence on survival as abiotic environmental factors (Tyler et al. 2008). Acorns and small saplings can be protected from cattle and deer with fences and from rodents with cages set belowground (similar to Tyler et al. 2008).

Our study of oaks on the preserve did not include sudden oak death, a disease caused by the pathogen *Phytophthora ramorum*. Sudden oak death has devastated oak woodlands elsewhere in California but has yet to be introduced to the Dangermond Preserve. TNC should further investigate the potential threat of sudden oak death.

Recommendation 3: Anticipate climate change and species range shifts

Our species distribution modeling indicated that climate suitability for some species at the preserve will likely change in the next century. Coast live oak is stable under the warm/wet scenario, with decreased suitability under the hot/dry scenario. Tanoak, the more northern tree species, is less suitable under the warm/wet scenario, and excluded from the preserve under the hot/dry scenario. Lemonade berry, the southern shrub species, sees increased suitability under both climate projections. La Purisima manzanita, the local endemic shrub, has less suitability under the warm/wet scenario and is excluded from the preserve under the hot/dry scenario (Chapter 4). We recommend that TNC anticipate these range shifts and prioritize conservation of species that are more likely to thrive in the future. We also recommend that TNC investigate the potential of coast live oak, lemonade berry, or other species to fill the functional roles of species like tanoak and La Purisima manzanita that may be lost in the future.

We recommend that TNC further investigate the potential of assisted gene flow to improve plant populations' ability to thrive under a warmer climate. Strategically utilizing genotypes from southern populations of the same species may increase climate tolerance and increase gene flow across its distribution (Pratt and Mooney 2013). This strategy would not work well for tanoak or La Purisima manzanita, as no populations exist further to the south, but it could be investigated for coast live oak or other species in the middle of their range at the preserve. However, uncertainty in the speed and trajectory of climate change make it difficult to completely endorse assisted gene flow. For example, plants might be able to adapt to new climate conditions on their own, without any additional help from interbreeding with "hardy" individuals. Additionally, hybrid populations could lose unique genotypic or phenotypic expressions that contribute to metapopulation diversity.

Recommendation 4: Conduct a detailed investigation into California red-legged frog habitat at the preserve, including the importance of stock ponds and cattle troughs

In our preliminary analysis of California red-legged frog (CRLF) aquatic habitat (Chapter 3), we identified areas of the preserve that are likely to have perennial water, constituting appropriate habitat for the species. We recommend Jalama Creek as a priority for CRLF conservation because it is predicted to have perennial water, and most CRLF observations at the property were concentrated along this stream. With that said, our hydrological model is theoretical (based on topography) because there are currently no stream gauges on the preserve. We highly recommend that TNC install and monitor stream gauges for a more complete watershed model.

Interestingly, only one CRLF presence point is located in the northwest region of the preserve, despite the fact that this region is designated as critical habitat under the Endangered Species Act (U.S. Fish and Wildlife Service 2006). We recommend that TNC investigate this area more thoroughly to understand why frogs have not been seen there.

We also recommend that TNC further investigate the importance of stock ponds and cattle troughs as habitat for CRLF. It seems that stock ponds and cattle troughs may be increasing habitat connectivity for the frogs between different sub-watersheds of the preserve, and we recommend that TNC consider maintaining and regularly filling these artificial structures — even if cattle are permanently removed from the property. This recommendation is contingent upon the exclusion of American bullfrogs from the preserve. Bullfrogs are predators of CRLF and are also known to inhabit stock ponds (Doubledee et al. 2003), but bullfrogs are not confirmed to occur at the Dangermond Preserve.

Future research on CRLF at the preserve should also assess the susceptibility of the population to chytridiomycosis, a waterborne infectious disease.

Recommendation 5: Incorporate adaptive management and use our analyses as a foundation for ongoing monitoring

TNC will face a lot of uncertainty in their management of the Dangermond Preserve, especially in their goal of planning for climate resiliency. Thus, we recommend adaptive management — an iterative process of improving management by repeatedly learning from the outcomes of management decisions and adjusting them. Adaptive management gauges the effectiveness of management techniques, incorporates new information, and adjusts priorities and strategies. Monitoring is at the core of adaptive management.

Our findings in this report can serve as a foundation for ongoing monitoring at the preserve. To monitor changes in the composition and structure of vegetation, TNC can continue to resurvey the 17 VTM plots in the future. To our knowledge, VTM surveys have not been repeated more than once anywhere in California — perhaps because they were digitized so recently. We think repeating these surveys again would be valuable because they are some of the best records of historical vegetation data in California, and it would be interesting to follow these plots over the next century. However, we recommend that TNC use the VTM data within a larger, more detailed monitoring plan going forward. In addition to including more survey plots, the VTM methods could be improved by recording counts for all species in a plot, rather than focusing on dominant species; including trees of all stem size, rather than trees above 4 inches diameter at breast height; and incorporating herbivory metrics.

TNC could also use our aerial photograph and vegetation map analyses as a historical baseline for ongoing vegetation monitoring. We do not recommend that our exact aerial photograph methods be repeated in the future, because better methods for remote vegetation monitoring exist now. We were unable to identify vegetation below broad habitat type in older black and white photographs (grassland, shrubland, and woodland), but modern-day photographs and satellite imagery can be used to train a computer to identify vegetation to the alliance or species level.

APPENDIX 1: RANCH HISTORY

The history of cattle ranching in the region dates back to the Spanish arrival in the 1700s. Hide and tallow were prized commodities for the Spanish, leading to a rapid growth in the coastal cattle population (Hardwick 2015). Based on livestock records from La Purisima Mission, it is estimated that cattle herds from Gaviota to Cojo increased by 400 to 500 percent between 1770 and 1796 (Dartt-Newton and Erlandson 2006).

In 1837, the Mexican government granted the 24,992-acre Rancho Punta de la Concepcion to Anastacio Carrillo. In 1851, the land was partitioned for the first time into Rancho La Espada (currently Vandenberg Air Force Base) and Rancho Cojo. Carrillo lived on Cojo and, at one point in time, had 1,700 head of cattle and 200 horses (Palmer 1999). Beef production was a huge business in Santa Barbara County during the 1850s, with an estimated 500,000 cattle in the county during that decade. The market for beef was driven by gold miner food demand, but droughts in the 1860s caused cattle numbers to decline by 99% to only 5,000 in the entire county (Palmer 1999).

In 1913, Fred H. Bixby purchased Cojo Ranch and stocked it with 565 cattle, 143 horses, 9 bulls, and 2 stallions (PHR Associates 1990). A report by PHR Associates describes ranching and crop agriculture on the Cojo and Jalama ranches from 1913 to 1989. Using financial records, journals, and interviews with ranchers, PHR Associates identified four distinct periods of agricultural operations within this time frame.

The first period spanned from 1913 to 1941. During this time, the value of Bixby's cattle fluctuated, with a low of $19,125 in 1917 and a high of $43,225 in 1927. We are currently unsure how much of this variation is due to changes in the number of cattle versus changes in the market value of cattle. Dairy cows and chickens were also raised on the property in order to feed the employees. In 1923, they acquired 30-40 goats, which were not pastured. A 1925 survey listed 627 acres devoted to barley, 242 acres to bean, and 25 acres to a walnut orchard.

The second period, from 1942 to 1952, began after the purchase of the Jalama Ranch, which facilitated an increase in livestock. Together, Cojo and Jalama had 1,630 cattle in 1943 and 1,296 cattle in 1947. Cojo was used primarily for crops, while Jalama supported more of the livestock. The greatest change in crop production from the first period was the addition of red mustard, which was very profitable. There were only small changes in the amount of land used for beans and barley.

Bixby's death marked the beginning of the third period, from 1953 to 1972. Cattle numbers were kept around 1,200 on Jalama and 800 on Cojo, although this was reduced to 600 during a drought in the 1960s. Less land was used for barley, and there was an attempt to grow alfalfa. This required the construction of dams and wells, but the alfalfa crop proved unsuccessful.

The fourth period began in 1973. In the 1970s, barley production stopped and the walnut orchard was removed. From around 1983-1986, wild mushrooms were harvested. By the mid-1980s, crop farming had ceased on Cojo; the fields reverted to pasture and were used as holding areas.

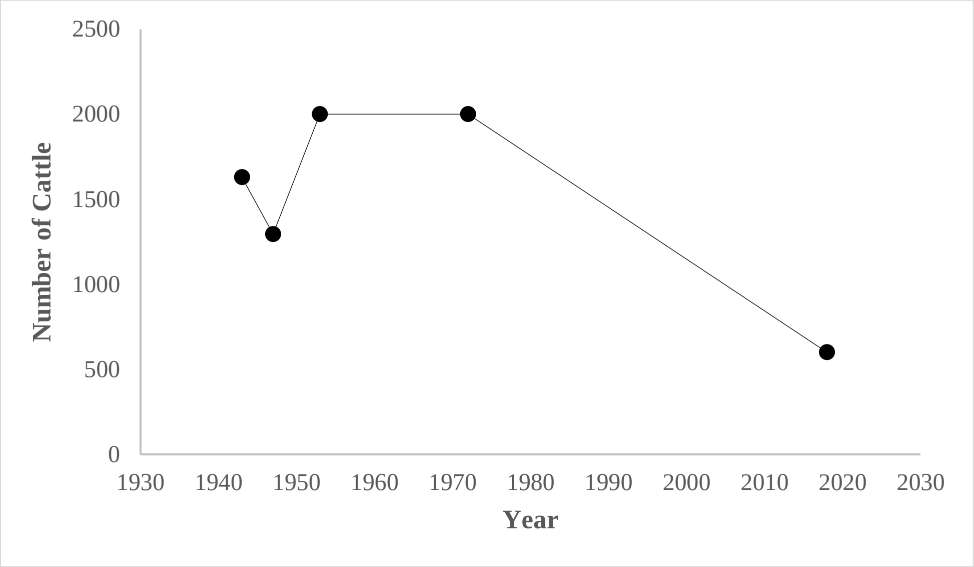


Figure A1-1. Number of cattle on the property (Cojo and Jalama ranches combined) over time. Data from PHR Associates (1990) and personal communication with Moses Katkowski (TNC staff).

APPENDIX 2: AERIAL PHOTOGRAPH ANALYSIS

Table A2-1. Guidelines for visual interpretation of three dominant habitat types at the Dangermond Preserve. Areas displayed represent the best example of habitat type and do not necessarily correspond to the same area between years.

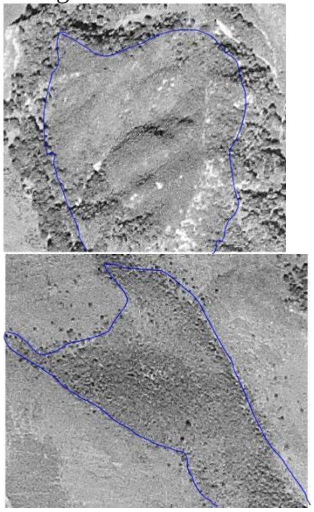
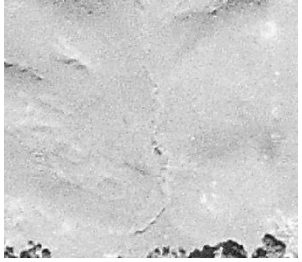
Habitat	1938	2012
Woodland	Dark gray circular points with gaps between points 	Dark green circular points with gaps between points 
Shrubland (includes scrub and chaparral)	Dark to light gray patches with no gaps between vegetation; appears more textured than grassland 	Dense, medium green or purple/gray patches with no gaps; appears more textured than grassland 
Grassland	Light gray land with no points or patches 	Typically brown land with no discernible points/patches 

Table A2-2. Transition rates of all observed combinations of 1938 and 1978 dominant habitat types. Transitions that were not observed in our study (e.g. grassland to other) are not included in this table. Transition rates between two habitat types, X and Y, are calculated as the number of sample points that transitioned from X-type in 1938 to Y-type in 1978, divided by the total number of X-type points in 1938.

1938	1978	Number of Points that Transitioned	Starting Number of Sample Points	Transition Rate (% of Starting Points)
Grassland	Grassland	126	174	72
Grassland	Shrubland	27	174	16
Grassland	Woodland	9	174	5
Grassland	Other	8	174	5
Grassland	Tie	4	174	2
Shrubland	Grassland	14	70	20
Shrubland	Shrubland	42	70	60
Shrubland	Woodland	10	70	14
Shrubland	Tie	4	70	6
Woodland	Grassland	3	83	4
Woodland	Shrubland	5	83	6
Woodland	Woodland	73	83	88
Woodland	Tie	2	83	2
Other	Grassland	2	7	29
Other	Other	4	7	57
Other	Tie	1	7	14
Tie	Shrubland	4	6	67
Tie	Woodland	2	6	33

Table A2-3. Transition rates of all observed combinations of 1978 and 2012 dominant habitat types. Transitions that were not observed in our study (e.g. grassland to other) are not included in this table. Transition rates between two habitat types, X and Y, are calculated as the number of sample points that transitioned from X-type in 1978 to Y-type in 1938, divided by the total number of X-type points in 1978.

1978	2012	Number of Points that Transitioned	Starting Number of Sample Points	Transition Rate (% of Starting Points)
Grassland	Grassland	92	145	63
Grassland	Shrubland	47	145	32
Grassland	Woodland	5	145	3
Grassland	Tie	1	145	1
Shrubland	Grassland	11	78	14
Shrubland	Shrubland	57	78	73
Shrubland	Woodland	9	78	12
Shrubland	Tie	1	78	1
Woodland	Grassland	6	94	6
Woodland	Shrubland	6	94	6
Woodland	Woodland	82	94	87
Other	Grassland	7	12	58
Other	Shrubland	3	12	25
Other	Other	2	12	17
Tie	Grassland	4	11	36
Tie	Shrubland	4	11	36
Tie	Woodland	2	11	18
Tie	Other	1	11	9

APPENDIX 3: VEGETATION MAP ANALYSIS

Map Alignment

In an effort to quantify and reduce map error, 31 ground control points were taken from the 2015 US Census Bureau, Department of Commerce Primary and Secondary Roads (Figure A3-1). Points were compared to intersections from the historic base map resulting in a root mean square (RMS) error of 172.04 meters. The base map was then shifted 45 meters east and 150 meters north to align with the coastline. A comparison of intersections for the shifted base map and modern roads revealed a substantially smaller RMS error of 56.72 meters. All layers were projected to California Teale Albers, NAD83 for the Lompoc Quad.

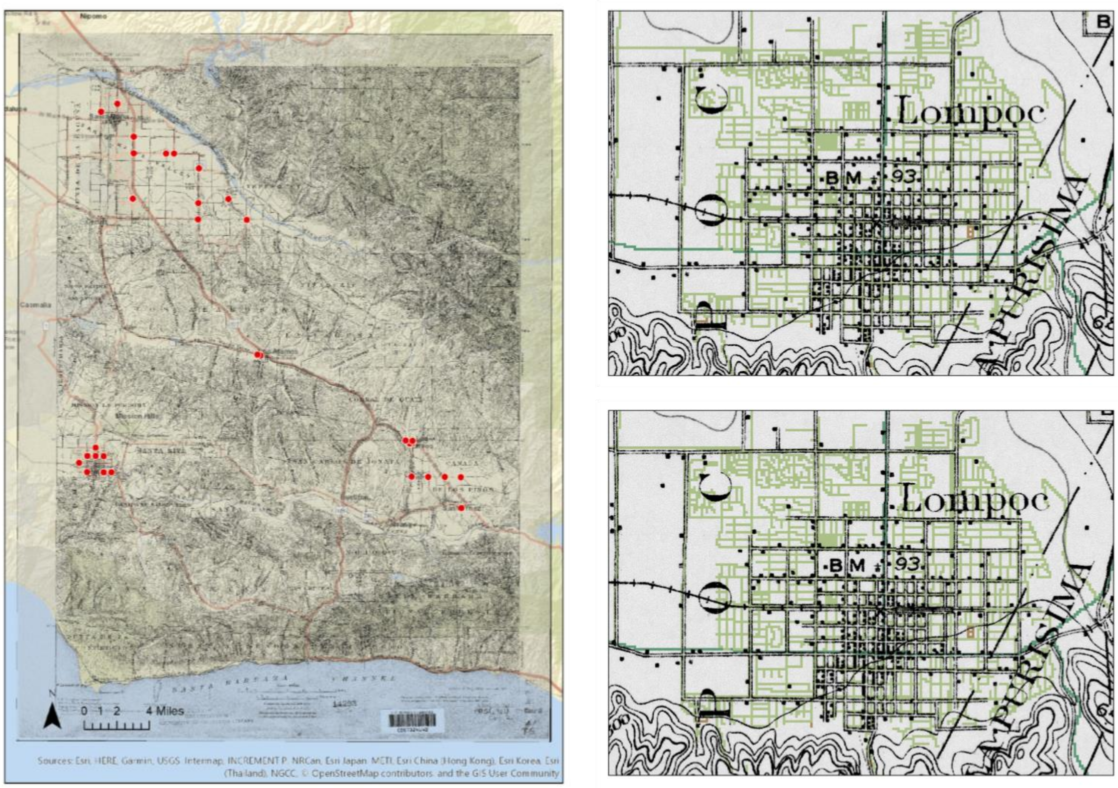


Figure A3-1. Topographic base map alignment. Red points in map on the left indicate locations used to calculate the RMS error for the original and shifted base maps. Stacked maps show the location of the base topographic map before (top) and after (bottom) shifting. Note: alignment of the shifted base map (bottom) is improved with respect to modern roadways.

Another step taken to reduce map error was aligning the habitat polygon layer to the base topographic layer (Figure A3-2). To accomplish this, the polygon layer was shifted 95 meters east. The polygon layer was then shifted the same distance as the base topographic map (45 meters east and 150 meters north) to align with modern topography.

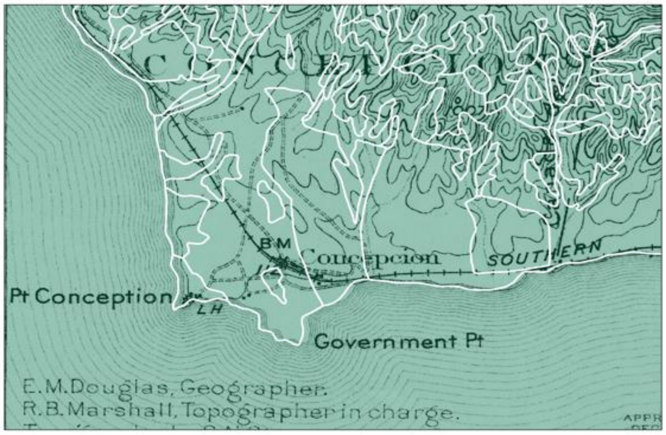


Figure A3-2. Habitat polygon layer alignment. Original alignment of the habitat polygon layer (white) to the base topographic map (black). Alignment was improved by shifting the map 95 meters east.

Habitat Transition Rates

Table A3-1. Habitat transition rates according to VTM and FRAP vegetation maps at 60-meter resolution. Transition rate alculated as the percentage of raster cells that converted from X-type in 1931 to Y-type in 2015 divided by the total number of X-type raster cells in 1931.

Transition	**Number of Raster Cells that Transitioned**	**Total Number of Raster Cells of Original Habitat Type in 1931**	**Transition Rate**
Woodland to Shrubland	1411	7188	20%
Woodland to Grassland	759	7188	11%
Grassland to Woodland	1655	13772	12%
Grassland to Shrubland	3911	13722	28%
Shrubland to Woodland	1721	6670	26%
Shrubland to Grassland	1471	6670	22%

Map Resolution and Habitat Area

Table A3-2. Habitat type area according to the 1931 VTM map and the 2015 FRAP map at 30-meter, 60-meter, and 160-meter resolution.

A. 30-Meter Spatial Resolution

Habitat Type	**1931 VTM Area (ha)**	**2015 FRAP Area (ha)**	**Percent Change**
Woodland	2594	3017	+ 16 %
Shrubland	2388	3163	+ 32 %
Grassland	4963	3687	-26 %

B. 60-Meter Spatial Resolution

Habitat Type	**1931 VTM Area (ha)**	**2015 FRAP Area (ha)**	**Percent Change**
Woodland	2588	3013	+ 16 %
Shrubland	2401	3156	+ 31 %
Grassland	4958	3689	-26 %

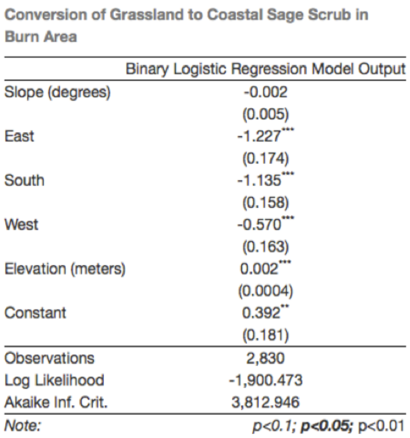
C. 160-Meter Spatial Resolution

Habitat Type	**1931 VTM Area (ha)**	**2015 FRAP Area (ha)**	**Percent Change**
Woodland	2626	3005	+14 %
Shrubland	2350	3195	+36 %
Grassland	4943	3663	-26 %

Binomial Logistic Regression Outputs

Table A3-3. Binomial logistic regression outputs for various habitat conversion probabilities. These regressions are for grassland to coastal sage scrub in areas that burned (a, b) and areas that did not burn (c), and for coastal sage scrub to grassland in areas that burned (d) and areas that did not burn (e). Aspects in table are relative to north.

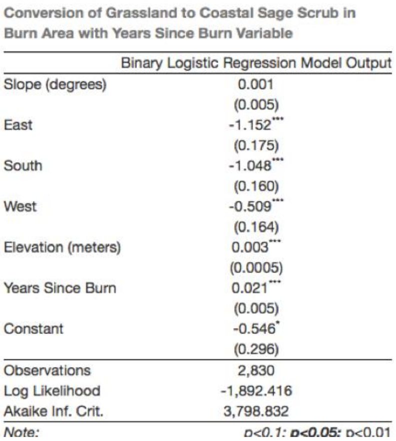
A



Conversion of Grassland to Coastal Sage Scrub in Burn Area

	Binary Logistic Regression Model Output
Slope (degrees)	-0.002
	(0.005)
East	-1.227***
	(0.174)
South	-1.135***
	(0.158)
West	-0.570***
	(0.163)
Elevation (meters)	0.002***
	(0.0004)
Constant	0.392**
	(0.181)
Observations	2,830
Log Likelihood	-1,900.473
Akaike Inf. Crit.	3,812.946
Note:	*p<0.1;* ***p<0.05;*** p<0.01

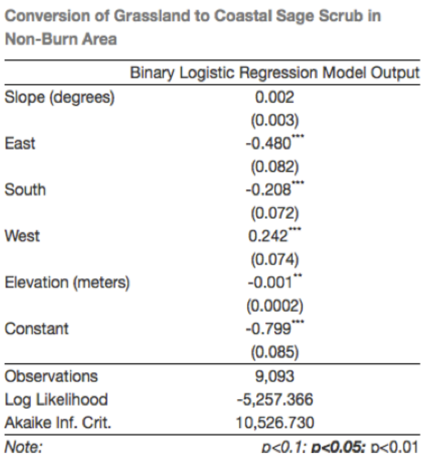
B



Conversion of Grassland to Coastal Sage Scrub in Burn Area with Years Since Burn Variable

	Binary Logistic Regression Model Output
Slope (degrees)	0.001
	(0.005)
East	-1.152***
	(0.175)
South	-1.048***
	(0.160)
West	-0.509***
	(0.164)
Elevation (meters)	0.003***
	(0.0005)
Years Since Burn	0.021***
	(0.005)
Constant	-0.546*
	(0.296)
Observations	2,830
Log Likelihood	-1,892.416
Akaike Inf. Crit.	3,798.832
Note:	*p<0.1;* ***p<0.05;*** p<0.01

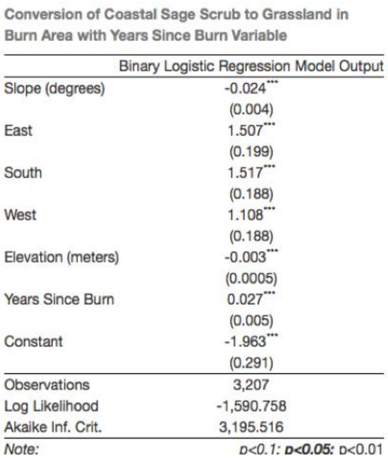
C



Conversion of Grassland to Coastal Sage Scrub in Non-Burn Area

	Binary Logistic Regression Model Output
Slope (degrees)	0.002
	(0.003)
East	-0.480***
	(0.082)
South	-0.208***
	(0.072)
West	0.242***
	(0.074)
Elevation (meters)	-0.001**
	(0.0002)
Constant	-0.799***
	(0.085)
Observations	9,093
Log Likelihood	-5,257.366
Akaike Inf. Crit.	10,526.730
Note:	*p<0.1;* ***p<0.05;*** p<0.01

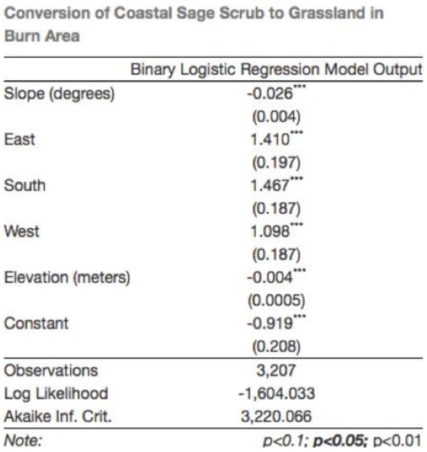
D



Conversion of Coastal Sage Scrub to Grassland in Burn Area with Years Since Burn Variable

	Binary Logistic Regression Model Output
Slope (degrees)	-0.024***
	(0.004)
East	1.507***
	(0.199)
South	1.517***
	(0.188)
West	1.108***
	(0.188)
Elevation (meters)	-0.003***
	(0.0005)
Years Since Burn	0.027***
	(0.005)
Constant	-1.963***
	(0.291)
Observations	3,207
Log Likelihood	-1,590.758
Akaike Inf. Crit.	3,195.516
Note:	*p<0.1;* ***p<0.05;*** p<0.01

E



Conversion of Coastal Sage Scrub to Grassland in Burn Area

	Binary Logistic Regression Model Output
Slope (degrees)	-0.026***
	(0.004)
East	1.410***
	(0.197)
South	1.467***
	(0.187)
West	1.098***
	(0.187)
Elevation (meters)	-0.004***
	(0.0005)
Constant	-0.919***
	(0.208)
Observations	3,207
Log Likelihood	-1,604.033
Akaike Inf. Crit.	3,220.066
Note:	*p<0.1;* ***p<0.05;*** p<0.01

Map of Sensitive Grassland Areas Surrounded by Shrubland

Our aerial photograph and vegetation map analyses revealed that grassland area has decreased at the preserve since the 1930s, and grassland to shrubland transitions were the most common. Given the fact that native grasslands are very rare on the property, TNC should closely monitor patches of native grassland that are surrounded by shrubland.

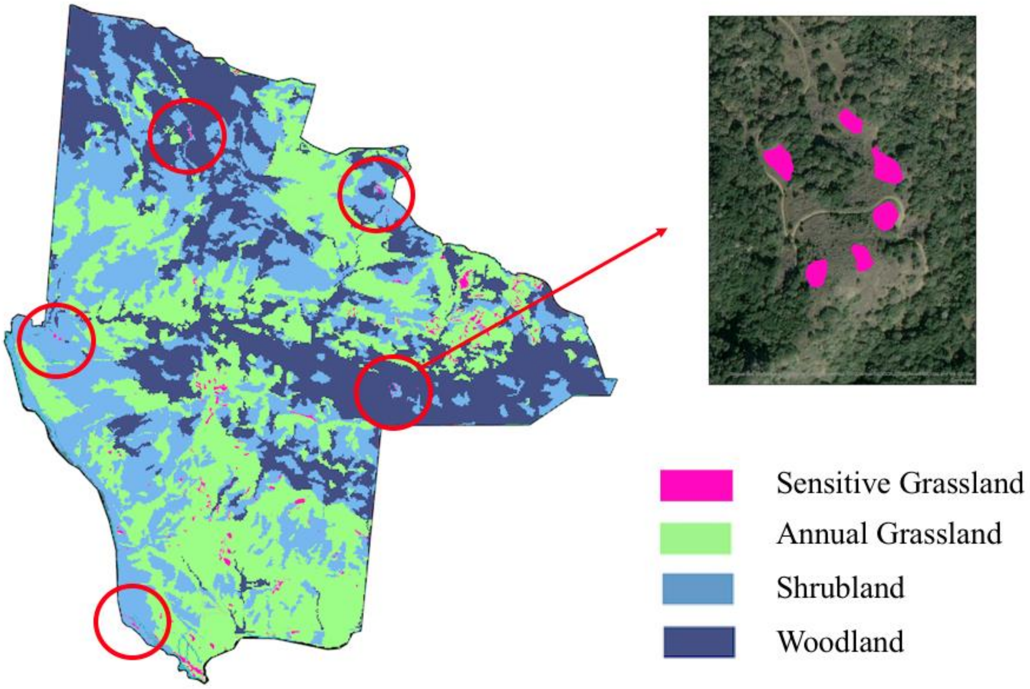


Figure A3-3. Sensitive grasslands at the Dangermond Preserve. Circled areas indicate patches of sensitive grassland surrounded by shrubland. These areas should be monitored into the future due to potentially high risk of conversion. Data from WRA Environmental Consultants (2017).

APPENDIX 4: VEGETATION TYPE MAPPING (VTM) RESURVEY METHODS

VTM Plot Sampling Protocol

The original protocol is found Albert Wieslander's original VTM methods manuscript (Wieslander 1935b). This updated version was adapted from Dr. Kelly Easterday's protocol, received through personal communication.

Conversions

1 Chain= 20.11682m
1 Chain= 66ft
1 meter= 3.28ft
1 foot= .3048m

Pre-Fieldwork Plot Relocation

Use historical plot-level attributes to locate possible site locations ahead of time in a GIS site suitability of given elevation (+/-50m), slope (+/-10%), and aspect (+/- 45°). See Plot Relocation Methods documentation.

Upload sited areas to ArcGIS Online and use Collector for ArcGIS in field (downloaded for offline use) to navigate to plots. Once in the field navigate to potential sites using ancillary information from original plots to locate best possible sites.

Use the many layers uploaded onto Collector from ArcGIS Online including: site suitability model, historic aerial imagery from the 1930s, the original 1905 topographic base map with plot locations, fire history, and a modern topographic map.

Siting the Plot

VTM field crew's mapped vegetation features with a minimum mapping unit of 40acres (a circle 504m in diameter) –in relatively large, homogeneous locations that exemplified vegetation types (R. Taylor, personal communication, July 2018. robert_s_taylor@nps.gov).

In gently rolling or flat county the center line of the sample plot follows a cardinal direction (N, S, E, W) as measured by compass, and is recorded on the plot sheet. In steep country the center line of the sample plot is at a right angle to the slope direction or contour –this means up and down the slope, not side slope.

Setting Up the Plot

Refer to Figure A4-1 below for general transect structure of the VTM field plot with dimensions.

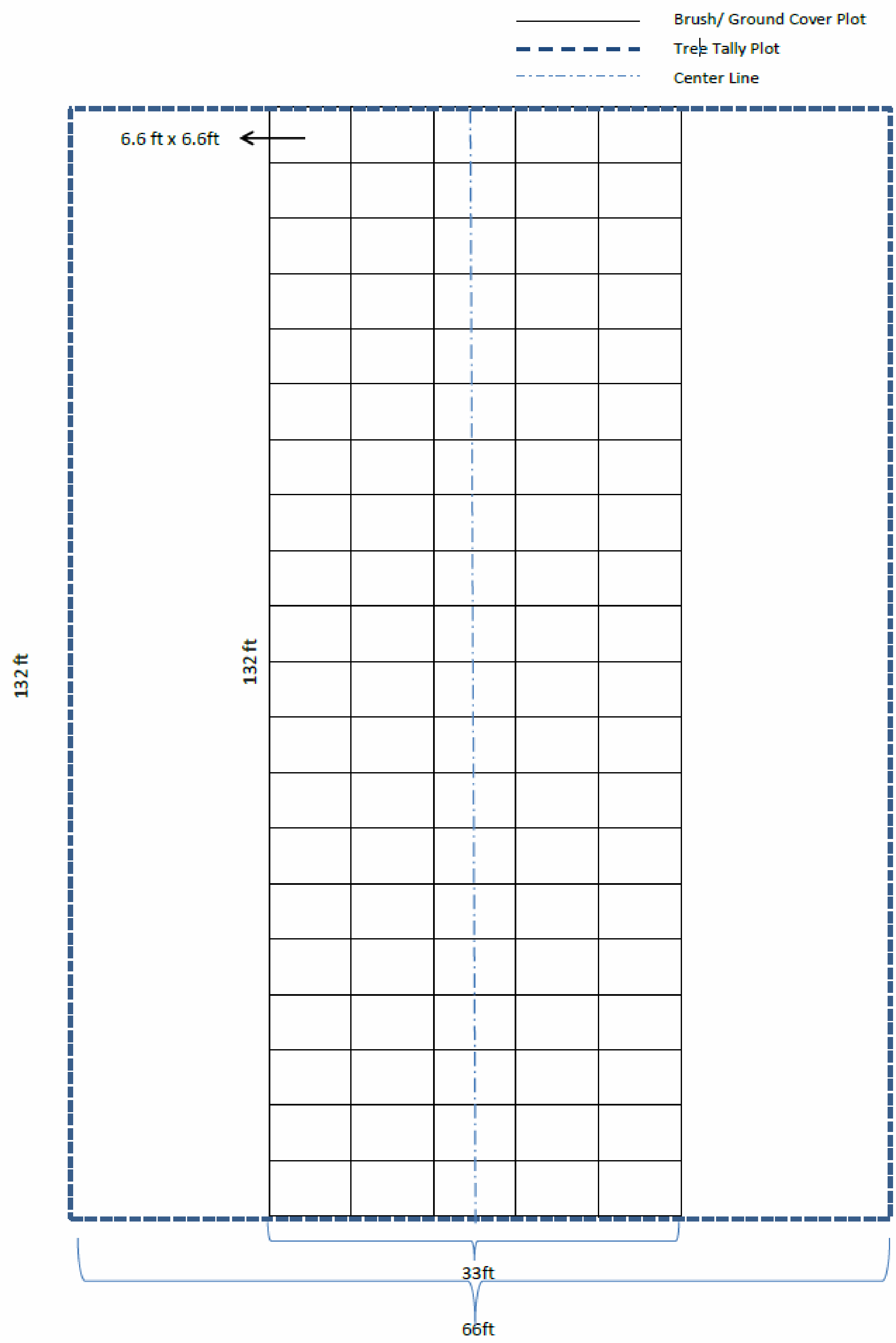


Figure A4-1. Repeat vegetation survey VTM plot layout.

1) Permanent Marker

Place a rebar stake at the beginning and end of the center transect. Use brass tags with Plot ID for identification. Cover with PVC pipe and spray paint orange for safety.

2a) Groundcover Plot

Use compass to find cardinal directions. If on a slope, center line will be perpendicular to contours. Run transect of 132 feet perpendicular to contour. Keep transect tape out. Flagging may be necessary in heavy brush or poison oak.

From the center line find 16.5 feet to both the right and left, and then flag/mark this distance along the length of the center line.

2b) Tree Tally Plot

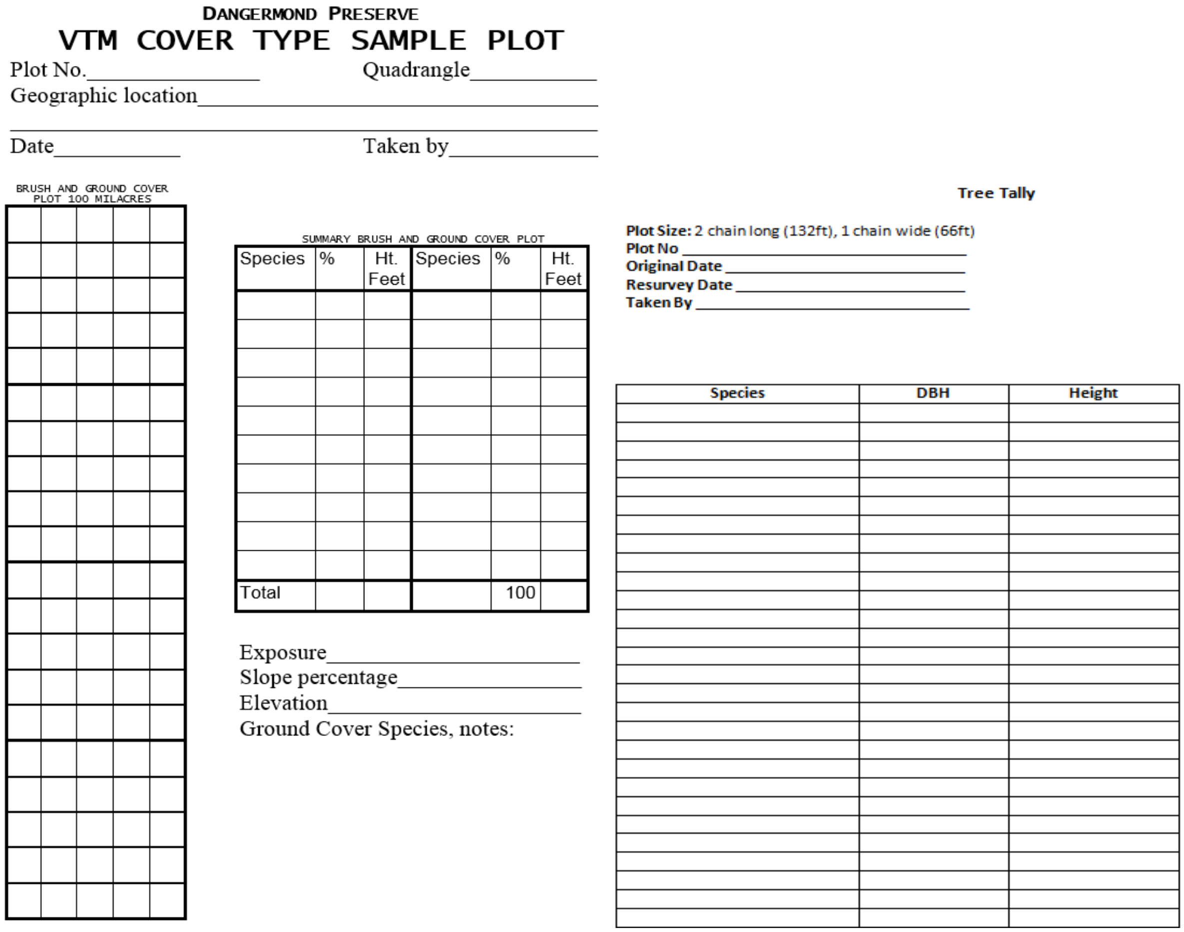
Walk an additional 16.5 feet from the outer edge (or 33 feet from the center line) of the ground plot on both right and left sides. This is the outer edge of the tree tally plot.

Recording the Plot

1) General Plot Details

Record the original plot ID, date of plot collection, observer, coordinates for the beginning of the transect, elevation from a modern topographic map, slope, and aspect. Input this information into Collector for ArcGIS using the 'New_Plot_Point' layer and write down on the paper plot sheet (Figure A4-2).

Take photographs from the start and from the end of the center transect, shooting towards plot center. Use a whiteboard in each photo to denote the Plot ID, date, photo bearing, and 'A' for the start of a transect and 'B' for the end of a transect.



DANGERMOND PRESERVE

VTM COVER TYPE SAMPLE PLOT

Plot No.________________ Quadrangle___________

Geographic location___________________________________

Date____________ Taken by_____________

BRUSH AND GROUND COVER PLOT 100 MILACRES

SUMMARY BRUSH AND GROUND COVER PLOT

Species	%	Ht. Feet	Species	%	Ht. Feet
Total				100	

Exposure________________________

Slope percentage_________________

Elevation________________________

Ground Cover Species, notes:

Tree Tally

Plot Size: 2 chain long (132ft), 1 chain wide (66ft)

Plot No ______________________________

Original Date ________________________

Resurvey Date ________________________

Taken By _____________________________

Species	DBH	Height

Figure A4-2. Plot datasheets for the brush and ground cover plots (left) and tree tally plots (right).

2a) Groundcover Plot

The recorder centers herself in the initial square of the middle tier and picks a point ahead to determine direction of the strip. Next, record by symbol the species that dominated the square in which they are standing using the original VTM species codes. If the species is dead its symbol is enclosed in parentheses. Assuming recorder is located in the center square: Look to the right ~10 feet and record the species dominating the adjacent square. Then look ~16.5 feet to the right outer edge of the plot and record the species dominating that outer square. Repeat for the left side. Then step ahead 6.6 feet and repeat the process 19 more times until at the end of the center line. It is helpful to bring two pieces of PVC pipe that are each 6.6 feet in length to use to visualize the plot squares (Taylor 2005).

In cells with greater than 50% vegetative cover, record the single most dominant species in that cell, regardless of where the individual plat is rooted – we are looking at top-down cover only.

Where less than 50% of any square is brush- or grass-covered, the character of the ground surface is indicated as follows:

Ba or X: Barren Area

R: Rock outcrops prohibits vegetation

Lit: litter

Trunk: tree trunk that takes up square

Leave no square blank.

When a new species is recorded in the plots automatically add it to the summary table, and add up all squares that species was present in to get percent cover. The number of cells dominated by each species are tallied to represent percent cover.

<u>2b) Tree Tally Plot</u>

From the center line to the outer edge of the tree plot, record the diameter at breast height (DBH) and species for each tree above 4 inches DBH.

Fieldwork Checklist

Field Equipment

- iPad and stylus pencil
- Receiver
- Clinometer
- Compass (declination preset)
- Hypsometer (for tree heights)
- Flagging
- Camera
  - Photoboard/whiteboard
  - Tripod
- Clipboard and Pencils
- Binder(s)
- Measuring Tapes
  - 50m tape
  - 20/30m tape
  - 10m diameter tape (for DBH)
- 12 inch metal ruler graduated in tenths of inches for litter/duff depth
- Plant ID Guide
- Plant ID Tools and Supplies
- Permanent Stakes, spraypaint and PVC
- Brass tags
- Hammer
- Pin flags
- Flagging
- Ziploc Bags
- Tyvek suit
- Garbage bag (poison oak)
- First Aid Kit
- Radios (from TNC)
- Food/Water/Snacks
- Sunblock
- State Parks pass
- Duffel Bag for gear

Plot Relocation Method using Collector for ArcGIS

Part 1: ArcGIS Pro

- Transfer maps from ArcMap into ArcGIS Pro. There are two options:
    - Import existing map
    - Create new map and drag/import layers individually
- To start either option: Create new .aprx file in ArcGIS Pro
- Import map that you have created in ArcMap
- Click ‘Import Map’ and follow pathway to your .mxd file
- Share Tab > Share As Group > Web Layer > Publish Web Layer
- Click Analyze, then Publish, and then wait for the data to consolidate and stage the web layer

Part 2: ArcGIS Online (AGOL)

- Sign into ArcGIS Online
    - You should see your newly created web layer under My Content
- Create your feature layer
    - Now you need to create a blank feature layer (this will be the layer you collect data in)
    - Configure layer to make it editable: click on the layer and go to Settings Tab > click Enable Editing and Enable Sync
- Create a webmap
    - Add your feature layer and other layers to your webmap
    - To add layers, open your webmap in Map Viewer. Click the Add dropdown, choose Search for Layers. Choose your layer by clicking the + button
- Hit SAVE
- Take your webmap offline and put in collector
    - Settings > Offline Mode > Choose Offline Mode
    - Enable Sync

Part 3: ArcGIS Collector

To add a feature point for data collection in Collector, make sure to load your webmap onto your device. Simply select the Collect New (+) button in the top right corner of the screen at any time. Once you have collected your data (plot key, aspect, slope degrees, elevation, transect bearing, and any additional notes) hit Submit (See Figure A4-3). The data is now stored on the device locally, and as soon as you return to a wi-fi network, you can sync your data on AGOL.

Plot Locations were digitized by UC Berkeley (Kelly et al. 2005) and projected into CA Albers NAD27 projection.

Using ArcMap 10.5.1 -
1. Clip plot layer to area around Dangermond Preserve.
2. Re-project plot points to CA Teale Albers NAD27.
3. Buffer each point with a 247m radius circle.
4. Split all plot error buffers into individual vector layers.
5. Use “SearchReduction” Tool to reduce the search area within each plot error buffer based on the original written site description that includes details for each plot concerning slope percent, aspect, and elevation.

“SearchReduction” Tool – Created using Model Builder.
1. Load USGS digital elevation model (DEM) raster layer.
2. Create slope and aspect layers from DEM using ‘Slope’ and ‘Aspect’ tools.
3. Convert plot error buffer to raster using ‘Polygon to Raster’ tool.
4. Use ‘Reclassify’ to create a mask that selects the desired slope, aspect, and elevation. Allow slopes +/- 10%, elevations +/- 50m, and aspect +/- 45°.
5. ‘Extract by Mask’
6. The output is a raster layer that shows the likely location of the VTM plot.

●	157G11 157G11
☐	157G11 157G11
🟩	113 113
🟥	1 0

Details

Location
Lat: 34.49608917° Long: -120.42297517°

157G11

PLOTKEY
157G11

ASPECT
340

SLOPE_DEG
17

ELEVATION
1,100

NOTES

TRANSECT_BEARING
340

Figure A4-3. VTM plot information in ArcGIS online. Screenshot showing the Collect New (+) button (top right) and what a feature looks like once it has been collected and submitted (right side). The image on the map itself is the plot search model containing polygons (green) that match the original plot’s slope, aspect and elevation. The blue dot is the original plot location determined by UC Berkeley surrounded by the green buffer circle. The pink dot is where the transect of the new plot begins. Yellow squares were areas we predetermined to be suitable for relocation prior to entering the field.

Plot Relocation Discussion

There are 20 plots within the preserve boundaries, but we surveyed 17 plots over eight days of fieldwork. The plot data for the remaining three plots currently cannot be located by UC Berkeley librarians and is likely lost. Each plot was permanently marked with two orange rebar stakes to assist in relocation for future monitoring efforts. Unfortunately, due to the human nature of the original VTM survey effort, there may still be the possibility that some plot locations were incorrectly recorded on the plot location map. We believe this to be the case for Plot 157F16, for which the plot description recorded a northeast aspect, but no slope with this aspect exists within the plot error buffer.

We believe the three missing plot data are ‘herbaceous plots’ which are slightly different than the shrub and tree plots in that they are located in grassland and record only species occurrence, not coverage. During our visit to UC Berkeley, both the Koshland Bioscience Library and the Maggi Kelly lab (the holders of the original plot data) were unable to locate the original plot data cards. They are actively searching for the missing data and are organizing a better storage system.

Using the ArcGIS model and the original plot location descriptions that include slope, aspect, and elevation, we were able to survey two plots per day. The most time consuming part is placing the plot in the correct location. With a 247-meter error buffer and sometimes conflicting plot location descriptions, this can be a difficult task. Furthermore, many of the plots were located on steep terrain, in thick brush, and with abundant poison oak. We referenced the original Wieslander manual often and tried to get into the minds of the original surveyors. We will never know how accurate our resample locations are, but we are confident they are in the same stand of vegetation of the original.

Limitations of the VTM Plot Resurvey

The major limitations in resampling VTM plots stem from 1) the original survey not permanently monumenting the vegetation plots, and 2) inaccuracies in the mapping methods used. The Maggi Kelly lab at UC Berkeley digitized plot locations by scanning, stitching, and georeferencing the original plot location map (Figure A4-4). The original 1931 plot location map was cut into tiles so that it could be folded without damaging the map in the field, thus these tiles needed to be stitched together to complete the full map. The digitization process calculated a 247-meter average error for the plot locations on the Lompoc quadrangle map, on which the Dangermond Preserve is located. Kelly et al. (2005) identify the following potential errors:

1) Error associated with the historic base maps: The plot locations were stamped onto a 1905 USGS topographic map that uses Clarke's spheroid of 1866 and a polyconic projection unique to each quadrangle. It is difficult to bring this into alignment with modern maps without some resulting error.
2) Error associated with the size of the surveyor's plot marker on the map
3) Error associated with the analyst locating the plot in the center of the marked circle
4) Error associated with the modern DRG (derived from NMAS standards)
5) Error associated with the registration of the original 1905 base map
6) Error associated when the section map is registered

To account for this error, we buffered the digitized plot locations with a 247-meter circle and utilized the original plot slope, elevation, and aspect descriptors to narrow our search within the error buffer (Taylor 2005). This was accomplished using a model (Figure A4-5) in ArcMap that masked out areas that did not match the site description. The result (Figure A4-6) is a much reduced area within which to site the resample location. Aerial images from 1938 were also compared to modern aerial images of the plot location to ensure that we were correctly siting plots in areas having the same general vegetation type as the original survey in 1931 (Figure A4-7).

Some studies have resampled individual VTM plots (Dolanc et al. 2013), while others have compared VTM data to modern surveys like the Forest Inventory Analysis (McIntyre et al. 2015, Fellows and Goulden 2008). Keeley (2004) argues that this is more problematic than other researchers suggest, because he found that southern California shrub communities can exhibit large spatial variation within small distances. Dolanc et al. resampled in the Sierra Nevada and noted that although it was likely their resample plots fell outside of the exact footprint of the original VTM plot, they were confident that they were located in the same forest stand (Dolanc et al. 2013). Following Dolanc et al.'s methods, and with guidance from our faculty advisor Kelly Caylor, we chose to conduct a single, well-placed resample plot for each of the 17 original plots for which historic data exists. We cannot know how accurate our resample locations are, but following the reasoning of Dolanc et al., we are confident they are in the same stand of vegetation of the original.

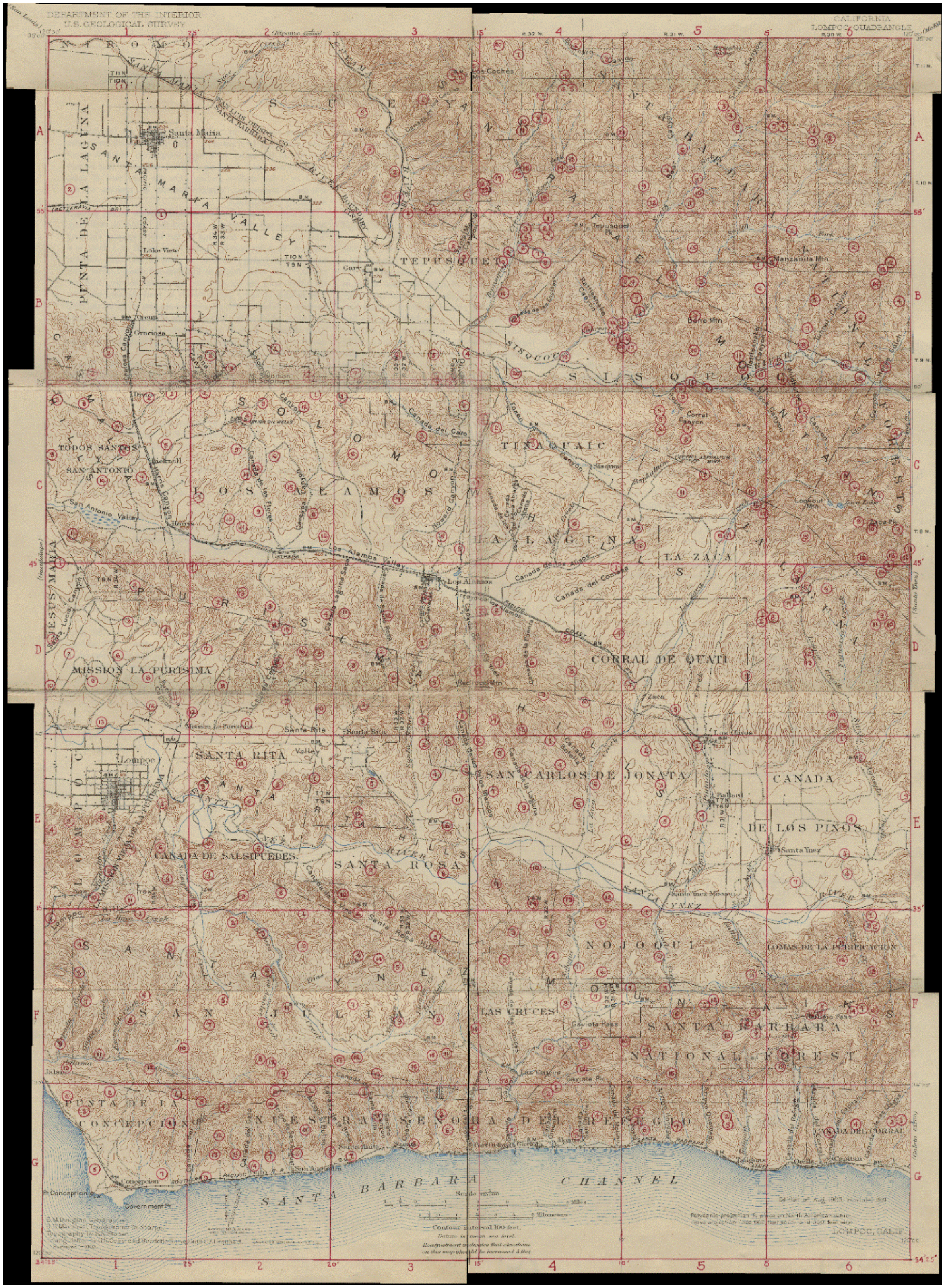


Figure A4-4. Scanned knitted version of the original 1931 VTM plot location map for the Lompoc quadrangle (Courtesy of Kelly Easterday at UC Berkeley).

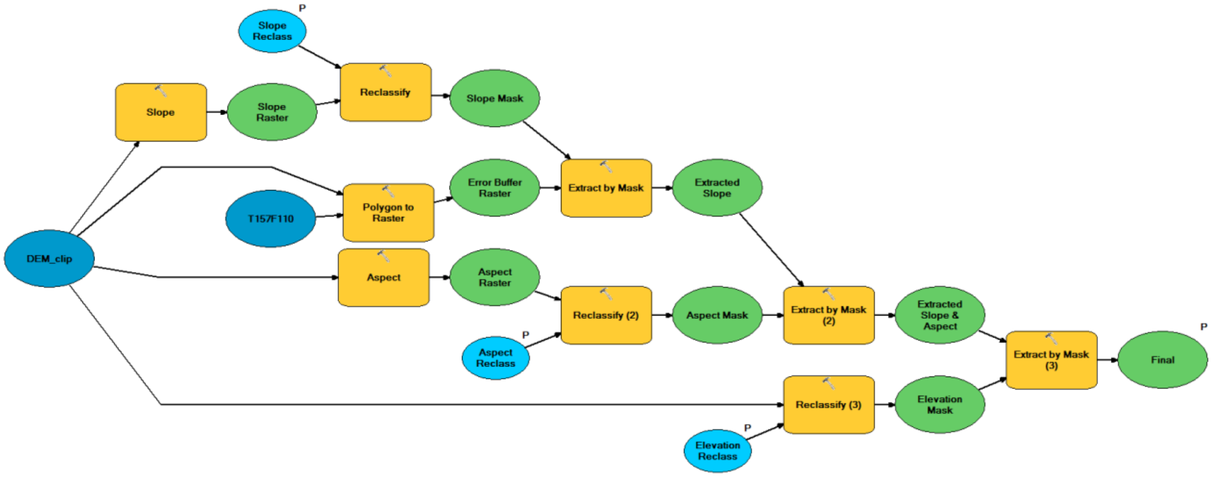


Figure A4-5. Plot relocation model in ArcGIS version 10.5.1.

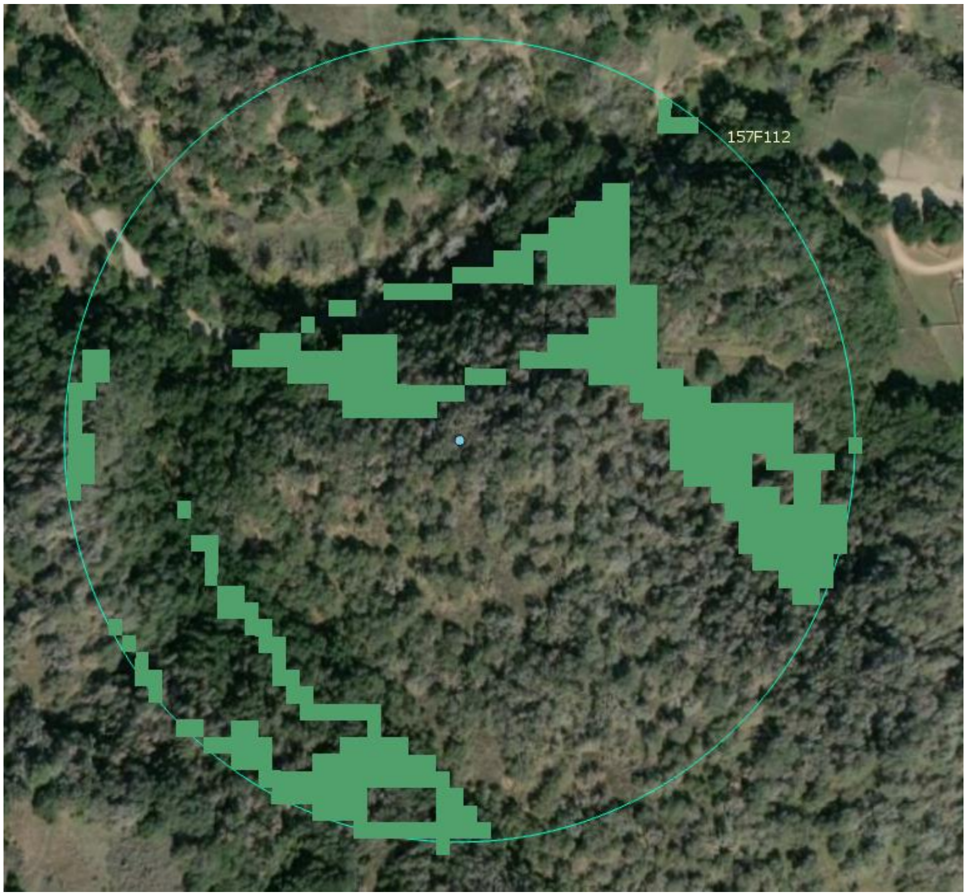
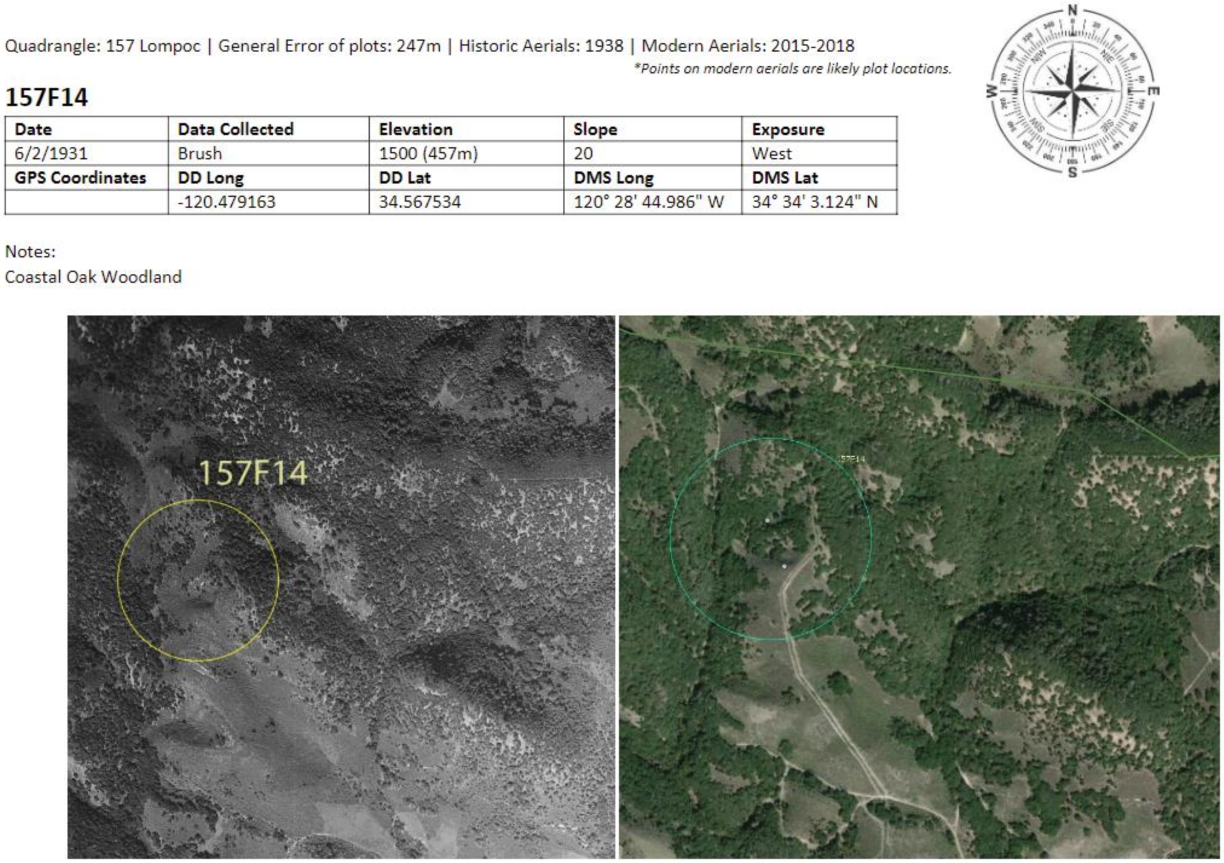


Figure A4-6. Areas within a VTM plot error buffer that match the descriptions of the original plot location. These areas were identified using our plot relocation model in ArcGIS.



Quadrangle: 157 Lompoc | General Error of plots: 247m | Historic Aerials: 1938 | Modern Aerials: 2015-2018

**Points on modern aerials are likely plot locations.*

157F14

Date	**Data Collected**	**Elevation**	**Slope**	**Exposure**
6/2/1931	Brush	1500 (457m)	20	West
GPS Coordinates	**DD Long**	**DD Lat**	**DMS Long**	**DMS Lat**
	-120.479163	34.567534	120° 28' 44.986" W	34° 34' 3.124" N

Notes:
Coastal Oak Woodland

Figure A4-7. Aerial photographs and site topographic characteristic were used to relocate historical survey plots.

APPENDIX 5: VEGETATION TYPE MAPPING (VTM) RESURVEY RESULTS

Table A5-1. List of all plant species observed during the 1931 and 2018 VTM surveys.

Scientific Name (1931)	Scientific Name (2018)	Common Name	Observed in 1931?	Observed in 2018?
Adenostoma fasciculatum	-	Chamise	Yes	Yes
-	-	Annuals	**No**	Yes
*Arctostaphylos andersonii**	-	Heartleaf manzanita	Yes	**No**
Artemisia californica	-	California sagebrush	Yes	Yes
Baccharis pilularis	-	Coyote brush	Yes	Yes
-	-	Barren Ground	Yes	Yes
Ceanothus cuneatus	-	Buckbrush	Yes	Yes
Coreopsis gigantea	-	Giant coreopsis	Yes	Yes
Diplacus aurantiacus	-	Sticky monkey-flower	Yes	Yes
Elymus condensatus	-	Giant wild rye	Yes	Yes
Encelia californica	-	California bush sunflower	Yes	Yes
-	-	Grass	Yes	Yes
Hazardia squarrosa	-	Sawtooth goldenbush	Yes	Yes
-	-	Litter	Yes	Yes
Lonicera hispidula var. *californica*	-	Pink honeysuckle	**No**	Yes
Lotus scoparius	*Acmispon glaber*	Deerweed	Yes	Yes
Mesembryanthemum aequilaterale	*Carpobrotus edulis*	Ice plant	**No**	Yes
Photinia arbutifolia	*Heteromeles arbutifolia*	Toyon	Yes	Yes
Polystichum spp.	-	Sword fern	Yes	**No**
Prunus ilicifolia	-	Holly-leafed cherry	Yes	**No**

Pteris aquilina lanuginosa	-	Bory Hook	Yes	**No**
Quercus agrifolia	-	Coast live oak	Yes	Yes
Rhamnus california	*Frangula californica*	Coffeeberry	Yes	Yes
Rhamnus crocea	-	Spiny redberry	Yes	Yes
Rhus diversiloba	*Toxicodendron diversilobum*	Western poison oak	Yes	Yes
Ribes malvaceum	-	Chaparral currant	Yes	**No**
Ribes sanguineum	-	Red flowering currant	Yes	**No**
Rubus vitifolius	*Rubus ursinus*	California blackberry, Pacific blackberry	Yes	Yes
Salvia leucophylla	-	Purple sage	Yes	Yes
Salvia mellifera	-	Black sage	Yes	Yes
Salvia spathacea	-	Hummingbird sage	**No**	Yes
Sambucus glauca	*Sambucus nigra ssp. caerulea*	Blue elderberry	Yes	Yes
-	-	Trunk	**No**	Yes

*We believe *Arctostaphylos andersonii* was misidentified in 1931. We recorded it as *Arctostaphylos species* in 2018.

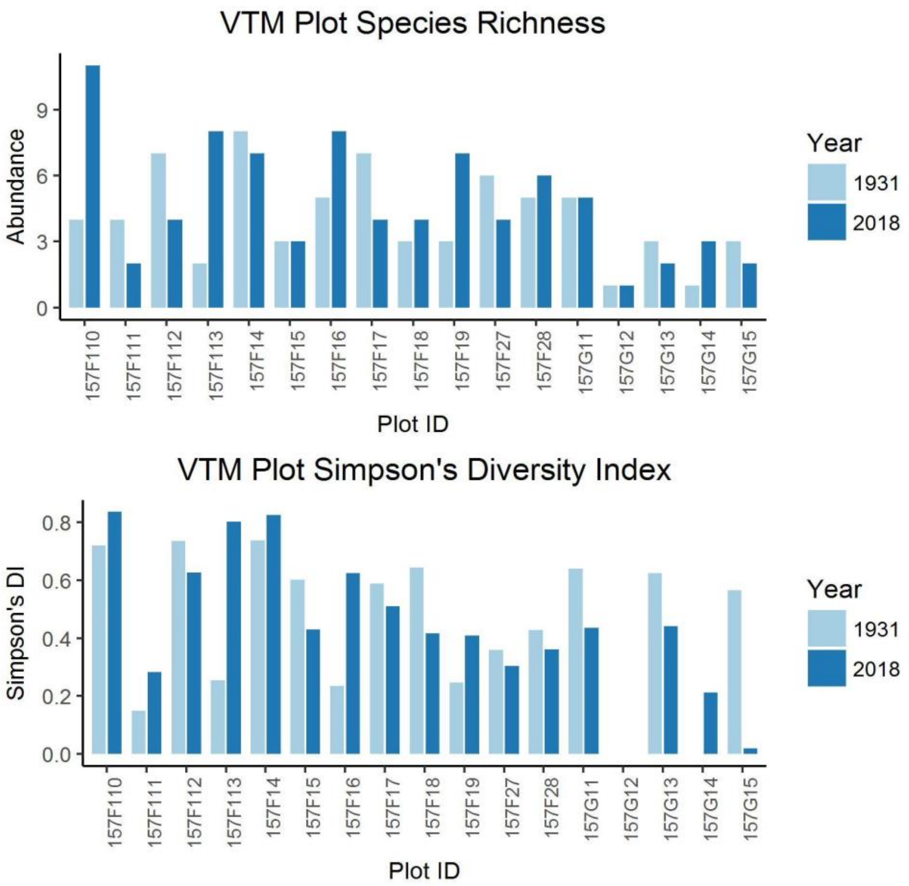


Figure A5-1. Species richness (top) and Simpson’s diversity (bottom) for all 17 VTM plots. Values for 1931 and 2018 are in light and dark blue, respectively.

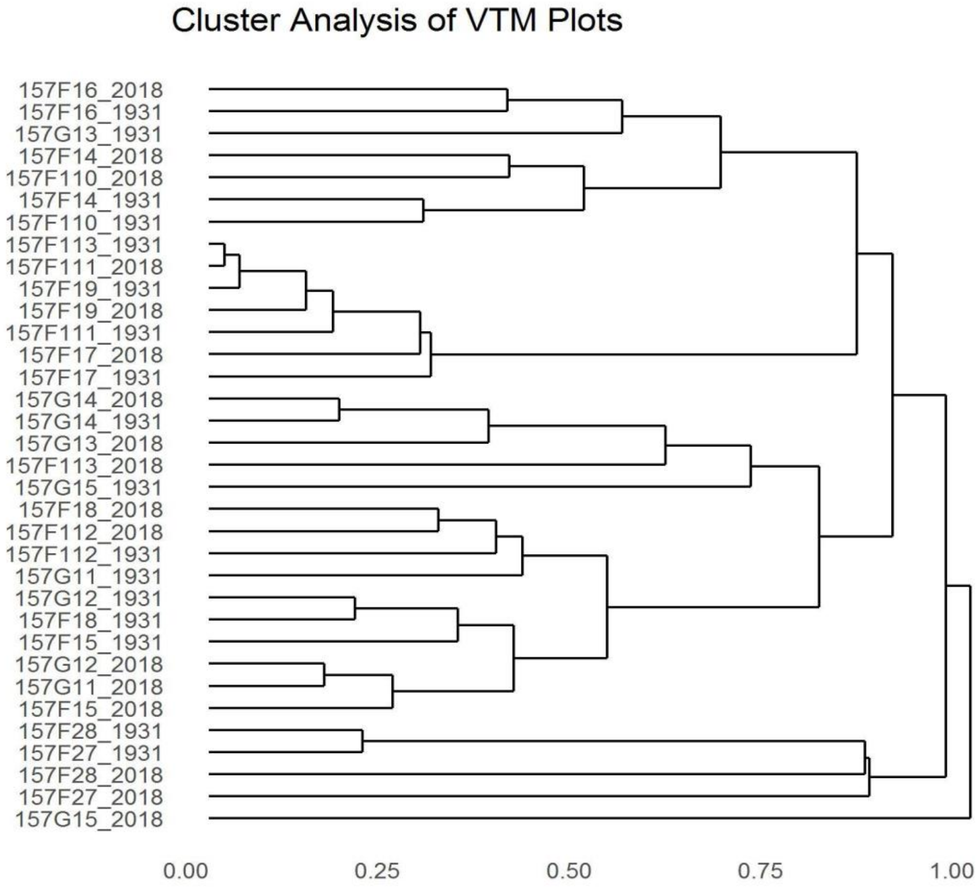


Figure A5-2. Hierarchical clustering results for all sampled VTM plots in 1931 and 2018. Plots are labeled with Plot ID_Year notation.

Vegetation composition in 2018 for plot 157G15 was the most dissimilar to all other plots, likely due to the complete dominance of iceplant (*Carpobrotus edulis*) found only in that plot. Some plots were most similar to each other over the two time steps; for example, plot 157F16 was most similar to itself (composition did not change over time). Conversely, some plots were more similar to other plots – 157F27 and 157F28 were most similar to each other in 1931 but not in 2018. In the case of these two plots, vegetation composition changed slightly over time but in a similar pattern at both locations.

APPENDIX 6: HYDROLOGY MODEL

To predict perennial water, the DEM layer was used as the input for the first step of the hydrological model. Each successive step used the previous step's raster output to ultimately yield a stream network with year-round water in the channels. The ArcGIS hydrology tools used are listed below in sequence order.

Fill

The first tool employed is Fill, using the DEM raster as the input and giving the 'filled' DEM as output. This tool fills in sinks and other imperfections in the surface raster where some pixels are lower or higher in elevation than all surrounding pixels and thereby disrupting flow. A simplified graphic below gives further explanation.

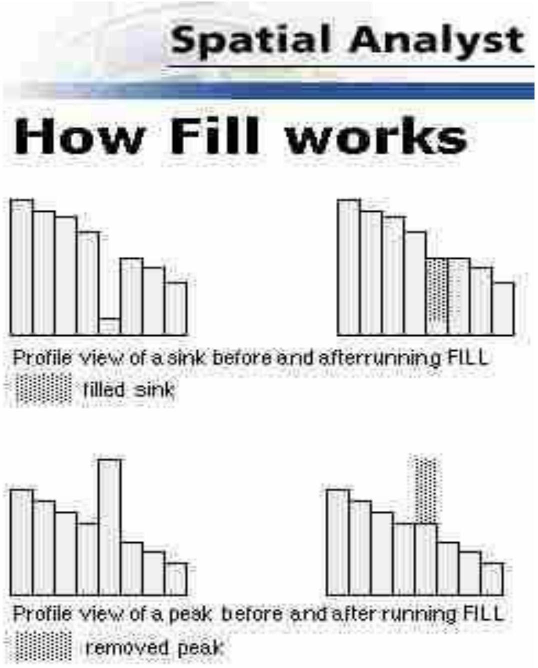


Figure A6-1. ArcGIS hydrology fill tool used to construct perennial water model. Credit: Tarboton et al., 1991.

Flow Direction

Using the ‘filled’ DEM output from the previous step as the input for the Flow Direction gives an output raster ‘flow_dir’. Due to the highly varied topography of the Preserve and to achieve the best prediction of perennial water, a more processing intensive step of using infinite flow directions was used rather than a more common D8 (eight directions) parameter. Infinite flow directions along with high spatial resolution gives a closer overall flow direction picture.

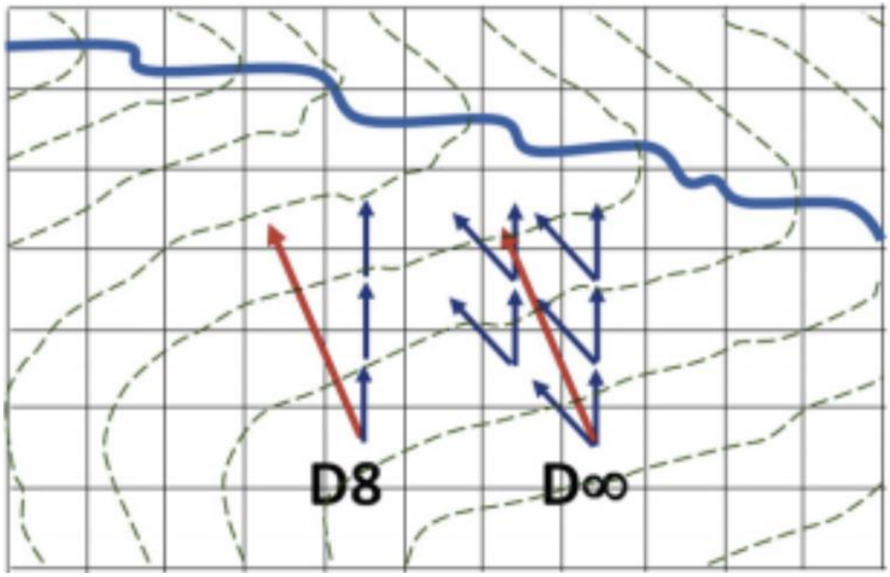
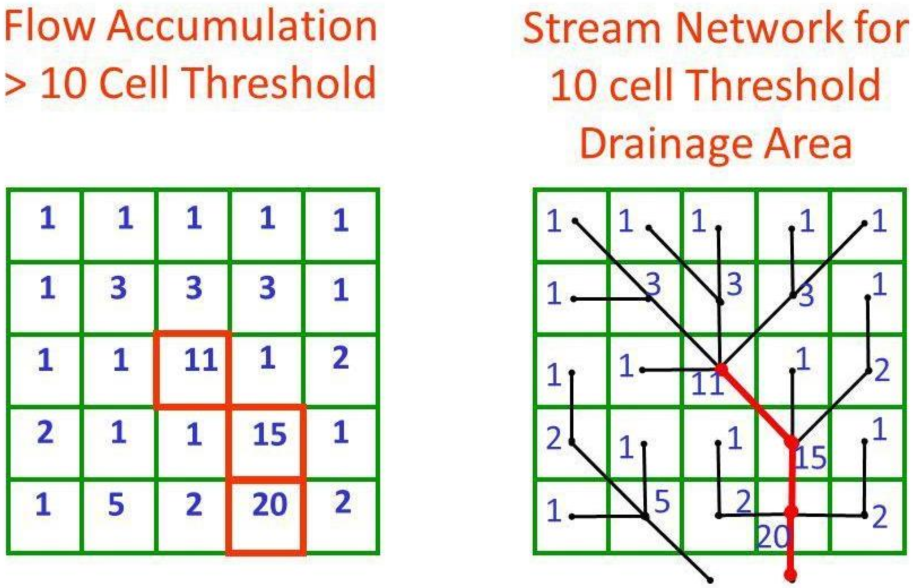


Figure A6-2. ArcGIS hydrology flow direction tool used to construct perennial water model. Credit: Tarboton et al., 1991.

A flow direction grid assigns a value to each cell to indicate the direction of flow – that is, the direction that water will flow from that particular cell based on the underlying topography of the landscape. This is a crucial step in hydrological modeling, as the direction of flow will determine the ultimate destination of the water flowing across the surface of the land.

Flow Accumulation

Using the previous steps ‘flow_dir’ output as the input for the flow accumulation tool yields an integer data set of the accumulated number of cells that are draining to any other cell, called ‘flow_accum’. The graphic below illustrates how the upstream cells are linked to the nearest downslope cell additively to create a stream system. Weighting biases were not applied for this analysis – these would be appropriate for drought or flood models – as this analysis aims for baseline conditions.



1	1	1	1	1
1	3	3	3	1
1	1	11	1	2
2	1	1	15	1
1	5	2	20	2

Figure A6-3. ArcGIS hydrology flow accumulation tool used to construct perennial water model.
Credit: Tarboton et al., 1991.

After this step, the Raster Calculator tool was used to create a threshold layer excluding all cell values below 9,999 using the following work flow: Spatial Analyst Tools → Map Algebra → Raster Calculator with statement “SetNull(“flow_accum” >=10000,1)”. The cell value 10,000 was selected on the advice of Dr. Kelly Caylor of the Bren School, who deemed this number appropriate for this model. The resulting output of this layer was called ‘stream_network’.

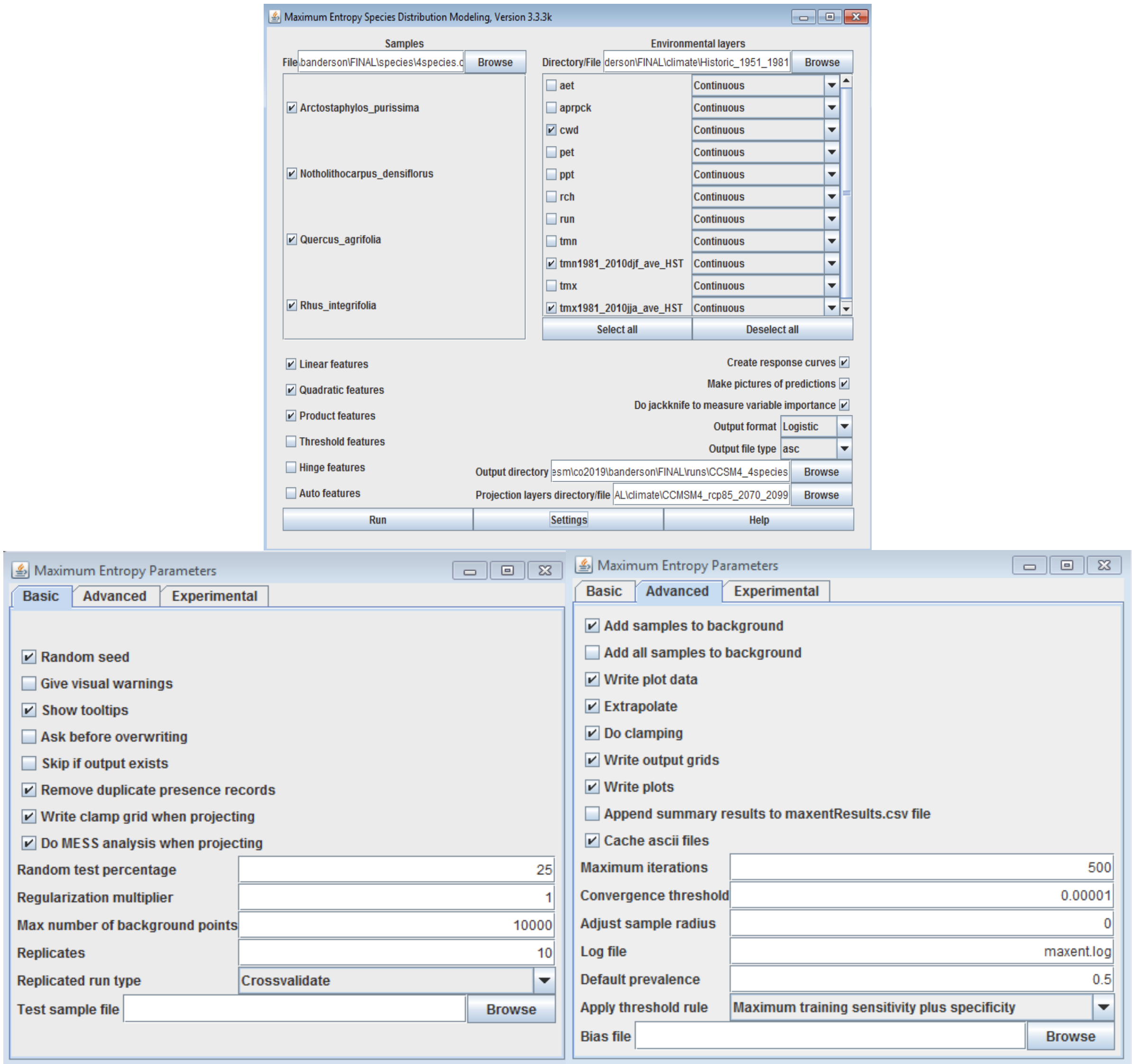
Stream Order

The last step involves using the ‘stream_network' output raster from the previous step along with ‘flow_dir’ as the inputs for the stream order tool. This final step assigns a relational numeric order to all segments of the stream network, with the highest values reflecting the stream with the most water.

APPENDIX 7: SPECIES DISTRIBUTION MODELING

Table A7-1. Environmental variables tested for inclusion in Maxent model.

Environmental Variable	**Source**	**Resolution**	**Selected**
Climatic water deficit (mm)	BCM	270 meter	Yes
Mean maximum summer temperature(Celcius)	BCM	270 meter	Yes
Mean minimum winter temperature(Celcius)	BCM	270 meter	Yes
Actual evapotranspiration (mm)	BCM	270 meter	No
April 1 snowpack (mm)	BCM	270 meter	No
Recharge (mm)	BCM	270 meter	No
Potential evapotranspiration (mm)	BCM	270 meter	No
Precipitation (mm)	BCM	270 meter	No
Runoff (mm)	BCM	270 meter	No
Digital elevation model	USGS	~10m	No
Percent clay	SSURGO	Vector	No
Percent sand	SSURGO	Vector	No
Percent silt	SSURGO	Vector	No
pH	SSURGO	Vector	No
Electrical conductivity	SSURGO	Vector	No
Sodium absorption ratio	SSURGO	Vector	No
Calcium carbonate	SSURGO	Vector	No



Maximum Entropy Species Distribution Modeling, Version 3.3.3k

Samples

File banderson\FINAL\species\4species.c

☑ Arctostaphylos_purissima
☑ Notholithocarpus_densiflorus
☑ Quercus_agrifolia
☑ Rhus_integrifolia

Environmental layers

Directory/File derson\FINAL\climate\Historic_1951_1981

☐ aet Continuous
☐ aprpck Continuous
☑ cwd Continuous
☐ pet Continuous
☐ ppt Continuous
☐ rch Continuous
☐ run Continuous
☐ tmn Continuous
☑ tmn1981_2010djf_ave_HST Continuous
☐ tmx Continuous
☑ tmx1981_2010jja_ave_HST Continuous

☑ Linear features
☑ Quadratic features
☑ Product features
☐ Threshold features
☐ Hinge features
☐ Auto features

Create response curves ☑
Make pictures of predictions ☑
Do jackknife to measure variable importance ☑
Output format Logistic
Output file type asc
Output directory esm\co2019\banderson\FINAL\runs\CCSM4_4species
Projection layers directory/file AL\climate\CCMSM4_rcp85_2070_2099

Maximum Entropy Parameters

Basic

☑ Random seed
☐ Give visual warnings
☑ Show tooltips
☐ Ask before overwriting
☐ Skip if output exists
☑ Remove duplicate presence records
☑ Write clamp grid when projecting
☑ Do MESS analysis when projecting
Random test percentage 25
Regularization multiplier 1
Max number of background points 10000
Replicates 10
Replicated run type Crossvalidate
Test sample file

Maximum Entropy Parameters

Advanced

☑ Add samples to background
☐ Add all samples to background
☑ Write plot data
☑ Extrapolate
☑ Do clamping
☑ Write output grids
☑ Write plots
☐ Append summary results to maxentResults.csv file
☑ Cache ascii files
Maximum iterations 500
Convergence threshold 0.00001
Adjust sample radius 0
Log file maxent.log
Default prevalence 0.5
Apply threshold rule Maximum training sensitivity plus specificity
Bias file

Figure A7-1. Maxent parameter settings. Top: File input settings. Bottom: Basic and advanced parameter settings.

Table A7-2. Maxent AUC values and computed suitability thresholds for binary predictions of species presence/absence using the warm/wet MPI RCP 4.5 climate projection.

Species	Area Under Curve	Maximum Sensitivity + Specificity Threshold
Coast live oak (*Q. agrifolia*)	0.867	0.243
Tanoak (*N. densiflora*)	0.912	0.202
Lemonade berry (*R. integrifolia*)	0.963	0.144
La Purisima Manzanita (*A. purissima*)	0.989	0.119

Table A7-3. Maxent AUC values and computed suitability thresholds for binary predictions of species presence/absence using the hot/dry MIROC RCP 8.5 climate projection.

Species	Area Under Curve	Maximum Sensitivity + Specificity Threshold
Coast live oak (*Q. agrifolia*)	0.867	0.238
Tanoak (*N. densiflora*)	0.912	0.267
Lemonade berry (*R. integrifolia*)	0.963	0.143
La Purisima Manzanita (*A. purissima*)	0.989	0.128

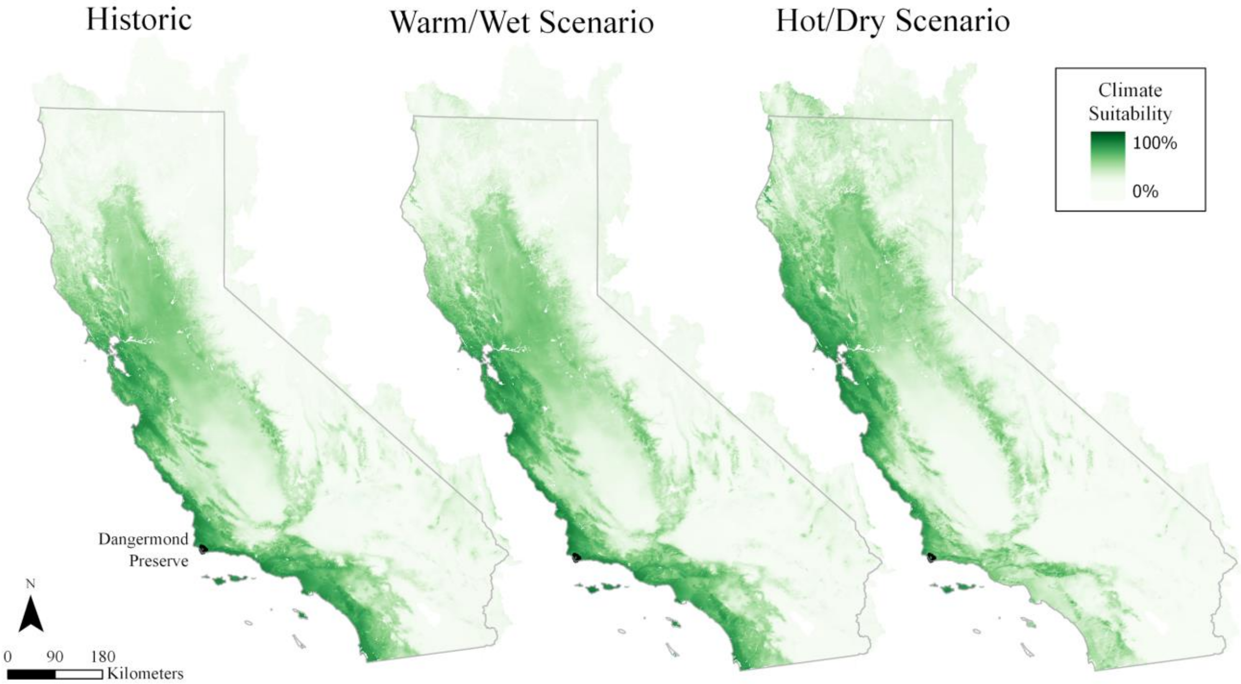


Figure A7-2. Coast live oak (*Quercus agrifolia*) suitability projection under historic conditions (left), warm/wet MPI RCP 4.5 scenario (center), and hot/dry MIROC RCP 8.5 scenario (right).

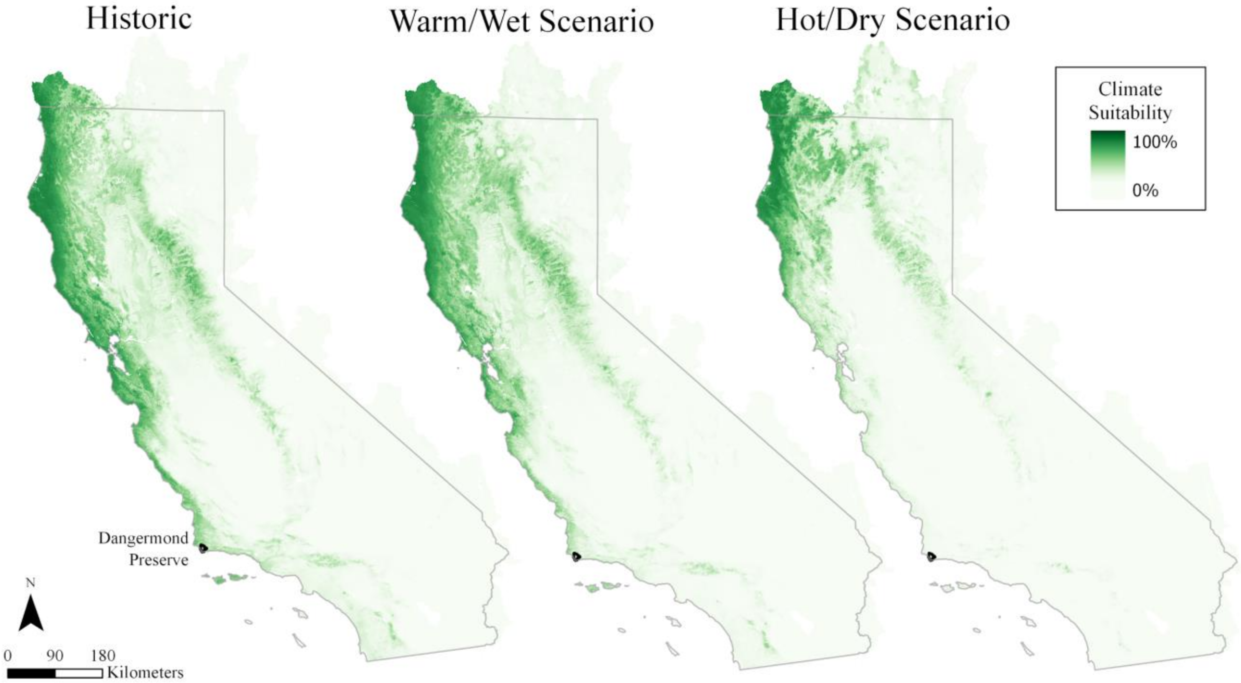


Figure A7-3. Tanoak (*Notholithocarpus densiflora*) suitability projection under historic conditions (left), warm/wet MPI RCP 4.5 scenario (center), and hot/dry MIROC RCP 8.5 scenario (right).

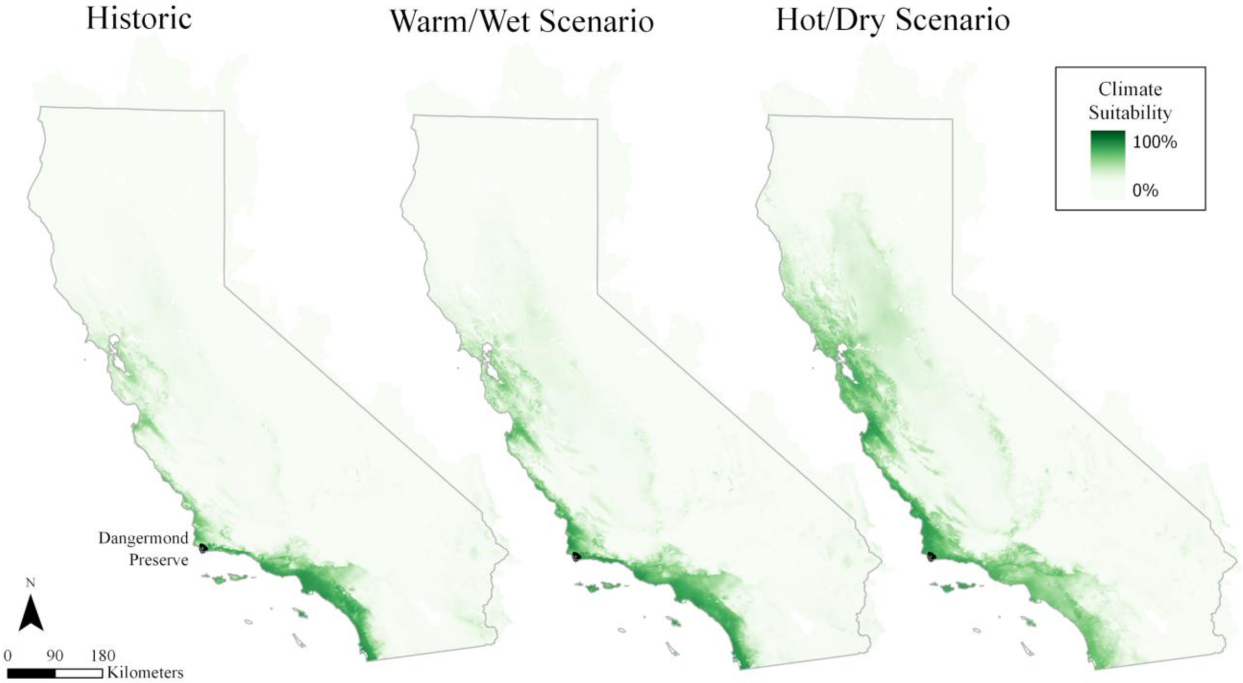


Figure A7-4. Lemonade berry (*Rhus integrifolia*) suitability projection under historic conditions (left), warm/wet MPI RCP 4.5 scenario (center), and hot/dry MIROC RCP 8.5 scenario (right).

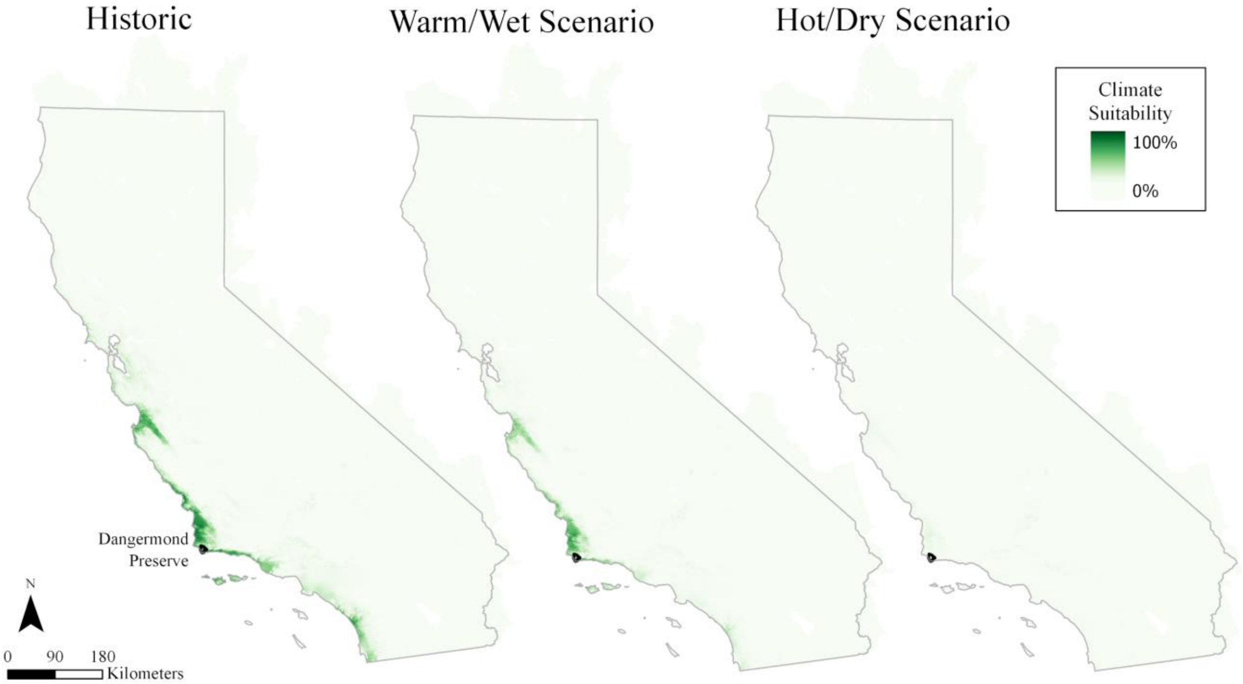


Figure A7-5. La Purisima manzanita (*Arctostaphylos purissima*) suitability projection under historic conditions (left), warm/wet MPI RCP 4.5 scenario (center), and hot/dry MIROC RCP 8.5 scenario (right).

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