ABSTRACT

ASSESSMENT OF WILDFIRE FREQUENCY AND COASTAL SAGE SCRUB VEGETATION DYNAMICS IN THE SANTA MONICA MOUNTAINS OF SOUTHERN CALIFORNIA

By

Scott W. Eckardt

December 2006

The distribution of coastal sage scrub (CSS) vegetation in Southern California is strongly influenced by local disturbance regimes. Focusing on CSS stand boundary shifts over time in the Cheseboro and Palo Comado Canyons of the Santa Monica Mountains, this study assesses the influences of wildfire frequency on changes observed in multiple historical aerial photograph sets. Fire perimeter data and field sampling data were also utilized to evaluate vegetation cover change over two distinct time periods: 1929 - 1976 and 1976 - 2003. Fire perimeter data and burn frequencies were correlated with CSS coverage change calculations at a coarser scale, and field sampling data was analyzed to determine the influences of fire frequency on CSS stand dynamics at a finer scale. While dramatic CSS coverage loss was observed in portions of the study area with documented high fire frequencies, correlations between CSS/grassland ecotone fluctuations and fire frequency were inconclusive.

ASSESSMENT OF WILDFIRE FREQUENCY AND COASTAL SAGE SCRUB VEGETATION DYNAMICS IN THE SANTA MONICA MOUNTAINS OF SOUTHERN CALIFORNIA

A THESIS

Presented to the Department of Geography

California State University, Long Beach

In Partial Fulfillment for the Degree

Master of Arts in Geography

By Scott W. Eckardt

B.S., 1998, California Polytechnic State University, San Luis Obispo

December 2006

WE, THE UNDERSIGNED MEMBERS OF THE COMMITTEE,

HAVE APPROVED THIS THESIS

ASSESSMENT OF WILDFIRE FREQUENCY AND COASTAL SAGE SCRUB VEGETATION DYNAMICS IN THE SANTA MONICA MOUNTAINS OF SOUTHERN CALIFORNIA

By

Scott W. Eckardt

COMMITTEE MEMBERS

Paul Laris, Ph.D. (Chair) Geography

Christopher T. Lee, Ph.D. Geography

Christine M. Rodrigue, Ph.D. Geography

ACCEPTED AND APPROVED ON BEHALF OF THE UNIVERSITY

Mark Wiley, Ph.D.
Associate Dean, College of Liberal Arts

California State University, Long Beach

December 2006

ACKNOWLEDGEMENT

I would like to acknowledge the guidance, support, and enthusiasm of Dr. Paul Laris, who helped me along my path during the thesis process. Also, thank you to Dr. Robert Taylor with the National Park Service for offering his valuable time and resources which were critical in completing this thesis. And finally, if not for Season's patience, support and motivation, you would not be reading this today.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The current distribution of native vegetation in Southern California has been strongly influenced by the region's topography, Mediterranean climate, wildfire regime, and human activity on the landscape. The dominant vegetation classes, including forest, woodland, shrubland, and grassland, exist in a dynamic state (Callaway and Davis 1993), changing in composition and distribution based on both environmental and anthropogenic influences. The dynamic nature of coastal sage scrub (CSS) vegetation communities in Southern California presents a unique opportunity for understanding the natural and human influences that shape its distribution. Dominant theories regarding shrubland succession and its evolution in the landscape have also shaped land management and research objectives aimed at habitat preservation and fire hazard reduction. While many studies have analyzed the abilities and constraints of CSS to establish and recover from site disturbance at a fine scale (Westman 1981a; Keeley and Keeley 1984; Westman and O'Leary 1986; Keeley 1987; Giessow and Zedler 1996; DeSimone and Zedler 1999), others have conducted analysis at a coarser scale by studying the shift in vegetation boundaries over time (Freudenberger, Fish and Keeley 1987; Callaway and Davis 1993; Trabaud and Galté 1996). However, the relationship between fire frequency and the dynamics of CSS vegetation communities is an area lacking significant research. This relationship is an important component to understanding the sustainability of CSS shrublands in Southern California, given the region's changing wildfire regime.

While recent research has addressed CSS growth and regeneration patterns at a fine-scale, few studies focusing on the spatial shift in vegetation communities have incorporated analyses of spatially explicit fire regimes and their effect on the current distribution of CSS shrublands in Southern California. Available fire perimeter data for the state of California (FRAP 2005) provides an opportunity to explore the correlation between fire regimes and the advancement, retreat, or static condition of CSS shrubland boundaries. The increasing social and political pressure toward preserving and restoring CSS habitat has also created a need for a better understanding of its dynamic nature and the factors that influence it, especially considering its functional role as habitat for the coastal California gnatcatcher (*Polioptila californica californica*). However, while CSS plays an important ecological role, the scientific understanding of its successional patterns and response to fire is not fully understood (Keeley and Keeley 1984). Consequently, this study explores the correlation between the quantity of times an area of land has burned based on available records (fire frequency) and CSS vegetation dynamics in an effort to provide valuable data for addressing this current knowledge gap.

Previous research regarding shrubland dynamics focused primarily on whether a site had burned or not and attempted to interpret the impacts of various forms of disturbance; however, no research has quantified fire frequency in attempting to understand the influences and constraints of CSS migration over time. Additionally, with the exception of Westman and O'Leary (1986), no studies have been completed that look specifically at CSS post-fire recovery for a period of time longer than two years.

Freudenberger et al. (1987) analyzed vegetation change in the Cheseboro and Palo Comado Canyons in Los Angeles County, California, between the early 1930's and 1980 by examining two sets of aerial photographs, revealing that vegetation boundary changes over time were multi-directional. While their methodology did include a review of fire history maps, no quantification of the effect of fire frequency was included to determine the effect of fire frequency on vegetation change. This study provides a re-evaluation of the Freudenberger et al. (1987) study, while also conducting further comparisons of vegetation change in the same study area between 1976 and 2003. Additionally, this study incorporates fire history data and compares burn frequency with observed shrubland boundary changes.

This study provides additional information about the impact of fire frequency on CSS stand dynamics by analyzing stand boundary changes over time in areas with documented fire frequencies. Current understandings regarding CSS shrubland dynamics indicate that stands experiencing higher fire disturbance frequencies will exhibit decline through the retreat of CSS shrubland boundaries. This study presents an analysis of CSS cover change over time by analyzing historic and current aerial photographs and includes a discussion of stand-level conditions sampled at the shrub/stand ecotone. The analysis included in this study addresses the influence that wildfire frequency has on the persistence of CSS in the landscape of Southern California. Specifically, do areas with a high documented frequency of burning exhibit CSS retreat and/or exclusion? Alternatively, do other components of wildfire, such as the duration of time between individual fires on a certain part of the landscape (return interval) or the rate of heat released by a fire at a specific time (fire intensity) (Helms 1998), play a more important role in shaping the distribution of CSS? Additionally, what are the impacts of other site disturbance factors, such as cattle grazing, acting in concert with fire disturbance? This study addresses these questions by analyzing CSS stand boundary changes over time in comparison with fire frequency data for the study area. Both fine and coarse scale analyses are included to better understand the interaction between fire frequency and CSS dynamics. The next chapter presents a review of current research in the fields of vegetation dynamics, disturbance factors, and CSS development and migration and addresses the modern and historical context in which CSS shrublands have been studied.

CHAPTER 2

EXISTING RESEARCH AND UNDERSTANDING

Context and Historical Perspective

Environmental variables play a significant role in the location and distribution of CSS in the landscape (Vogl 1976; Axelrod 1978); however, political and social influences have also served to dictate the existing vegetation mosaic in Southern California. With an increasing population, importance has been placed on maintaining environmental integrity through the preservation of undeveloped lands as open-space. One example of the regional efforts to maintain environmental quality through the promotion of open-space is seen in the development and implementation of the Natural Communities Conservation Program (NCCP). The NCCP is responsible for the creation of large blocks of open-space throughout Southern California that attempt to preserve the habitat of listed or endangered species while allowing for economic development in specified areas (Bowler 1990). The creation of the NCCP in 1991 coincided with the listing of the coastal California gnatcatcher as an endangered bird species that utilizes coastal sage scrub as its primary habitat (Bowler 1990; Bowler 2000). The prioritization of CSS in this context and its influence in shaping regional planning efforts, however, reflects social values toward environmental preservation, while promoting the existence of certain vegetation types over others. The link between regional preservation strategies, such as the NCCP, and vegetation dynamics is found in the shifting of land management priorities and techniques once land is designated for preservation. The removal of grazing or prescribed fire from the landscape, for example, often initiates a shift in the distribution of different plant communities, as the frequency and intensity of disturbance factors are effectively changed.

Fire suppression policies provide another example of the influence of politics in shaping vegetation distributions in the landscape. Current research, however, is divided in the interpretation of the effect that fire suppression policies have had on wildfire frequency and severity in Southern California. In a study by Minnich (1987), historic accounts of fire activity in Southern California revealed that, prior to modern suppression efforts, fires tended to be smaller in size and intensity, resulting in a patchy vegetation structure. This vegetation structure supported small, season-long burns and, it is argued, prevented the occurrence of large-scale conflagrations as available fuel sources were highly fragmented across the landscape (Minnich 1987). In another study by Minnich (1983) fire perimeter data for Southern California and northern Baja California was analyzed for a period of nine seasons. Based on a comparison between average annual fire size and more extreme fire events that produced significantly larger fire perimeters, Minnich (1983) concluded that the vegetation mosaic in southern California has shifted from a fine-scaled mosaic to a coarser scale. Thus, he argued, based on vegetation accumulation and an increase in available anthropogenic ignition sources, "fire suppression in Southern California has lead to larger fires" (Minnich 1983: 1292).

Conversely, research by Keeley, Fotheringham, and Morais (1999), Keeley and Fotheringham (2001), Keeley (2002a), Moritz (2003), and Moritz et al. (2004) argue that fire suppression policies do not promote the existence of large-scale conflagrations.

Moritz (2003) studied fire perimeter data for the Los Padres National Forest covering a period of 84 years and determined that a fine-grained mosaic of vegetation age classes perpetuated by small fires would not prevent large conflagrations. His findings indicate that both young and old vegetation will burn during extreme weather conditions and contradicts "the assertion that in the absence of fire suppression, large fires would be constrained by more complex age-class mosaics on the landscape" (Moritz 2003: 351). These conflicting opinions regarding the relationship between vegetation and fire regimes highlight the uncertainty in scientific research that ultimately influences land management policy decisions regarding fire suppression efforts. Consequently, these decisions affect disturbance factors which alter the distribution and dynamics of plant communities throughout Southern California.

Varying perspectives on shrubland development, dynamics, and succession patterns also exist in different areas of the world that are influenced by Mediterranean climate. Shrubland vegetation in Mediterranean-influenced areas is dominated by two vegetation types, "an evergreen schlerophyll shrubland and a drought deciduous or semi-deciduous scrub" (Keeley and Keeley 1984: 105). American perspectives view such shrublands as climax successional vegetation formations influenced by topography, moisture, and fire regimes, whereas European researchers view this type of vegetation as a secondary successional formation that, without anthropogenic influence, would develop into oak woodland and forest (Rodrigue 2004). Specifically, in the European context, the evergreen schlerophyll shrub types, found in Southern California chaparral, and the semi-deciduous scrub vegetation, found in California CSS (Keeley and Keeley 1984), are viewed as inferior secondary successional formations that are maintained through human-influenced disturbance (Rodrigue 2004). From the American perspective, however, the ability of these shrub types to adapt to environmental variables has enabled their long-term persistence in the landscape, despite altered disturbance regimes. The role of human influence in the development and distribution of shrublands ultimately lies at the heart of the difference between American and European perspectives. This difference in opinion regarding the origin of Southern California shrublands is important in considering the role of fire in shaping CSS vegetation communities. An important question raised by Trabaud and Galtié (1996) asks "has the frequency of fire produced the presence of shrublands or has the existence of shrublands allowed the occurrence of repeated wildfires" (223)?

Coastal Sage Scrub Development and Migration

The origin of coastal sage scrub in Southern California and its patterns of development, succession, and resilience are important components in understanding the relationships between fire disturbance and distribution of CSS stands in the landscape. While much research has focused on an analysis of the site factors influencing the existence and dynamics of CSS stands (Westman 1981a; Zedler, Gautier, and McMaster 1982; Keeley and Keeley 1984; Hobbs 1986; Westman and O'Leary 1986; Keeley 1987; Giessow and Zedler 1996; DeSimone and Zedler 1999), it has been argued that the origin and persistence of CSS is the result of anthropogenic influences such as burning, land clearing, and grazing (Vogl 1976; Axelrod 1978). The physiological characteristics of the component shrub species of CSS have allowed this vegetation type to persist in Southern California (Kirkpatrick and Hutchinson 1980), even though it is estimated that current CSS coverage in California is only 10-15% of its original extent (Westman

1981a). While extensive urbanization is likely the cause of the majority of CSS loss over time, the invasion of exotic grasses and shrubs, especially at the wildland-urban interface, is another threat to the persistence of CSS stands. Both factors, in combination with high fire frequencies, continue to pose a threat to the remaining stands of CSS in Southern California.

Coastal sage scrub, often referred to as soft chaparral, is a unique plant community occupying more xeric upland sites throughout central and Southern California, and northern Baja California. According to Axelrod (1978) and Kirkpatrick and Hutchinson (1980), it is generally found on dry south slopes, and grows primarily on coarser alluvial soils, coastal terraces, and rocky areas within an elevation belt below that of chaparral communities. Generally, CSS consists of soft-stemmed plant species that often reach no greater than 1.5 meters in height and is dominated by shrub species, including California sagebrush (*Artemisia californica*), coyote bush (*Baccharis pilularis*), buckwheat (*Eriogonum* spp.), California encelia (*Encelia californica*), and black sage (*Salvia mellifera*), although numerous other shrub and grass species are associated with CSS (Axelrod 1978; Bowler 1990). Several sub-associations of CSS have also been classified according to location and species composition. The sub-associations include Diablan, Lucian, Venturan, Riversidian, and Diegan (Axelrod 1978) and have been the focus of several studies. The general physical structure of CSS stands tends to be more open than chaparral, allowing for greater light penetration to understory forbs or juvenile shrubs. This has influenced the ability of CSS stands to regenerate, resulting in the existence of single stands represented by different age classes.

The response of CSS to disturbance is an important component in its ability to persist in the landscape and ultimately dictates its spatial distribution and change over time. Certain biological features have allowed the shrub and grass species of CSS to respond to recurring disturbance, invade neighboring vegetation types, or regenerate existing stands of CSS. Numerous studies have been completed that attempt to understand the capabilities and limitations of CSS to recover following disturbance (Zedler et al. 1983; Keeley and Keeley 1984; Westman and O'Leary 1986; Keeley 1987; Giessow and Zedler 1996; DeSimone and Zedler 1999), or how the shrublands persist over time (Axelrod 1978; Westman 1981a; Westman 1981b). While a significant amount of research has been completed that analyzes the environmental constraints, growth and recovery patterns, and distribution of other Mediterranean shrubland vegetation types, including mattoral in Chile, maquis in France, macchia in Italy, chaporro in Spain, and chaparral in California (Westman 1981a), a relatively small amount of research has been dedicated to coastal sage scrub. Consequently, the paucity of current research regarding CSS distribution and growth patterns presents a limitation to understanding this shrubland community.

The post-fire response of CSS plays a significant role in its survival. Following a fire in CSS, typical response involves a dominant cover of grasses and forbs in the first post-fire year, although shrub sprouting from intact root systems has been observed and plays an important role in the long-term re-establishment of the stand (Westman 1981a; Keeley and Keeley 1984). In fact, in studying the resilience of CSS stands following disturbance, Westman and O'Leary argue that species resprouting techniques are "a key predictor of competitive success, and hence a predictor of the pace, manner and degree of recovery following disturbance" (1986: 187). Shrub seedling recruitment, though less common in the first post-fire year, is significantly higher in the second year following fire based on vigorous seed production by stump sprouting shrubs during the first year. According to Keeley and Keeley (1984), second-year seedling establishment in CSS can exceed that of California chaparral by a factor of two. As CSS stands mature, the herbaceous annual understory declines, giving way to a shrub-dominated stand. This process ultimately reduces the species richness of the stand creating a shrub-dominant ecosystem. Westman (1981a) noted, however, that a second flush of herbaceous annual grasses was observed in 15-25 year old CSS stands.

The implications of this post-fire recovery process for the purposes of fire management and CSS preservation lie in the propensity of herbaceous vegetation to ignite and carry fire. The proliferation of fire-following herbs places recently burned stands of CSS in danger of burning too soon. As discussed by Zedler et al. (1983), short fire intervals can severely limit CSS recovery as repeated fires destroy seedlings that establish after the first fire. In this case, two fires burning in the same location in San Diego County in 1979 and 1980, were studied and revealed that, based on individual plant species, up to 90% of the seedlings that sprouted following the 1979 fire were destroyed in the 1980 fire. Giessow and Zedler (1996) also suggest that increased fire frequency increases the quantity of non-native grasses establishing in CSS stands. Consequently, the heavy seed-production technique used by CSS shrub species to recover following disturbance may impede their successful establishment if fire return intervals are too short.

Coastal sage scrub species also have unique seeding characteristics that allow for expansion and invasion into neighboring plant communities and the grassland-shrubland ecotone (Kirkpatrick and Hutchinson 1980). Prolific seeding following disturbance and the capacity of shrub seeds to germinate without requiring the influence of fire are the primary differences between CSS and California chaparral. Specifically, many chaparral species require the heat of wildfire to break seed coats and initiate germination (Keeley 1987). Coastal sage scrub species, however, germinate more readily without the influence of fire, enabling a greater capacity for establishment. Consequently, the potential for population expansion of chaparral is more limited than that of CSS, which is "capable of colonizing other forms of disturbance" (Keeley 1987: 434). In an analysis of CSS seed banks and shrub seedling recruitment on a site in Orange County, California, DeSimone and Zedler (1999) analyzed the capacity of CSS to utilize small-scale disturbances in regeneration. The results indicated that CSS seedlings were able to take advantage of small-scale openings in the sage scrub-grassland ecotone caused by drought-induced shrub mortality or animal foraging impacts (DeSimone and Zedler 1999: 2019). Additionally, plot sampling in grasslands adjacent to CSS stands revealed the existence of juvenile shrubs indicating the capacity of CSS to colonize grasslands, even in the absence of fire activity. However, although the post-fire phase of CSS recovery has been studied, "much less is known about population dynamics between recurring fires" (DeSimone and Zedler 1999: 2018). This conclusion is important in attempting to understand the influences of CSS migration over time. The seeding capabilities and fire-response mechanisms of CSS emphasize the dynamic nature of this vegetation type, given its capacity to establish, regenerate, and even colonize other vegetation communities.

The origin and persistence of coastal sage scrub in the landscape is also an important component in understanding the effects of disturbance in shaping its distribution. Many ecologists argue that CSS is a community type influenced and maintained by anthropogenic forces; however, differences exist in the interpretation of its former extents. In studying the origin of CSS in California, Axelrod (1978) argues that humans have been responsible for increasing the area of land covered by CSS through cattle grazing and fire management activities, as he considers coastal sage scrub to be a disturbance-dependent plant community. Vogl (1976) presents a different argument, emphasizing that since CSS is subject to decline based on higher disturbance levels, it may not be as extensive as in the past. Despite the differences, however, both authors suggest that human influences have played a major role in shaping CSS distributions. Vogl even claims that CSS "should perhaps be considered as an anthropogenic formation" (1976: 81). Keeley's analysis of Native American impacts on natural fire regimes (2002b) supports this assertion and indicates that the current grassland/shrubland mosaic is a result of intentional burning on the part of Native Americans to maintain valuable hunting and gathering lands. The perpetuation of this mosaic in modern times, it is argued, is maintained by a system of disturbance resulting from Euro-American land management practices and additional human ignition sources. Based on the studies of shrubland origins and an understanding of CSS disturbance recovery techniques, the development and existence of CSS stands in the landscape can be seen as dynamic and constantly changing based on the intensity, frequency, and source of disturbance.

Vegetation Dynamics

The shifting of coastal sage scrub stand boundaries over time is a result of the influences of various disturbance factors along with the recovery and reproduction potential of the community itself. The unique capabilities of CSS to recover from disturbance, capitalize on available gaps, and even colonize existing vegetation communities contribute to its dynamic nature. Analysis of CSS stands at a coarser spatial and temporal scale, however, reveal the changes in land cover at a more regional level and allow for a better understanding of the influences that certain disturbance factors have on the expansion or reduction of vegetation community boundaries. Several studies have analyzed the changes in vegetation distributions over time based on the influence of disturbance regimes (Callaway and Davis 1993; Trabaud and Galtié 1996), while other research has focused more specifically on the changes of individual CSS stands (Malanson 1984; Hobbs 1986; Freudenberger et al. 1987). These studies also reveal unique methodologies for observing and interpreting the influence of disturbance in shaping the vegetation mosaic in Southern California (Leak and Graber 1974; Swetnam, Allen, and Betancourt 1999).

Callaway and Davis (1993) present a study that interpreted two sets of historic aerial photographs to analyze the changes of vegetation patterns and determine the influences of fire, grazing, topography, and substrate in influencing the shifting of vegetation boundaries over time. Aerial photographs taken in 1947 and 1989 for Gaviota State Park in central coastal California were utilized to quantify changes in oak woodland, chaparral, grassland, and coastal sage scrub vegetation communities. Field verification of over 90% of the areas presenting changes was conducted and the data analyzed. The results from this study indicate that fire promoted the conversion of CSS to grassland over time, which supports current perspectives regarding shrubland-grassland interactions. However, the authors point out that "biotic interactions may determine a dynamic 'shifting mosaic' landscape even in the absence of large-scale disturbance" (Callaway and Davis 1993: 1573).

A similar technique using aerial photograph analysis was used by Freudenberger et al. (1987) in determining grassland-shrubland dynamics throughout the Los Angeles Basin. The initial aerial photographs used in this study were taken between 1929 and 1936, while the secondary photographs were taken between 1979 and 1980. The focus area of this study, the Calabasas quadrangle, presented multi-directional vegetation shifts and was consequently studied in greater detail. As with Callaway and Davis (1993), Freudenberger et al. conducted field sampling efforts to determine the migration of vegetation boundaries over time. Findings from this study indicate that disturbance factors have impacted vegetation shifts over time and the authors suggest that "a 10 year fire frequency, coupled with intensive grazing, are sufficient to inhibit sage invasion into grassland" (Freudenberger et al. 1987: 24). However, no quantifiable data are presented for determining the effect of wildfire frequency on such changes. It is the Freudenberger et al. study that serves as the basis for this study.

Other methodologies have been used in attempting to understand the role of fire in shaping vegetation communities and influencing their distribution. For example, Malanson (1984) utilized fire perimeter data to test a hypothesis that fires determine the boundaries of CSS sub-associations. His findings, however, indicated that fire extents were not responsible for vegetation patterns observed in the landscape, and that CSS sub-associations “are maintained irrespective of fire, not because of it” (Malanson 1984: 127). Numerous field methods have also been employed, often in concert with an analysis of aerial photographs, fire perimeter data, or historic vegetation maps. Leak and Graber (1974) present a method for detecting the migration pattern of vegetation communities by conducting a transect sample and correlating vegetation age with position relative to vegetation boundaries. Finally, in a study by Trabaud and Galtié (1996) in France, an analysis of repeated fires on the same site was studied to determine the effect of fire frequency on vegetation diversity and spatial patterns.

Studies analyzing vegetation changes over time (Malanson 1984; Freudenberger et al. 1987; Callaway and Davis 1993; Trabaud and Galtié 1996) represent a different approach to understanding the effects of disturbance on vegetation dynamics; however, uncertainties regarding the CSS-grassland interactions emerge when analyzing the results of such research. For example, based on research conducted at a more fine scale, one would expect that increased fire frequencies would result in conversion of shrublands to grasslands, or serve to maintain existing grasslands. In fact, this assertion is supported by both Callaway and Davis (1993), and Freudenberger et al. However, as indicated by Axelrod (1978), coastal sage scrub is a community that increases due to disturbance, which presents an uncertainty in the existing science regarding the role of fire in affecting vegetation dynamics.

The characterization of the shrubland boundary itself may also reveal information about the static or dynamic nature of the CSS stand. In a study by Hobbs (1986), the grassland/CSS boundaries located in three study sites in Southern California were classified based on differential profiles. Hobbs argues that narrow ecotones, areas with abrupt changes, should be associated with areas that are unstable and may be perpetuated by repeated grazing. Areas with broad ecotones generally have lower disturbance and are sometimes characterized by the presence of small *Artemisia californica* shrubs in the transition zone (Hobbs 1986). This condition indicates an advancement of shrubland boundaries.

Finally, it should be noted that these findings are based on the assumption that human-influenced disturbances are responsible for vegetation dynamics. However, as argued by Swetnam et al. (1999), such concepts of vegetation dynamics ignore the influences of "demographic responses to climatic variability, or even the recovery from past disturbances, including prehistoric humans" (1999: 1193). The original assertions by Vogl (1976) and Axelrod (1978) that current CSS distributions are essentially a relict of anthropogenic influences has shaped even current research that largely omits discussions of global-scale influences, such as climate change. Ultimately, it is the uncertainty regarding the origin and influences of shifting vegetation boundaries that warrants this research.

CHAPTER 3

METHODOLOGY

The methodology for this study builds upon the work of Freudenberger, Fish, and Keeley in 1987. The approach used includes two important advancements over the original work: first, the study period was extended by adding data covering the period of 1976 - 2003 to the original 1929 - 1976 period; and second, spatially explicit fire perimeter data were used in interpreting landscape cover change. Utilizing multiple sets of digital aerial photographs, fire history data, and field documentation, grassland-CSS shrubland dynamics within a portion of the Calabasas quadrangle were studied. Specifically, the Cheseboro Canyon/Palo Comado Canyon area was analyzed for this study (Figure 1, Figure 2).

Two distinct analyses were conducted for this study to assess vegetation boundary changes over time. The initial analysis focused on vegetation distribution change detection between 1929 and 1976, mimicking the analysis by Freudenberger et al. (1987). Once complete, this analysis was compared to the results presented by the original authors. The second analysis focused on the same study area, but analyzed grassland-CSS shrubland boundary changes between 1976 and 2003. Unlike the initial research, this study then compared vegetation change data with known fire frequency and fire return interval data for the study area to assess the impact of fire frequency on CSS boundary changes over time.

The CSS shrubland boundary changes in the Cheseboro Canyon/Palo Comado Canyon area were analyzed by comparing the extents of CSS shrublands at three distinct time periods. Aerial photographs of the study area taken in 1929, 1976, and 2003 were analyzed and the extents of CSS stands for each time period were determined. These data were then analyzed in a geographic information system (GIS) to determine changes in the extent of CSS coverage over time. Categorization of CSS coverage by year was conducted to assist in this analysis. Following the analysis of the extents of CSS shrubland boundaries in each of the three time periods, the changes in spatial extent of these stands were visually compared with fire history data for the site by overlaying the data sets in a GIS. Finally, field sampling of the study area was conducted to gain a better understanding of the movement of shrubland boundaries over time. A detailed discussion of the methodology used in aerial photograph analysis, CSS boundary delineation, GIS analysis, and field sampling follows.

Description of Study Site

Located within the USGS Calabasas 7.5 minute quadrangle within both Los Angeles and Ventura Counties in Southern California, the Cheseboro and Palo Comado Canyon area (Figure 1) is the focus area for this study. These two canyons are situated east of the City of Agoura Hills in the Santa Monica Mountains of Southern California and the land is currently managed as open space by the National Park Service (NPS) as part of the Santa Monica Mountains National Recreation Area. Current land use within the study area includes hiking, biking, and horseback riding along numerous roads and trails. Historically, cattle grazing in this area of Southern California played an important role in the local economy as well as affecting the distribution of vegetation across the landscape

(Maslach 2000). As discussed by Maslach, "the most significant changes in vegetation of the Las Virgenes Valley occurred on the ranchos and homesteads of the 19th century" (2000: 67). Since the early 1800's, ranching and cattle grazing has occurred throughout the upper Las Virgenes Valley, and continued in the study area until grazing pressure was reduced in 1985 (Thomas 1986), although land was acquired by the NPS in 1981 (Levin 1985).

The study area consists of two primary drainages, Cheseboro and Palo Comado Canyons, as well as a small portion of open-space immediately north of Agoura High School, adjacent to Thousand Oaks Boulevard. The topography is varied, with elevation differences between canyon bottoms and ridge tops often exceeding 150 meters (500 feet). Ridge top elevations measure greater than 575 meters (1,900 feet) and some slope angles exceed 70 percent. Current upland vegetative cover is primarily a patchy mosaic of grassland and coastal sage scrub (Figure 2), while canyon bottoms are characterized by oak woodlands and riparian vegetation types within and adjacent to stream channels. Fire history within the study area is varied, with some areas burning up to eight times within the CDF fire history record time period. Conversely, some areas within the study area have burned only once during this time period.

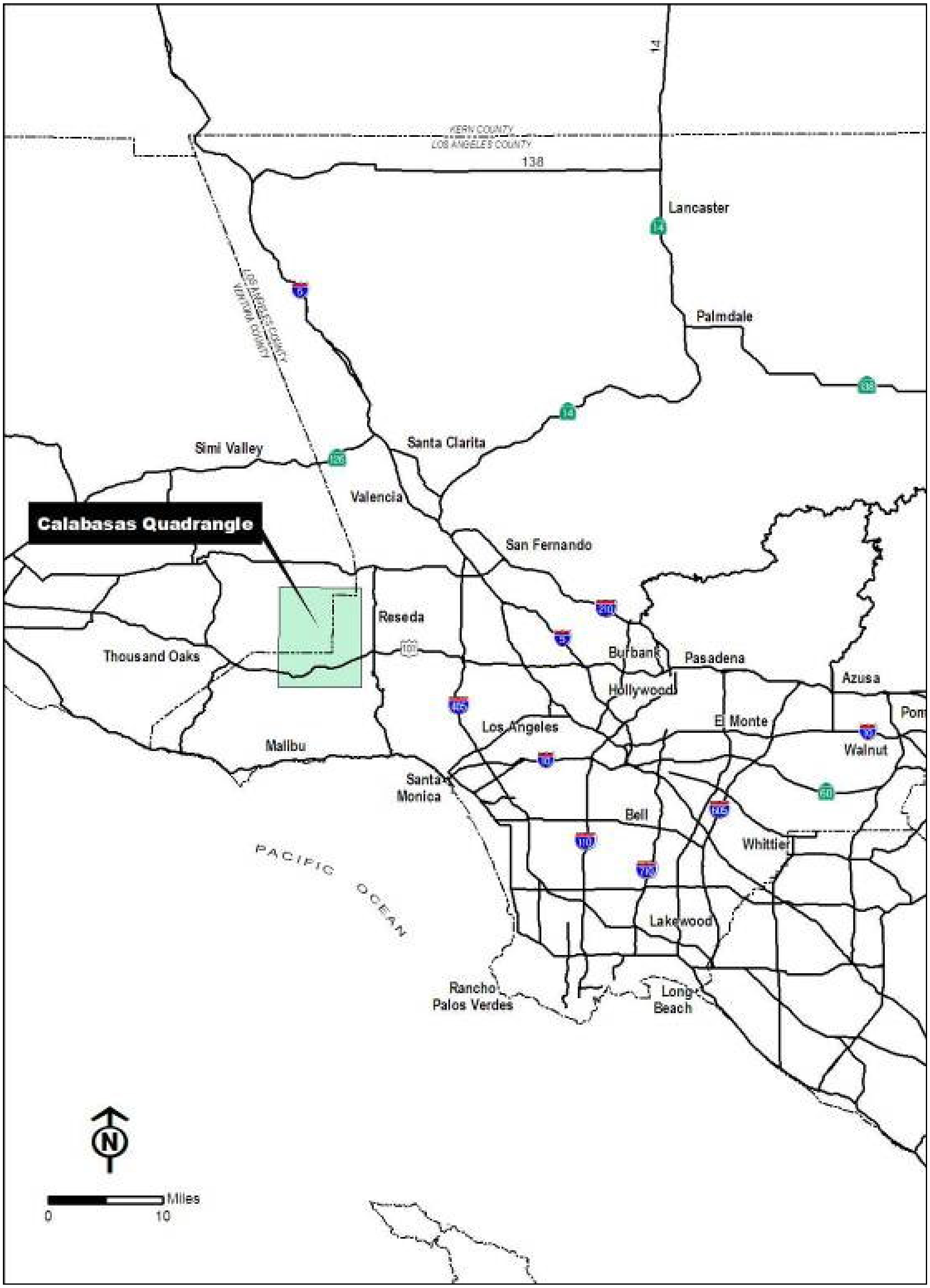

FIGURE 1. Vicinity map of study area.

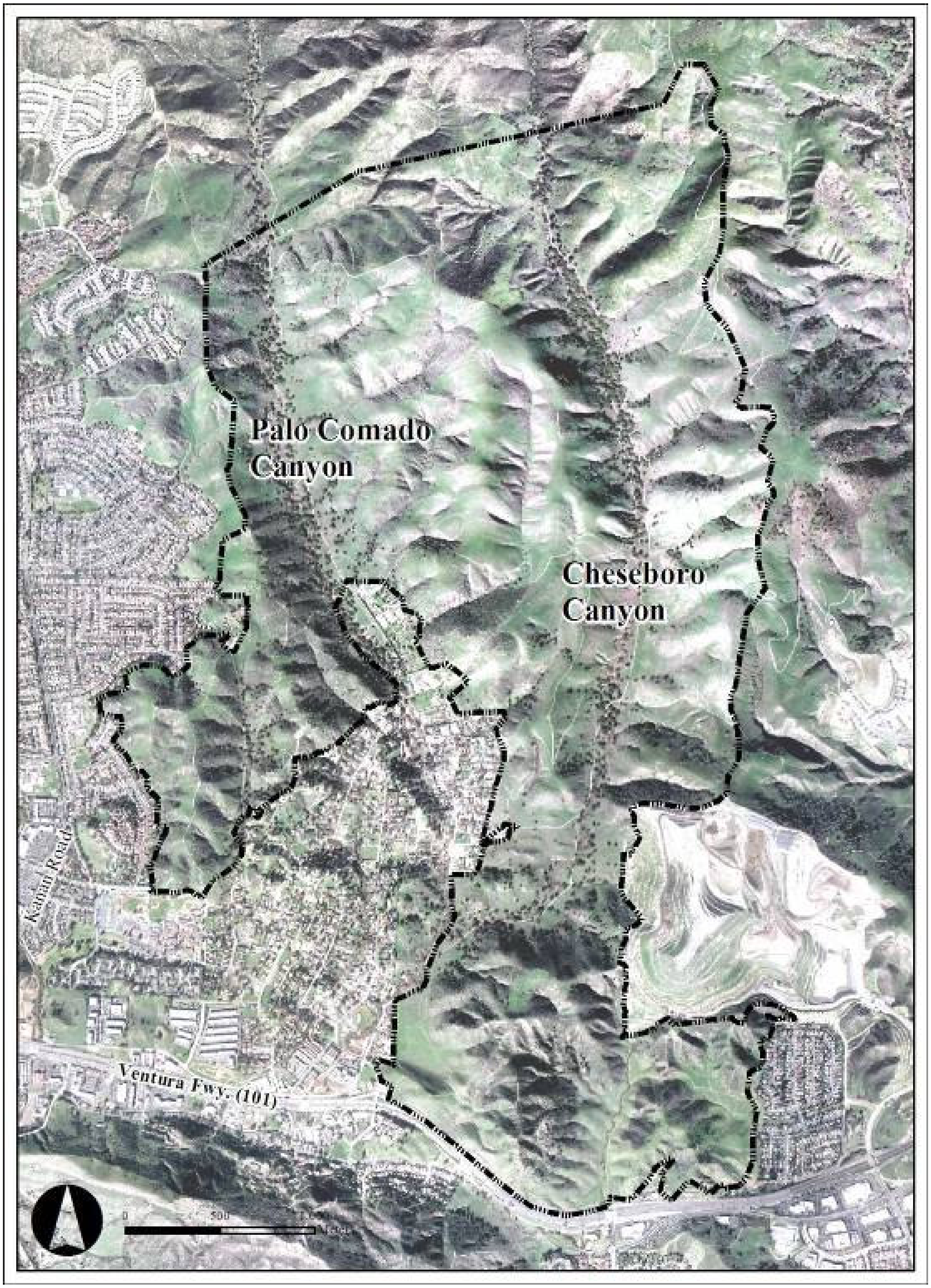

FIGURE 2. Delineation of study area.

Aerial Photograph Georeferencing

Three sets of digital aerial images for the study area were acquired for the time periods, including 1929, 1976, and 2003. Images for 2003 were acquired from the U.S. Geological Survey (USGS) via the Seamless Data Distribution System website. A total of five individual images from 2003 covered the study area. Each USGS image was a color digital photograph in .tif format and georeferenced to NAD 1983, UTM Zone 11 coordinates with a resolution of 0.65 meters. Digital aerial images from both 1929 and 1976 were acquired from the National Park Service office in Thousand Oaks, California. The 1976 black and white digital aerial image mosaic was received in .img format georeferenced to NAD 1927, UTM Zone 11 coordinates. The 1976 image mosaic required re-projection to align it with the NAD 1983, UTM Zone 11 coordinate system. The 1929 black and white aerial images were received in .tif format and were scanned images from the Fairchild Collection housed at Whittier College in Whittier, California. The original 1929 photograph set covering the project area, consisting of five individual images (J-24, J-25, J-36, J-37, and J-38), was not georeferenced, thus each photograph required alignment to the UTM, Zone 11 coordinate system prior to analysis.

Re-projection of the 1976 image mosaic was conducted utilizing the projection tools in ArcGIS 9.1 software. The resulting image was saved in the NAD 1983, UTM Zone 11 coordinate system. Georeferencing of the 1929 aerial photograph set was necessary for comparison with the other photograph sets. Utilizing the Georeferencing tool set in ArcGIS 9.1 software, each of the five images from the 1929 set was georeferenced to the NAD 1983, UTM Zone 11 coordinate system. Using the georeferenced USGS 2003 image set as a base, each 1929 photograph was georeferenced using a minimum of four control points. Control points used were uniquely identifiable landscape features that were visible in both image sets, and included trees, roads, buildings, and other static objects. Stream channels and drainage features were not used as control points, given the potential for spatial shifting over time as a result of erosion and deposition activity. Table 1 presents a summary of control points and root mean square error (RMSE) values associated with georeferencing of the 1929 images.

TABLE 1. RMSE Values for 1929 Aerial Photo Georeferencing.

1929 Image	Number of Control Points	RMSE Value
J-24	5	1.292
J-25	6	0.386
J-36	4	0.415
J-37	5	1.417
J-38	5	0.495

Delineation of CSS Boundaries

Prior to digitizing CSS stand boundaries, the extents of the study area were determined and digitized from the 2003 image set, creating a study boundary shapefile used in the analysis of all three time periods. The boundary file delineated the study area and included all areas of land within Cheseboro and Palo Comado Canyons from the Ventura Freeway in the south, to the transition to chaparral vegetation in the north. Additionally, a portion of land immediately north of Agoura High School was included in the study area. Any urban or developed areas existing on the 2003 aerial photograph set were excluded from the study area for all time periods, including the landfill adjacent to the east side of Cheseboro Canyon (Figure 2).

Following re-projection of the 1976 aerial image mosaic and georeferencing of the 1929 aerial images, the boundaries of CSS stands were digitized for each time period. Using AutoCAD Map 2005 software, the study boundary shapefile and each georeferenced aerial image was loaded and the boundaries of CSS stands were digitized by using the polyline creation tool. The creation of polygons around each CSS stand within the study area was conducted for each of the three study years and was used to generate a separate AutoCAD file for 1929, 1976, and 2003.

GIS Analysis

Each of the three AutoCAD files generated for the study area represented the extent of CSS stands for a given year. Each file was loaded into ArcGIS software and exported in shapefile format in the NAD 1983, UTM Zone 11 coordinate system. Each of the three shapefiles was then converted to a raster data file using the Spatial Analyst extension in ArcGIS. The resulting raster files were maintained in the same coordinate system and were created with pixel areas measuring 1 square meter. The three raster data files delineating CSS stand coverage within the study area for each of the three time periods were reclassified using the Spatial Analyst extension in ArcGIS. For the 1929 raster file, all areas covered by CSS were assigned a value of 1, while all other areas (non-CSS) were assigned a value of 0. For the 1976 raster file, all areas covered by CSS were assigned a value of 10, while all other areas (non-CSS) were assigned a value of 0. Finally, for the 2003 raster file, all areas covered by CSS were assigned a value of 100, while all other areas (non-CSS) were assigned a value of 0. Following reclassification, the 1929 raster file and the 1976 raster file were summed together to create a file depicting the changes in CSS stand distribution between 1929 and 1976. Similarly, the

1976 raster file and the 2003 raster file were summed together to generate a new file depicting the changes in CSS stand distribution between 1976 and 2003. Finally, the 1929 raster file and the 2003 raster file were summed together to create a file depicting changes between 1929 and 2003, excluding the intermediate 1976 data. Based on the classifications of CSS and non-CSS coverage, areas of land that existed as non-CSS retained a value of 0, while the resulting values for other areas indicated the change in status over time.

Fire History Data Set

Fire history data for the state of California is available via the California Department of Forestry and Fire Protection (CDF) Forest and Resource Assessment Program (FRAP). This data set contains polygon GIS data for CDF fires measuring 300 acres and greater in size, and U.S. Forest Service (USFS) fires measuring 10 acres and greater between 1950 and 2003. However, some fires before 1950 and some CDF fire burning less than 300 acres are also included (FRAP 2005). Initially, the data set was loaded into ArcGIS and an area covering the entire study area was clipped out. This data set was then saved in the NAD 1983, UTM Zone 11 coordinate system. As the data set consists of numerous overlapping polygons depicting fire perimeters for the study area, some editing was necessary to create a GIS file that represented both the number of times an area had burned and the years in which such areas burned.

Using the FRAP historical fire data set, the "regionpoly" command was utilized to create a polygon coverage with no overlapping regions and a lookup table with all the fire records for each polygon number. The polygon number field was also included in the polygon attribute table for the polygon coverage initially created. The "infodbase" command was then used to create a .dbf file of the lookup table. Using Microsoft Excel, a concatenated year column for each polygon number was created by using formulas to first convert the multiple rows of years for each polygon number into columns and then to concatenate the columns of years into one column. Total fire counts per polygon were created by using a pivot table which placed the polygon numbers in rows and the total of burn years in a column. Then, the .dbf file was merged with the polygon attribute table of the polygon coverage in ArcGIS and exported to a shapefile. Once in shapefile format, polygon values were queried for values of 1. All polygon values equal to 1 were deleted from the data set as they represented "no data" records or non-burned areas in between burned polygons. Finally, the accuracy of the new fire frequency shapefile was tested by comparing the polygon attribute table against the original shapefile regions coverage and querying random polygons in ArcGIS.

The resulting fire frequency shapefile was then used to determine the number of times a certain area within the study area had burned. Fire frequency for the study area ranged from zero fires to seven fires. This data was utilized in determining the location of field sampling sites and in interpreting the changes in CSS boundaries over time.

The fire history data set utilized in conducting this analysis contains fire perimeter data in polygon format with certain acreage and time limitations, as previously mentioned (FRAP 2005). As such, small fires or those intentionally set by ranchers may not have been included in the database. Additionally, the data set is limited to fire perimeters only, which depict only the final extent of the burn area. Consequently, the data set does not account for un-burned portions of land within the final fire perimeter, nor does it include fire intensity or fire spread rate data.

Field Sampling

Using the methodology presented by Leak and Graber (1974) and that used by Freudenberger, Fish, and Keeley (1987) as a model, eight separate CSS stands in the study area were sampled and shrub height, species, and location data were collected. The methodology employed in sampling attempts to detect the migration of vegetation boundaries by comparing shrub age with relative distance from the grassland-shrubland ecotone. In this case, overall shrub height was used as a surrogate for shrub age. Selection of CSS stands for field sampling was not random. Utilizing the fire frequency maps derived from fire history data for the study area, CSS stands with different fire frequencies were chosen for field sampling. The intent was to sample CSS stands that exhibited different fire frequencies.

Field sampling was conducted on December 17, 18, and 19, 2005 and involved quadrat sampling along eight transects, one for each of the CSS stands selected for sampling. Each transect consisted of eight contiguous 2 by 3 meter quadrats. Following the determination of CSS stand fire frequency, the CSS stand-grassland ecotone was located in the field. From the ecotone, a bearing, perpendicular to the ecotone edge, was determined and a contiguous series of 2 by 3 meter quadrats were sampled starting at the ecotone, and extending a total of 16 meters into the stand. Quadrat boundaries were determined by measuring distances of each side with a cloth measuring tape. Within each quadrat, the species and height of each shrub that had a part falling within the boundaries of the quadrat was documented. Shrubs in each quadrat were tallied based on 10 centimeter height classes, ranging from 0 to 200 centimeters (2 meters). Additionally, the slope (percent), aspect (degrees), general site condition, and general soil texture were recorded for each transect. Also, each transect line was drawn in the field on a printed copy of the 2003 aerial photograph (scaled at 1" = 200') and the transect area was documented with digital photographs. Sampled CSS stands occurred on slopes with various inclines (ranging 20 to 70% slope) and aspects while fire frequencies for sampled CSS stands varied from 2 to 4. As a considerable portion of the study area burned in October 2005 during the Topanga Fire, many areas were inaccessible for field sampling. Consequently, sampling was limited to areas with low fire frequency (burned 1 to 2 times) and moderate fire frequency (burned 3 to 4 times).

Following field sampling efforts, sampling data was entered into spreadsheets for further analysis. A separate spreadsheet was created for each transect and the quantities of observed shrubs, by height class, were determined. These values were used in assessing the GIS- derived data for CSS stand boundary changes between 1929 and 1976 as well as between 1976 and 2003.

CHAPTER 4

RESULTS

This chapter presents a discussion of the results from GIS analyses conducted for the 1929 to 1976 time period, the 1976 to 2003 time period, and the 1929 to 2003 time period, as well as the results from field sampling efforts conducted within the study area. Additionally, this chapter discusses observed landscape changes related to wildfire regimes documented for the site and quantifies fire frequencies for each time period. Each of the aerial photographs sets were used in this study to serve as a basis for vegetation boundary delineation for each of the two time periods. Comparison of the changes in CSS coverage revealed multi-directional CSS/grassland ecotone shifts, although the study area exhibited a net loss in CSS coverage over time. The inclusion of fire history data for the study area provided a method for assessing the influence of fire frequency on such shrubland boundary changes. Field sampling and data analysis provided site information from a finer geographic scale, revealing CSS stand advancement or retreat characteristics not observable from aerial photograph interpretation. Maps depicting CSS coverage for 1929, 1976, and 2003 are presented in Figures 3, 4, and 5, respectively.

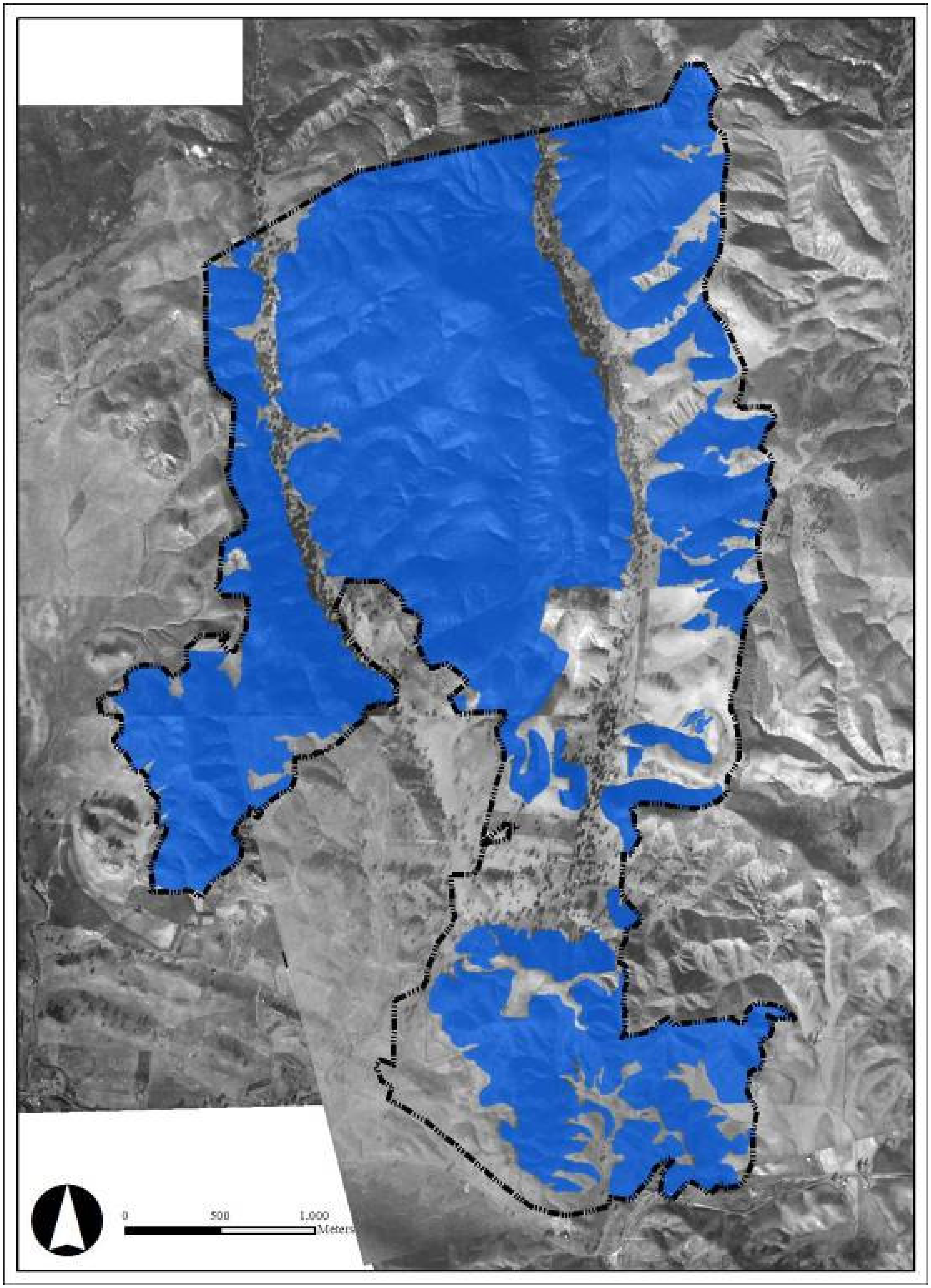

FIGURE 3. Coastal sage scrub distribution for 1929.

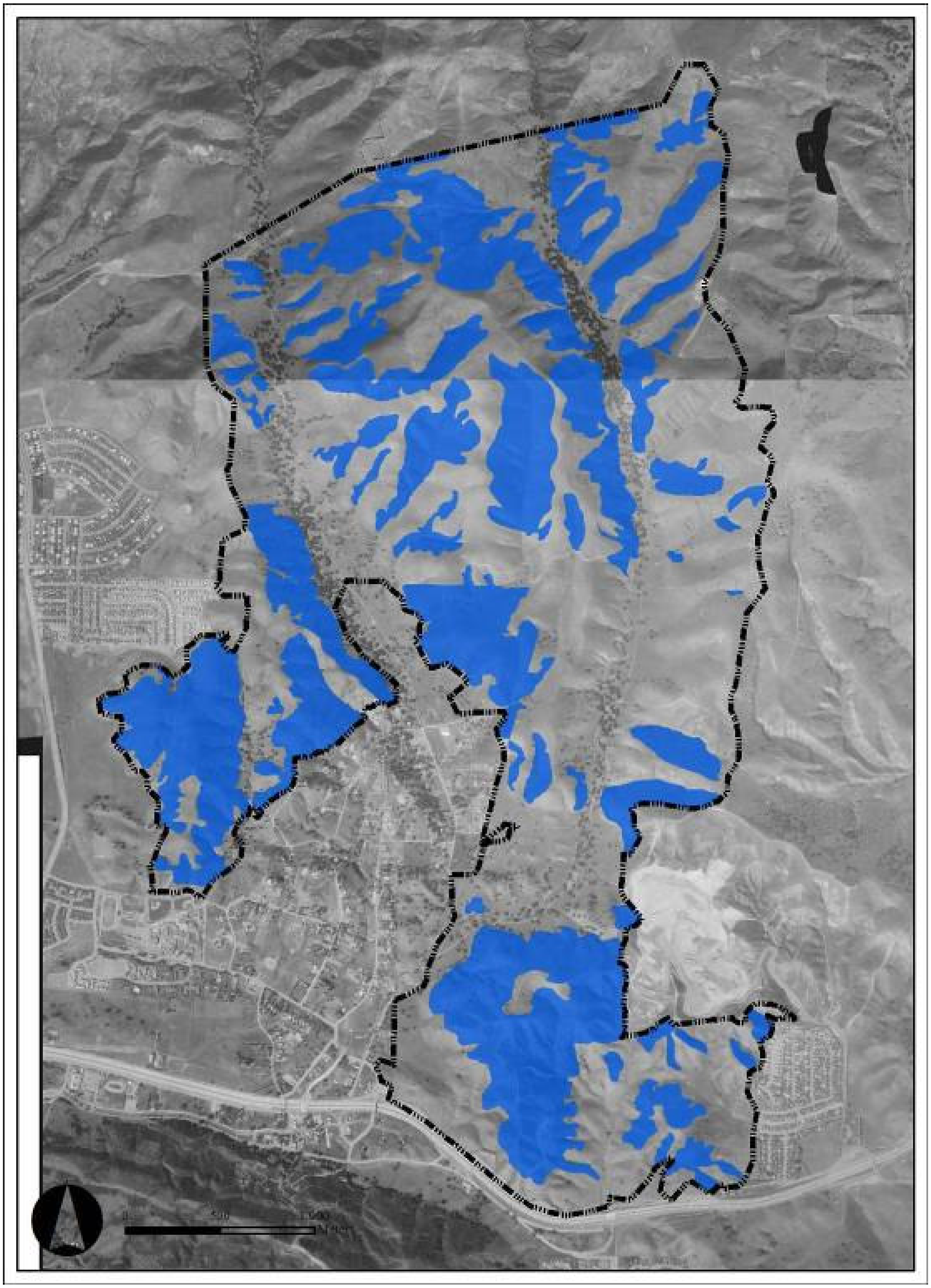

FIGURE 4. Coastal sage scrub distribution for 1976.

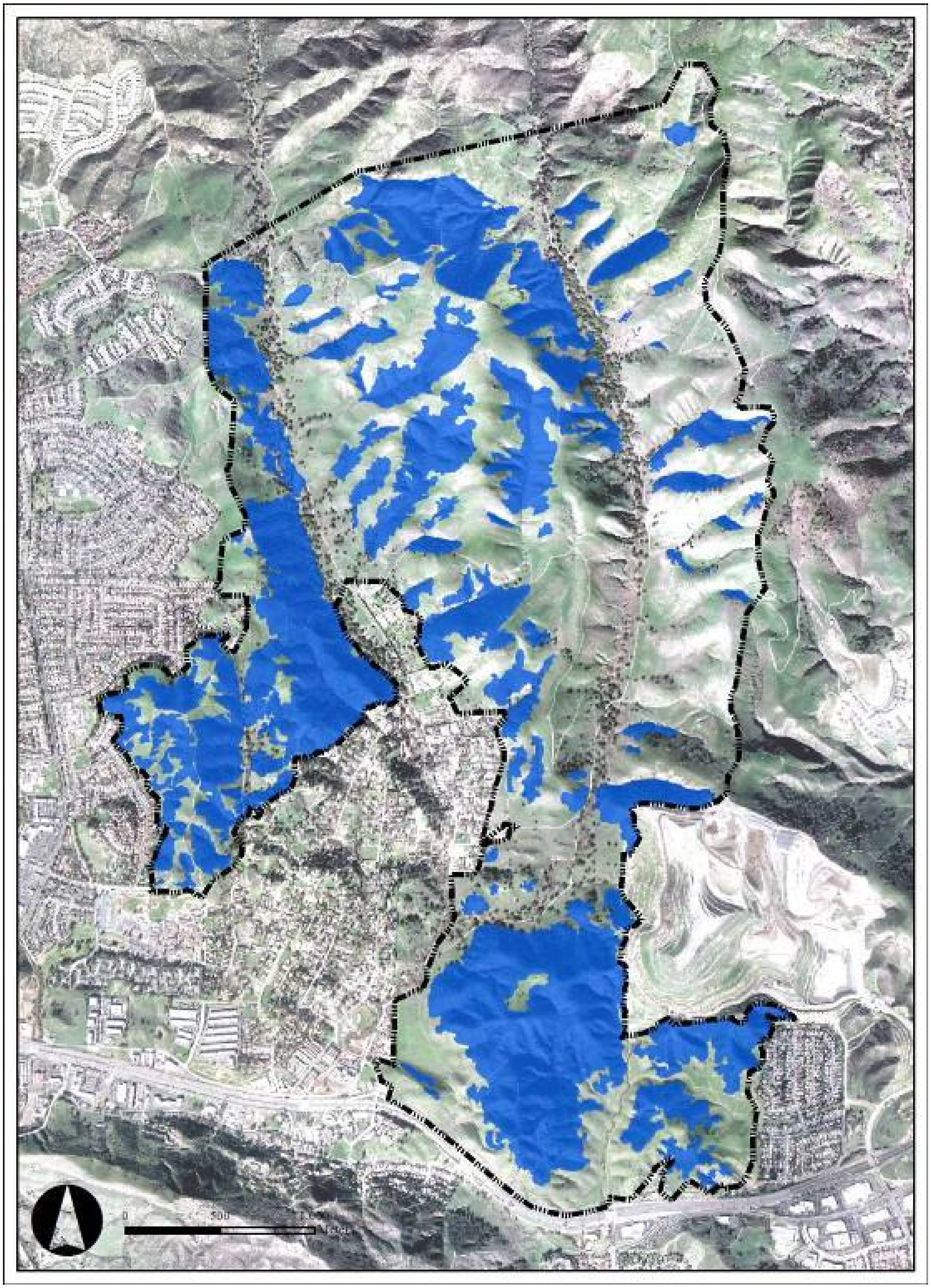

FIGURE 5. Coastal sage scrub distribution for 2003.

Vegetation Change Analysis: 1929 to 1976

The comparison of CSS coverage within the study area between 1929 and 1976 reveals a considerable loss of CSS shrublands over time. The remaining CSS stands present in 1976 exist primarily as isolated patches surrounded by grassland, consistent with the condition observed by Freudenberger et al. (1987). This condition is dissimilar to that observed on the 1929 aerial image, which depicted more contiguous CSS shrublands within the study area. Fire frequencies documented for this time period range between 1 and 4, with two individual fires burning considerable portions of the study area. Table 2 presents the differences in CSS coverage area between 1929 and 1976. Approximately 70.2 percent of the 2,941 acre study area was covered in CSS in 1929 (2,063 acres). By 1976, CSS coverage measured only 1,097 acres, representing only 37.3 percent of the study area. Overall, CSS coverage was reduced within the study area by 53.2 percent during this period. Areas covered with CSS in 1929 were converted primarily to grassland cover by 1976. Table 2 presents the raster values and associated CSS stand coverage classification between 1929 and 1976.

TABLE 2. Raster Values and Associated Area Calculations for 1929 and 1976.

Cell Value	1929	1976	Square meters	Square kilometers	Acres	Percent
0	Non-CSS	Non-CSS	3,161,155	3.16	781.14	26.6%
1	CSS	Non-CSS	4,300,364	4.30	1,062.64	36.1%
10	Non-CSS	CSS	393,468	0.39	97.23	3.3%
11	CSS	CSS	4,047,007	4.05	1,000.03	34.0%
total:			11,901,994	11.90	2,941.04	100.0%

Shrubland boundary changes between 1929 and 1976 were not unidirectional, however. Of the 1,097 acres of CSS present within the study area in 1976, 1,000 were mapped as CSS in 1929. Ninety-seven of the acres mapped as CSS in 1976 were classified as non-CSS in 1929, indicating shrubland boundary advancement. Additionally, as 1,844 were classified as non-CSS in 1976, only 1,063 of these acres were classified as CSS in 1929. Consequently, 781 acres classified as non-CSS in 1976 were also classified as non-CSS in 1929, indicating either static shrubland boundaries or no conversion of vegetative cover to CSS. Areas experiencing CSS retreat and conversion to grassland were concentrated primarily in the central and northern portions of the study area, while areas experiencing CSS advancement into grasslands were concentrated primarily in the southern portion of the study area, adjacent to the current location of the Ventura Freeway. A map depicting CSS cover change for the study area between 1929 and 1976 is presented in Figure 6.

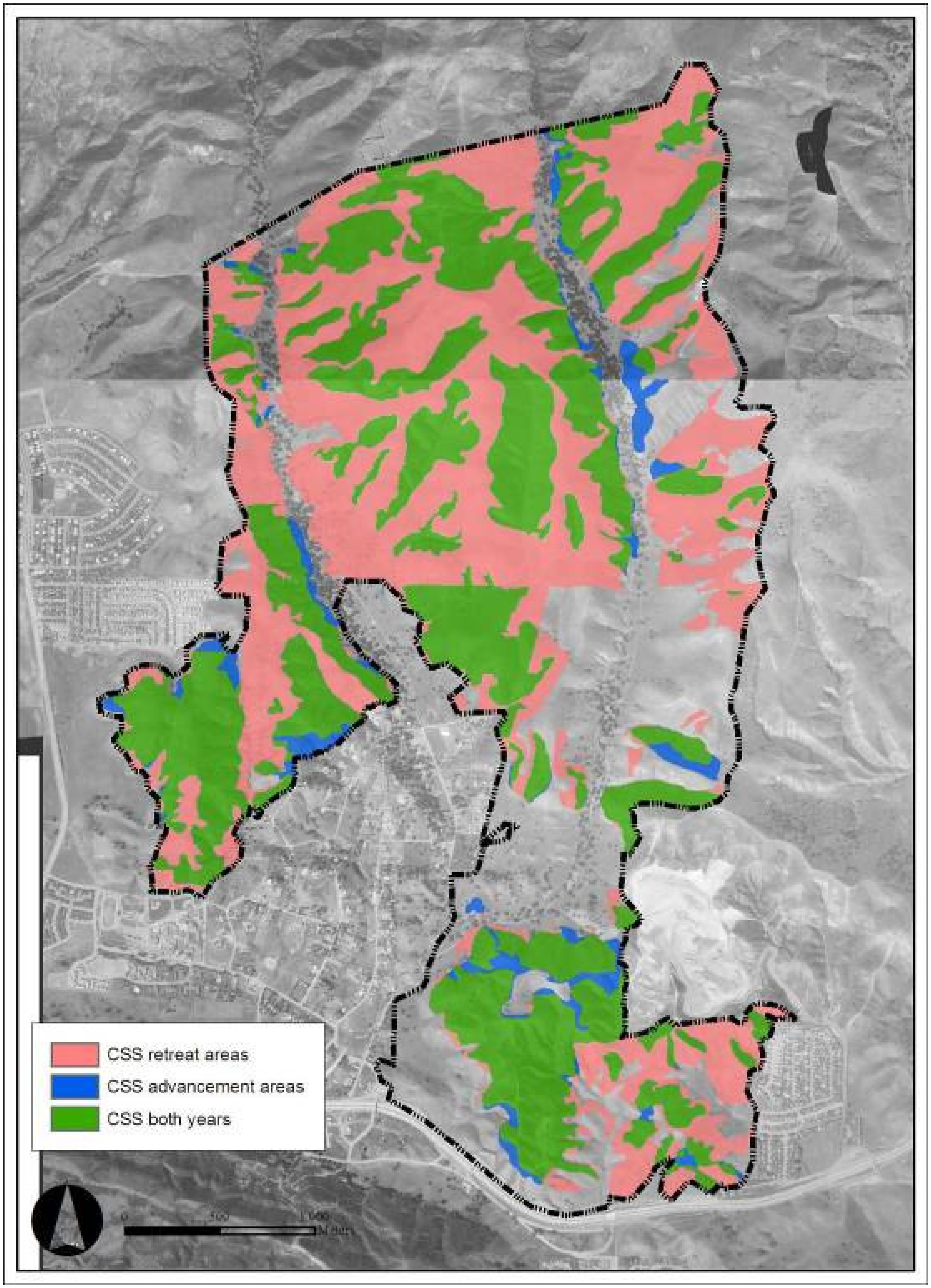

FIGURE 6. Coastal sage scrub coverage change between 1929 and 1976.

Fire Frequency Analysis: 1929 to 1976

In an analysis of fire data for this time period, duplicate records for one particular fire appeared to be included within the FRAP database. Specifically, two fires in 1967, the Palmer Fire and the Devonshire-Parker Fire, cover nearly the same land area and include the same Alarm Date record, indicating the time and date of the fire. Consequently, the Devonshire-Parker Fire was removed from the database prior to analysis. As mentioned, the Simi Hills Fire (1949) and the Clampitt Fire (1970) burned considerable portions of the study area during the 1929 to 1976 time period, while the Palmer Fire (1967) burned a large portion of the eastern section of the study area. The Agoura No. 26 Fire burned a small portion of the south west section of the study area in 1931.

The frequency of burning during this time period ranges from 1 to 4 and no portions of the study area remained unburned. The distribution of fire frequencies (quantity of times burned) across the study area is uneven, with higher frequencies (burned 3 or more times) concentrated in the eastern and south eastern portions of the study area. The remaining areas generally burned less frequently. The time between burns also varied for the study area during this time period. The Agoura No. 26 Fire burned a relatively small area in 1931, followed by the Simi Hills Fire in 1949, which burned the majority of the study area. The Palmer Fire burned 18 years later in 1967 in the eastern portion of the study area, followed by the Clampitt Fire three years later in 1970, which burned the majority of the study area. The fire return interval for this time period varied, depending on location. Areas along the eastern edge and in the southeast section of the study area were subject to a very frequent burn interval (1967 and 1970), while the rest of the study area burned no more than 18 years apart. The frequency of fires during the 1929 to 1976 time period is depicted in the maps presented in Figure 7.

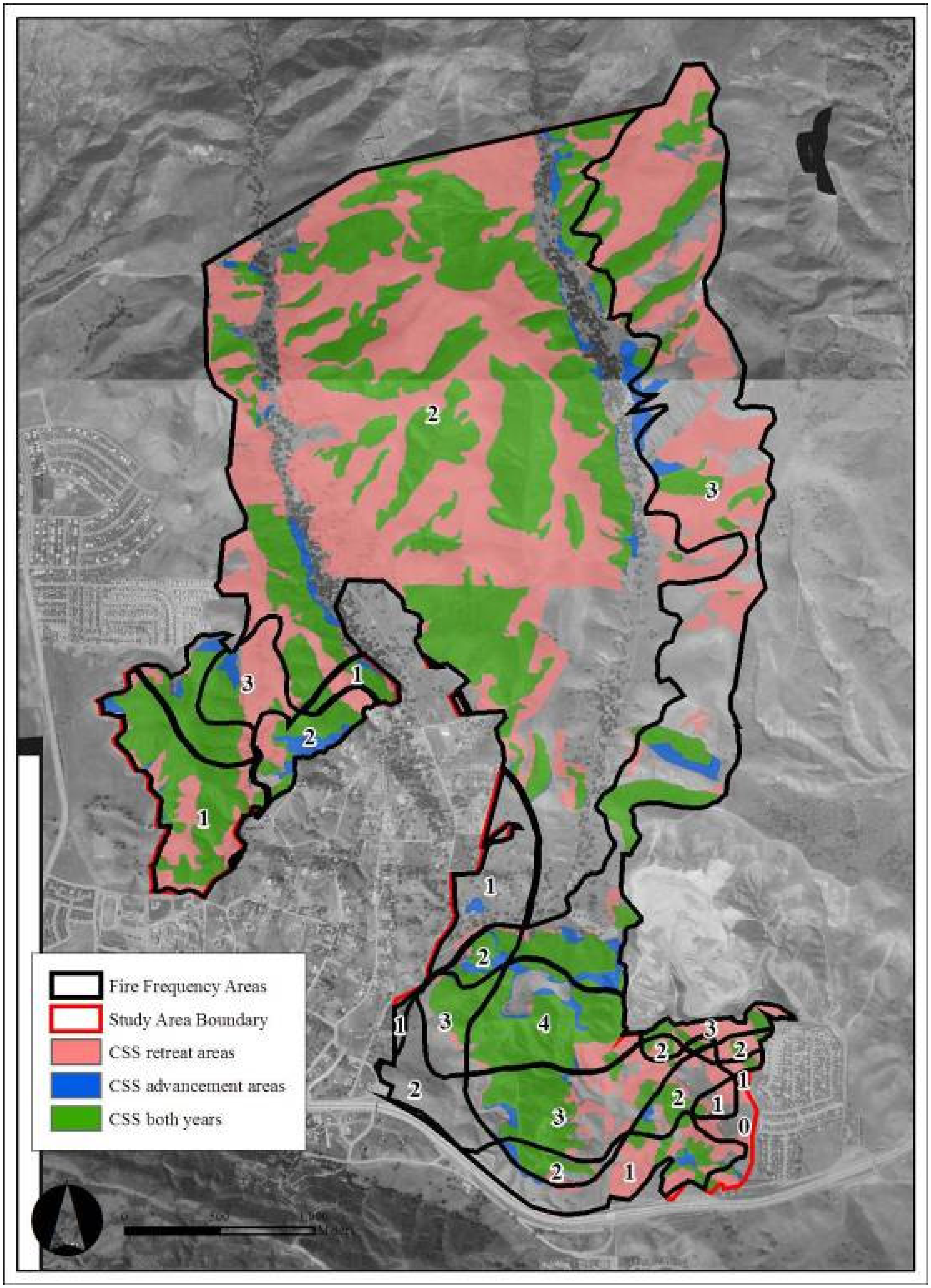

FIGURE 7. CSS coverage change and fire frequency between 1929 and 1976.

Vegetation Change Analysis: 1976 to 2003

The changes in CSS coverage between 1976 and 2003 were not as dramatic as those documented for the 1929 to 1976 time period, although an overall loss in CSS coverage for the study area was observed. Multi-directional changes in CSS shrubland boundaries were also noted for this time period. CSS stands continued to exist primarily as isolated patches surrounded by grasslands in 2003, however, shrublands did advance into grassland in some areas, and new CSS patches were documented in 2003 that did not exist in 1976. Table 3 presents the differences in CSS coverage between 1976 and 2003. While the total area covered with CSS in 1976 totaled 1,097 acres, that observed for 2003 totaled 1,064 acres (36.2 percent of the total study area), representing a 3.0 percent decrease in CSS coverage between 1976 and 2003. Areas exhibiting CSS coverage loss between 1976 and 2003 were converted to grassland cover by 2003. Table 3 presents the raster values and associated CSS stand coverage classification between 1976 and 2003.

TABLE 3. Raster Values and Associated Area Calculations for 1976 and 2003.

Cell Value	1929	1976	Square meters	Square kilometers	Acres	Percent
0	Non-CSS	Non-CSS	6,287,054	6.29	1,553.56	52.8%
10	CSS	Non-CSS	1,308,882	1.31	323.43	11.0%
100	Non-CSS	CSS	1,174,465	1.17	290.22	9.9%
110	CSS	CSS	3,131,593	3.13	773.83	26.3%
total:			11,901,994	11.90	2,941.04	100.0%

As mentioned, CSS shrubland boundary changes for this time period were not unidirectional, although an overall loss of CSS shrublands was observed for this time period. Greater fluctuations between vegetative cover were observed during this time period, however. For example, of the 1,064 acres of CSS present within the study area in 2003, 774 were mapped as CSS in 1976. Two hundred and ninety of the acres mapped as CSS in 2003 were classified as non-CSS in 1976, indicating a more dramatic advancement of CSS shrublands than observed in the previous time period. Conversely, of the 1,844 acres mapped as non-CSS in 1976, 1,554 acres remained as non-CSS in 2003, while 323 acres converted from CSS to non-CSS during this time period. In comparison with the CSS shrubland boundary changes observed during the 1929 to 1976 time period, CSS loss during the 1976 to 2003 period was not as dramatic, while conversion of non-CSS coverage to CSS stands was considerably more dramatic. As with the previous time period, areas experiencing CSS retreat and conversion to grassland were concentrated primarily in the central and northern portions of the study area, while areas experiencing CSS advancement into grasslands were found in both the southern and western portions of the study area. A map depicting CSS cover change for the study area between 1976 and 2003 is presented in Figure 8.

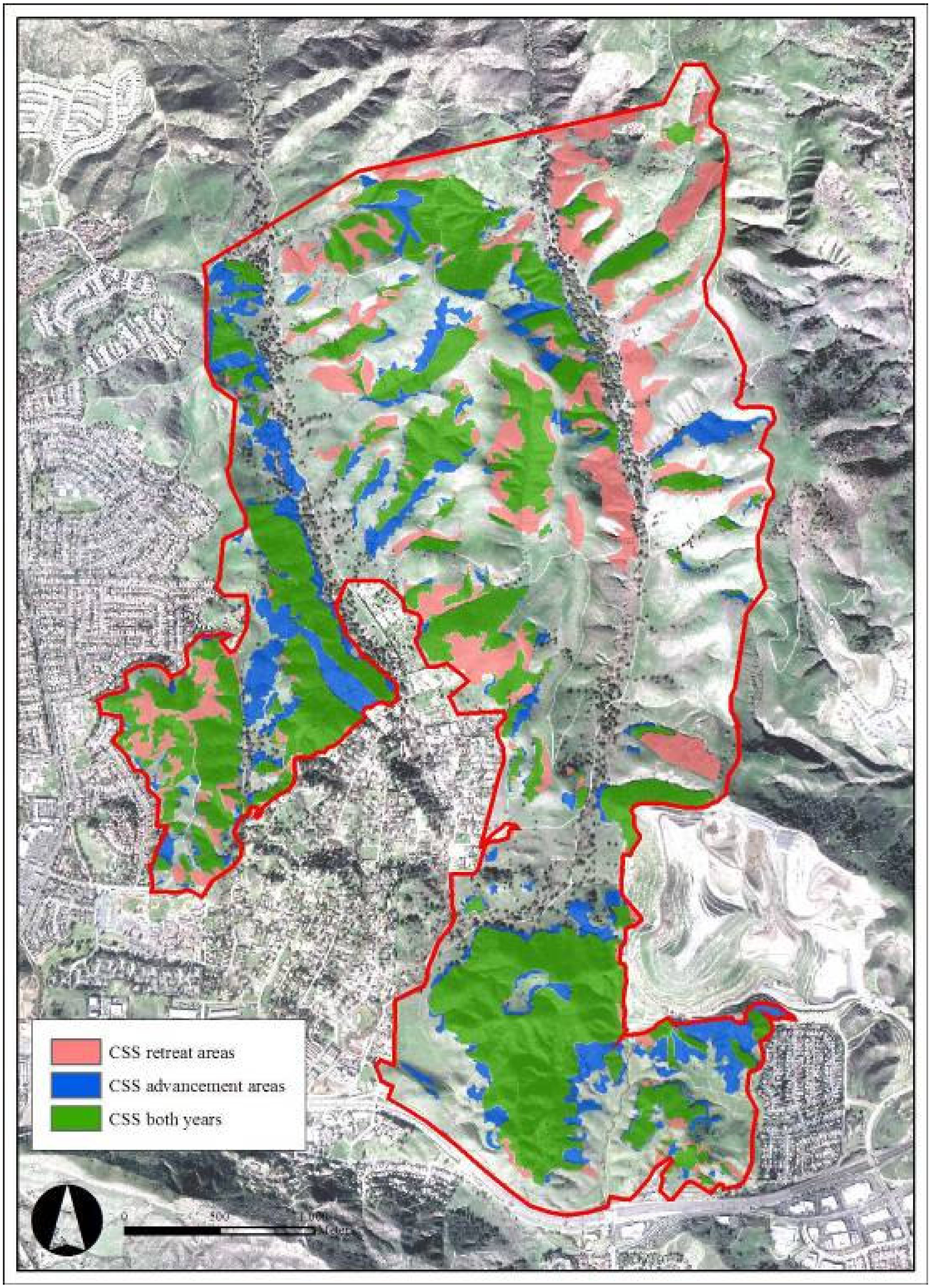

FIGURE 8. Coastal sage scrub coverage change between 1976 and 2003.

Fire Frequency Analysis: 1976 to 2003

Fire perimeter records used in the analysis for the 1976 to 2003 time period included those used in analyzing the 1929 to 1976 period. This technique was chosen to account for cumulative fire frequency within the study area and to determine the fire-free period for different areas of the site. As indicated for the 1929 to 1976 period, the record from the Devonshire-Parker Fire was removed from the database prior to analysis. In addition to the four fires that burned between 1929 and 1976, nine fires burned within the study area between 1976 and 2003. The first fire burning within this time period was the 1982 Dayton Canyon Fire which burned nearly the entire study area. Subsequent fires in 1984, 1986, 1993, and 1994 burned relatively small portions of the property. The Cheseboro Fire (1993), Palo Comado Fire (1994), and both the Boundary I and Boundary II Fires (1995) burned considerable areas, primarily in the north and north-east sections of the study area. In fact, the highest concentration of fires burned within the northern and north-eastern portions of the study area between 1976 and 2003.

The frequency of burning for any individual area within the study area during this time period increased from that documented for the 1929 to 1976 time period and ranged between 1 and 7 fires (cumulative). Several years (1993, 1994, and 1995) included two recorded fires during the same year, although each burned separate portions of the study area. With the exception of the 1982 Dayton Canyon Fire which burned nearly the entire study area, the distribution of fire frequencies across the study area remained uneven. Higher fire frequencies (burned 5 or more times, cumulatively) were observed primarily in the eastern and north-eastern portions of the study area, although areas exhibiting high fire frequencies were observed in south-east and south-west portions of the study area.

The Dayton Canyon Fire burned nearly the entire study area in 1982. A series of relatively smaller fires burned within the study area in 1984 (Crummer Fire), 1986 (un-named fire), 1993 (Lost Hills Fire), and 1994 (Toth Fire). A series of larger fires burned the northern and north-eastern portions of the study area in 1993 (Cheseboro Fire), 1994 (Palo Comado Fire), and 1995 (Boundary I and II Fires). The interval between fires differed from that observed for the 1929 to 1976 time period and varied depending on location. A twelve year fire-free interval occurred between the 1970 Clampitt Fire, which burned a majority of the study area, and the 1982 Dayton Canyon Fire, which also burned the majority of land within the study area. While three smaller fires burned the study area over this time period, a high concentration of fires burned the northern and north-eastern portions of the study area with short intervals. Areas in upper Cheseboro Canyon within the north and east section of the study area were subject to a very short intervals between burns (1984, 1993, 1994, and 1995), while the rest of the study area remained relatively unburned for 21 years. The frequency of fires during the 1976 to 2003 time period is depicted in the maps presented in Figure 9.

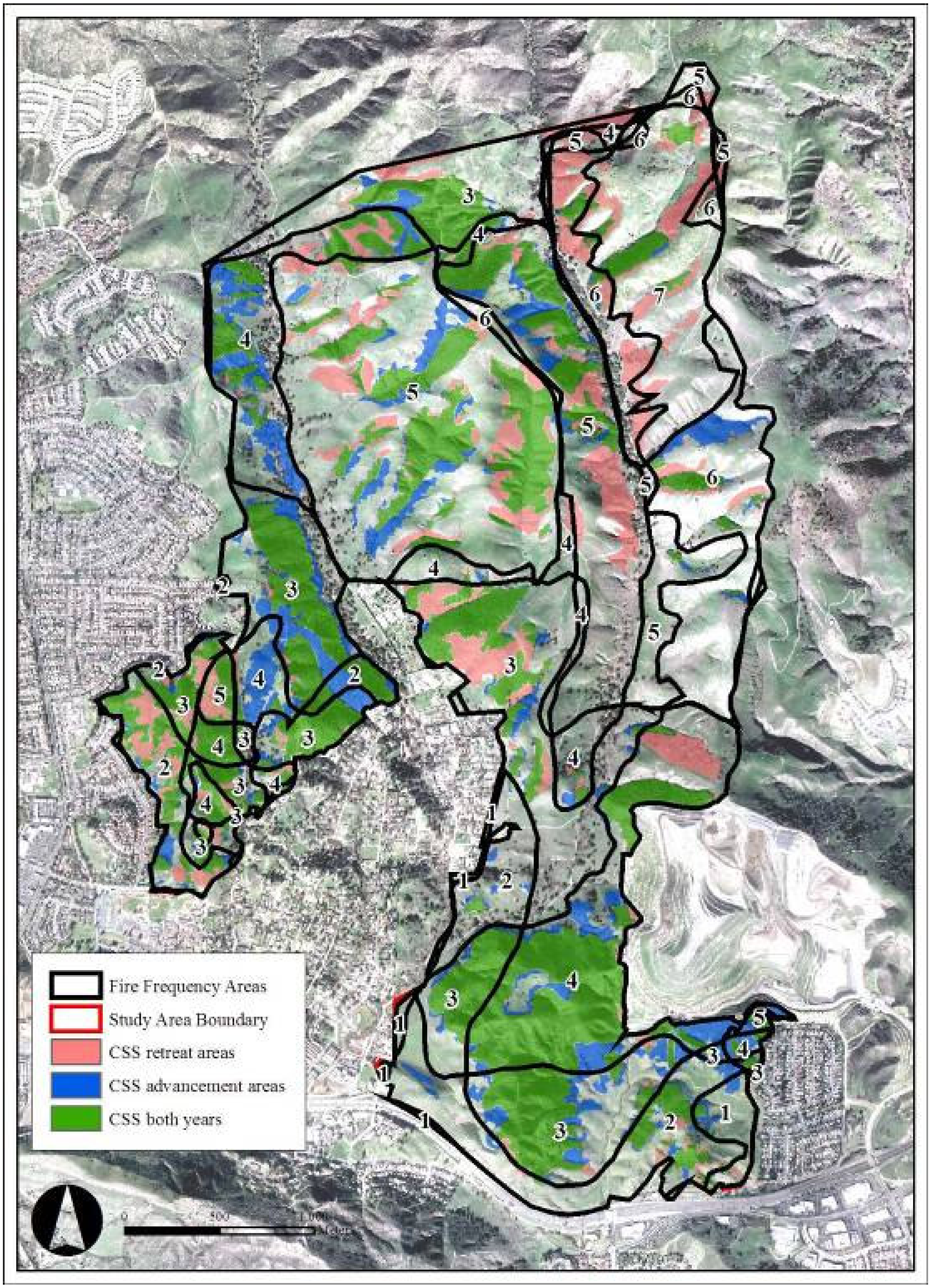

FIGURE 9. CSS coverage change and fire frequency between 1976 and 2003.

Vegetation Change Analysis: 1929 to 2003

Excluding the 1976 data, the changes in CSS coverage between 1929 and 2003 were observed, indicating similar CSS cover changes as the 1929 to 1976 period. Specifically, both the 1929 to 1976 period and the 1929 to 2003 period revealed nearly equal conversion of CSS to non-CSS coverage (a 36.1% change between 1929 and 1976 and a 37.9% change between 1929 and 2003). Multi-directional changes in CSS shrubland boundaries were also noted for this time period, although conversion of non-CSS to CSS was relatively minor (3.9%). The analysis of CSS coverage change between 1929 and 2003 indicates that the majority of CSS coverage loss occurred primarily in the first time period (1929 to 1976), when viewed in comparison with the data from the 1929 to 1976 period. Table 4 presents the raster values and associated CSS stand coverage classification between 1929 and 2003.

TABLE 4. Raster Values and Associated Area Calculations for 1929 and 2003.

Cell Value	1929	1976	Square meters	Square kilometers	Acres	Percent
0	Non-CSS	Non-CSS	3,089,082	3.09	763.33	26.0%
1	CSS	Non-CSS	4,506,854	4.51	1,113.66	37.9%
100	Non-CSS	CSS	465,541	0.46	115.04	3.9%
101	CSS	CSS	3,840,517	3.84	949.01	32.3%
total:			11,901,994	11.90	2,941.04	100.0%

Field Sampling

Field sampling of individual CSS stands conducted using the methodology presented by Leak and Graber (1974) and utilized by Freudenberger et al. (1987) resulted in the quantification of individual shrubs categorized by species and height in relation to distance from the CSS shrubland/grassland ecotone. Variations in species composition and shrub height distributions existed for each of the sampled stands. Fire frequencies also varied for each stand, ranging from 2 to 4, while fire free periods remained relatively constant. Of the eight sampled CSS stands, Stands 2, 3, 4, 5, 7, and 8 burned last in the 1982 Dayton Canyon Fire, Stand 1 burned in the 1995 Boundary I Fire, and Stand 6 burned in the 1994 Toth Fire. Consequently, the fire-free period for most of the sampled CSS stands was 21 years, while that for Stand 1 was 8 years, and that for Stand 6 was 9 years. Locations of individual transects is presented in Figure 10. A discussion of each of the individual stands follows, and a summary of stand characteristics is presented in Table 5 while a summary of transect shrub height distributions is presented in Table 6. Detailed transect data collected during field sampling efforts is presented in Appendix A, while site photographs taken during field sampling are presented in Appendix B.

Stand 1 (sampled by Transect 1) is located on a south facing slope with a 70 percent inclination and is composed of coastal buckwheat (*Eriogonum cinereum*) and black sage (*Salvia mellifera*). This stand has burned 4 times, most recently in 1995, resulting in an 8 year fire-free period. Shrub heights sampled in all quadrats ranged between 60 and 120 cm, with only a few smaller shrubs located in the first and fourth quadrat. This stand did not exhibit seedling establishment within shrubland/grassland ecotone, and the lack of small shrubs or seedlings observed within the stand itself indicates the lack of stand regeneration. The quantity of shrubs documented in all of the quadrats was also relatively low, indicating low stand density.

Stand 2 (Transect 2) is situated on a north facing slope with a 26 percent inclination and is composed of coast goldenbush (*Haplopappus venetus*) and purple sage (*Salvia* *leucophylla*). This stand has burned 3 times, most recently in the 1982 Dayton Canyon Fire, resulting in a stand age of 21 years. Shrub heights for this stand ranged between 10 and 200 cm and shrubs of various heights were fairly evenly distributed throughout each of the quadrats. The variety in shrub heights documented for this stand indicates stand regeneration occurring both within the stand and at the shrubland/grassland ecotone. Additionally, the high quantity of shrubs sampled indicates a relatively high stand density, although species diversity is low.

Stand 3 (Transect 3), located on a southwest facing slope measuring 45 percent in inclination, is composed of California sage (*Artemisia californica*), black sage (*Salvia mellifera*), and coast goldenbush (*Haplopappus venetus*). Fire frequency for this stand is 3, and the most recent burn occurred during the 1982 Dayton Canyon Fire, resulting in a stand age of 21 years. Overall, shrub heights within this stand had a wide range, between 20 and 200 cm. Distribution of shrub heights between the quadrats indicated that smaller shrubs were generally located in the central portion of the transect while medium and larger sized shrubs were distributed fairly evenly along the transect. This composition indicates stand regeneration within stand boundaries, but the lack of shrub boundary advancement. Additionally, a moderate quantity of shrubs sampled indicates a moderate stand density.

Stand 4 (Transect 4) is situated on a northeast facing slope measuring 37 percent inclination and is composed of coast goldenbush (*Haplopappus venetus*), California sage (*Artemisia californica*), and purple sage (*Salvia leucophylla*). Fire frequency for this stand is 4 and the most recent fire burned the stand in 1982, resulting in a 21 year old CSS stand. Sampled shrub heights range from 40 to 160 cm, with a range of heights distributed fairly evenly between each quadrat. The existence of smaller shrubs in quadrats 1 and 2 indicate stand advancement, while the presence of smaller shrubs in quadrats 4 through 7 indicate stand regeneration within the stand boundary. Additionally, a moderate quantity of shrubs within the sampled quadrats indicates a moderate stand density.

Stand 5 (Transect 5) is located on a north facing slope measuring 32 percent inclination and is composed of coast goldenbush (*Haplopappus venetus*), California sage (*Artemisia californica*), and purple sage (*Salvia leucophylla*). Fire frequency for this stand is 4 and the most recent burn was the 1982 Dayton Canyon Fire. Shrubs within sampled quadrats are typically taller, with heights ranging primarily between 80 and 200 cm, while quadrats 3 and 4 include a few smaller shrubs. The distribution of shrub heights indicates a relatively static shrubland boundary and the lack of shorter shrubs within the central portion of the stand indicates little or no stand regeneration. The relatively low amount of shrubs within the sampled area also indicates low stand density.

Stand 6 (Transect 6) exists on a northeast facing slope with a 45 percent inclination. The stand is composed of coastal buckwheat (*Eriogonum cinereum*), California sage (*Artemisia californica*), coast goldenbush (*Haplopappus venetus*), purple sage (*Salvia leucophylla*), bush mallow (*Malacothamnus fasciculatus*), and the non-native shrub horehound (*Marrubium vulgare*). The fire frequency for this stand is 4, with the most recent fire burning the stand in 1994 (Toth Fire). This stand exhibits a wide range of shrub heights, between 5 and 200 cm, where the majority of smaller shrubs are concentrated closer to the shrubland/grassland ecotone. This indicates shrubland boundary advancement, while the relatively lower number of small shrubs in the stand interior indicates the lack of stand regeneration. The presence of exotic shrubs (horehound) is not unexpected, given the proximity of an off-road vehicle trail adjacent to the stand. The relative density of the stand is moderate, considering the moderate quantity of shrubs sampled along the transect.

Stand 7 (Transect 7) is situated on a northwest facing slope with a 20 percent inclination and is composed of coastal buckwheat (*Eriogonum cinereum*), California sage (*Artemisia californica*), coast goldenbush (*Haplopappus venetus*), purple sage (*Salvia leucophylla*), and bush mallow (*Malacothamnus fasciculatus*). The stand has burned twice and last burned in the 1982 Dayton Canyon Fire, resulting in a 21 year fire-free period. Shrub heights in this stand range primarily between 70 and 130 cm, although some smaller shrubs were located in quadrats 5 through 7. The presence of smaller shrubs in the stand interior indicates stand regeneration, while the lack of smaller shrubs at the shrubland/grassland ecotone indicates either a static or retreating shrubland boundary. While species composition is relatively high (including five species), the quantity of shrubs sampled is moderate, indicating an overall moderate stand density.

Stand 8 (Transect 8) is located on a southeast facing slope with a 42 percent inclination. The species composition of the stand is low, consisting of California sage (*Artemisia californica*) and purple sage (*Salvia leucophylla*). The stand has burned twice, most recently in the 1982 Dayton Canyon Fire. Sampled shrub heights range primarily between 70 and 130 cm, while a few smaller shrubs are located in quadrats 4 through 6. The lack of smaller shrubs at the shrubland/grassland ecotone indicates either a static or retreating stand boundary, while the presence of smaller shrubs within the stand interior indicates overall stand regeneration. The relatively small amount of shrubs included in the transect sample indicates a relatively low stand density.

TABLE 5. Summary of Stand Characteristics.

Transect No.	Slope (%)	Aspect (deg.)	Qty. Fires	Most Recent Fire	Dominant Species
1	70	180	4	1995 Boundary I Fire	*Eriogonum cinereum*
2	26	10	3	1982 Dayton Canyon Fire	*Haplopappus venetus*
3	45	245	3	1983 Dayton Canyon Fire	*Artemisia californica*
4	37	310	4	1984 Dayton Canyon Fire	*Artemisia californica*
5	32	0	4	1985 Dayton Canyon Fire	*Artemisia californica*
6	45	25	4	1994 Toth Fire	*Marrubium vulgare*
7	20	310	2	1985 Dayton Canyon Fire	*Eriogonum cinereum*
8	42	115	2	1985 Dayton Canyon Fire	*Artemisia californica*

TABLE 6. Summary of Transect Shrub Height Distributions.

Transect No.	Height Range by Quadrat (cm)							
	1	2	3	4	5	6	7	8
1	20-100	50-120	60-110	40-120	50-120	50-120	50-100	60-100
2	10-100	10-100	30-140	20-150	10-200	20-140	10-200	10-170
3	70-150	90-160	0	90-140	20-150	90-200	90-180	70-170
4	40-100	50-120	80-140	50-160	60-140	40-130	60-160	70-160
5	90-100	90-100	40-100	30-140	90-200	80-160	50-200	100-200
6	40-70	0-70	10-150	40-150	0-100	40-150	100-150	80-200
7	70-110	70-150	90-200	80-130	40-120	50-130	50-200	90-200
8	70-120	60-100	70-150	40-120	20-120	50-120	90-150	90-140

Finally, the review of soil maps for the study area (NRCS 2002) indicated that the major soil types located in the upland CSS stand sample areas are the Linne-Los Osos Haploxerepts association, consisting of Linne silty clay loam (with slope inclinations ranging from 9 to 75 percent), and the Los Osos clay loam (with slope inclinations ranging from 30 to 50 percent). Soil descriptions for these soil types indicate soils derived from shale parent material with weathered bedrock found at depths of 30 inches (75 cm). Soil pH values for the Linne silty clay loam soils ranges from 7.9 to 8.4, while that for the Los Osos clay loam ranges from 5.6 to 7.3. Soils are well drained with clay content typically measuring no greater than 35 percent. Soil conditions observed within each of the CSS stands sampled for this study consisted of coarse, sometimes rocky soils with rock fragments reaching between 1 and 2 inches in diameter and are consistent with the soil type descriptions documented for the study area (NRCS 2002).

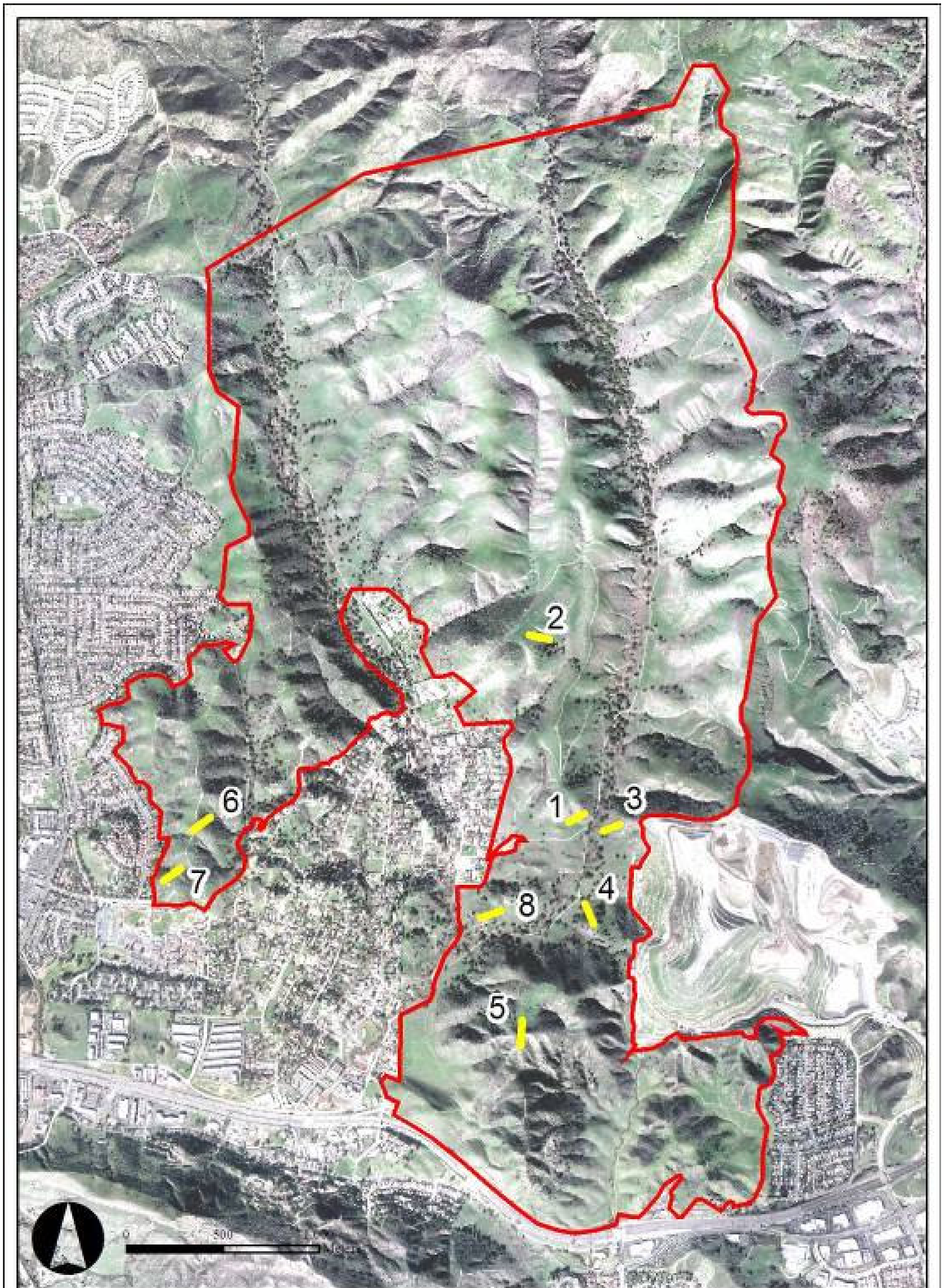

FIGURE 10. Individual transect locations.

CHAPTER 5

DISCUSSION

The analysis of CSS distribution change between each of the two time periods (1929 to 1976, 1976 to 2003) revealed major changes in CSS coverage within the study area. While the dramatic loss of CSS between 1929 and 1976 was not observed during the 1976 to 2003 time period, observation of multi-directional changes in shrubland boundaries were noted for both time periods. The inclusion of fire history data in this study revealed some consistencies between disturbance levels and CSS stand boundary shifts and CSS coverage loss, although it seems that fire frequency may be less of an indicator of shrubland boundary dynamics than fire return interval (duration of time between fires burning a particular area) or, potentially, the heat intensity of individual fires. Additionally, as discussed by Minnich and Scott (2005), the presence of exotic annual grass species likely plays a role in the deterioration of CSS stands by altering natural light and soil moisture conditions that support CSS stand growth. Observations of grassland and CSS boundary changes made during aerial photograph analysis are generally consistent with current research in the field that suggests that CSS will convert to grassland cover in the presence of frequent disturbance (Freudenberger et al. 1987; Minnich and Scott 2005; O'Leary and Westman 1988), although inconsistent patterns did emerge during data analysis. Field sampling efforts, however, did not reveal any discernable trends in ecotone fluctuations based on documented fire frequencies. This chapter discusses the results of this study in comparison with existing research in the field of CSS shrubland dynamics and evaluates the role of fire frequency data in interpreting CSS stand boundary changes.

Comparison with Freudenberger, Fish and Keeley Study

In the study by Freudenberger et al. (1987), grassland and CSS distribution changes were documented between 1929 and 1980 within 23 individual USGS quadrangles throughout Southern California. As multi-directional changes in grassland/CSS ecotone boundaries were observed within the Calabasas quadrangle, an intensive study was conducted in the Cheseboro Canyon/Palo Comado Canyon area. The authors utilized historical aerial photographs and vegetation maps to determine CSS shrubland boundaries and document either advancement or retreat over time. Additionally, field sampling was conducted within nine CSS patches to document stand conditions at a fine scale. Utilizing a methodology for determining the advancement or retreat of vegetation community boundaries presented by Leak and Graber (1974), the original authors conducted belt transects and documented shrub species, height, and distance from the ecotone. Additionally, general soil texture, slope inclination, and aspect were documented for each of the nine sampled CSS patches.

The results of the Freudenberger et al. (1987) study in the Calabasas quadrangle revealed substantial increases in grasslands, primarily in Cheseboro, Palo Comado, and Las Virgenes Canyons. However, a small portion in the southern portion changed from grassland to CSS. This condition revealed that CSS stand boundary changes in the study area were multidirectional, indicating that CSS shrubland boundaries were observed to be either advancing into neighboring grasslands, or retreating and being replaced by grasslands. The Clampitt Fire of 1970 burned the majority of the study area (FRAP 2005) prior to the Freudenberger et al. study and was mentioned as a reason for the increase of grasslands at the expense of CSS stands. Additionally, as argued by the authors, the nine patches of CSS sampled were located in areas of diverse slope aspects and inclinations; therefore, it was argued that topographic position was not a factor in CSS stand distribution (Freudenberger et al.). Unfortunately, quantifications of the CSS or grassland areas exhibiting change over time were documented for the entire Calabasas quadrangle, not the intensive study area, so direct comparisons of acreage changes between the two studies are not possible.

The analysis of CSS shrubland boundary changes in the Cheseboro and Palo Comado Canyon areas presented in this study for the 1929 to 1976 time period are generally consistent with those presented by Freudenberger et al. (1987). As indicated in Table 2, observations of vegetative cover change revealed a substantial loss of CSS cover (and an increase in grassland cover) and that multi-directional changes occurred. In this study, approximately 1,062 acres of land were converted from CSS to grassland over a 48 year time period, while approximately 97 acres were converted from grassland to CSS. Although the loss of CSS was more dramatic than the loss of grassland over this time period, the multi-directional change indicated consistency with previous research conducted in the same study area.

Freudenberger et al. (1987) argued that a 10 year fire return interval, in combination with extensive grazing, is an adequate disturbance regime to inhibit the advancement of CSS into neighboring grasslands. However, fire history data for the study area indicates a much longer fire-free period for the majority of the site. Specifically, most of the study area had a 21 year fire-free period, between the 1949 Simi Hills Fire and the 1970 Clampitt Fire. During that time, only the eastern portion of the study area burned during the 1967 Palmer Fire (1967). Given the relative lack of burning in most of the study area, a 20 year fire return interval, in combination with extensive grazing, may be a more appropriate disturbance regime sufficient to inhibit the invasion of CSS into neighboring grasslands in the study area. This finding also indicates that grazing may have had more of an influence than wildfire in vegetation dynamics during the 1929 to 1976 time period. Additionally, the short three year fire interval (1967, 1970) in the eastern portion of the study area may have affected the observations documented by Freudenberger et al. by reducing overall CSS coverage in that area.

Vegetation Change and Fire History

As noted, the dramatic loss of CSS documented between 1929 and 1976 is consistent with that observed by Freudenberger et al. (1987). Fire frequency data for the study area during this time period revealed that four fires had burned between aerial photograph dates. The northern portion of the study area that exhibited the most dramatic change from CSS to grassland cover was subject to fires in 1931, 1949, 1967, and 1970, although areas where CSS advancement occurred (in the southeast portion of the study area) were also subject to the same fire regime. Based on existing research in the field (Zedler et al. 1983; Keeley and Keeley 1984; Westman and O'Leary 1986; Keeley 1987; Giessow and Zedler 1996; DeSimone and Zedler 1999), it is expected that areas subject to higher fire disturbance frequencies and shorter intervals would convert from CSS to grassland. This expected outcome was observed in the northern portion of the property where CSS loss was dramatic. However, the static and advancing nature of the CSS stands in the southern portion of the study area that was subject to the same fire disturbance frequency and interval is not explained by the research. Visual interpretation of the aerial photographs for 1929 also revealed an east-west trending linear CSS/grassland boundary that may have been attributed to a cattle fence segregating the northern portion of the canyon from the south (Figure 11). In this image, the north side of the fence was dominated almost entirely by CSS, while the south side exhibited more fragmented CSS cover consisting of isolated stands surrounded by grasslands. From this interpretation, it is assumed that grazing activity in the northern portion of the study area began after 1929. Consequently, the dramatic loss of CSS in the northern portion of the study area noted in the 1976 photo set may be a result of the initiation of grazing activity in the area.

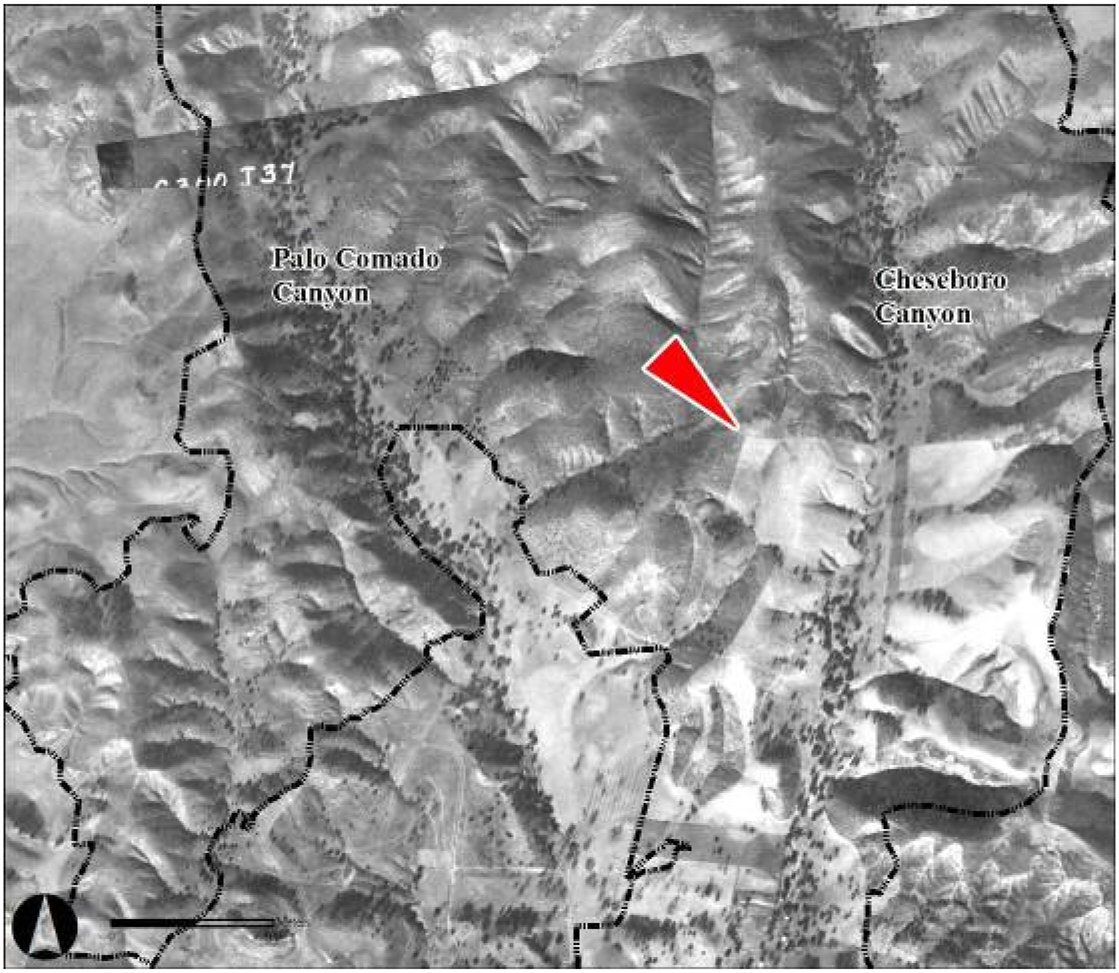

FIGURE 11. East-west trending CSS/grassland boundary from 1929 photo.

A visual analysis of a 1947 aerial image of the study area provides further insight into the influences of CSS loss in the study area. This image indicates that very little loss of CSS coverage occurred within the study area between 1929 and 1976, indicating that the dramatic shift observed between 1929 and 1976 occurred primarily between 1947 and 1976. Based on fire history data, only the 1931 Agoura No. 26 Fire burned a relatively small portion of the study area between 1929 and 1947. Therefore, the higher rate of conversion of CSS to grassland after 1947 correlates well with increased fire frequencies (1949, 1967, and 1970).

While the dramatic loss of CSS in the northern portion of the study area between 1929 and 1976 is likely attributed to a combination of high fire frequencies, a short fire return interval, and the initiation of cattle grazing in the area, the CSS boundary changes observed in the southern portion do not conform with the expected outcomes from current research in the field. Specifically, if frequent disturbance should result in a conversion of CSS to grassland (Freudenberger et al. 1987; Minnich and Scott 2005), the static or advancing nature of the CSS stands in the southern portion of the study area subject to frequent grazing is not explained.

The aerial photo analysis for the 1976 to 2003 time period revealed a less dramatic conversion of CSS to grassland and multi-directional CSS boundary changes were also observed. While approximately 39 percent of the study area was classified as experiencing some sort of vegetative cover change between 1929 and 1976, only 21 percent of the study area experienced change between 1976 and 2003, indicating a decrease in the rate of vegetative cover change. While cumulative fire frequencies ranged between 1 and 7, the fire return intervals varied across the study area. The occurrence of the Dayton Canyon Fire in 1982 that burned nearly the entire site provides a general baseline for analysis of the 1976 to 2003 time period, effectively allowing a determination of fire-free period for the entire site following 1982. Analysis of fire and vegetation change data for this time period also indicates inconsistency with general research conclusions regarding disturbance and CSS recovery.

The concentration of land converting from CSS to grassland cover is concentrated primarily in the northern and eastern portions of the study area, consistent with increased fire frequencies and shorter fire intervals. For example, upper Cheseboro and Palo Comado Canyons experienced a disproportionate amount of the CSS loss during this time period and were subject to five fires occurring in 1982, 1984, 1993, 1994, and 1995. It would be expected that this high frequency, coupled with very low fire intervals would be sufficient to prevent the conversion of grassland to CSS. However, although this area did experience CSS loss, it also experienced conversion of grassland to CSS. The multi-directional CSS stand boundary movements observed in the northern and eastern portions of the study area are inconsistent with expected results based on the physiological response mechanisms of the shrub species comprising CSS. These observations indicate that other characteristics of disturbance, such as fire intensity, may have a greater effect on CSS vegetation dynamics and play a more important role in shaping the distribution of CSS stands in the landscape.

Field Sampling

It was expected that CSS stands with higher fire frequencies would exhibit retreat, observable through the lack of seedlings at the shrub stand edge. Conversely, CSS stands with lower fire frequencies were expected to exhibit advancement into neighboring grasslands via the establishment of seedlings beyond the general stand boundary. Documentation and assessment of shrub heights relative to position along each transect, however, revealed no discernible trend in stands with the same fire frequencies. In fact, no discernible trend emerged when comparing transect data from low fire frequency areas with that from high fire frequency areas.

By analyzing transect data (Appendix A), areas with fire frequencies of 2 (Transects 7 and 8) revealed shrub heights clustered near the center of the height spectrum, between 70 and 130 cm. Areas characterized by fire frequencies of 3 (Transects 2 and 3) revealed dissimilar sampling results from each other. While Transect 2 exhibited a relatively even distribution of shrub heights (between 10 and 100 cm), Transect 3 exhibited a heavier concentration of larger shrubs between 90 and 150 cm. Areas with fire frequencies of 4 (Transects 1, 4, 5, and 6) also revealed dissimilar sampling results with Transects 1 and 4 characterized by a clustering of sampled shrub heights between 50 and 140 cm, while Transects 5 and 6 exhibited a greater variation in shrub heights distributed throughout all of the transect quadrats.

As grazing has been removed from the study site and all but two of the sampled stands (Stands 1 and 6) burned most recently in 1982, the disturbance regime for sampled stands remains relatively constant. Grazing after the 1982 Dayton Canyon Fire may have affected the conditions observed during sampling, although it would be expected that CSS stand boundaries would advance in the absence of grazing or fire disturbance. However, the field sampling results are inconsistent with the expected outcomes, indicating that either the methodology presented by Leak and Graber (1974) that was utilized in this study may not be an appropriate sampling technique for CSS communities, or that characteristics of wildfire other than frequency may have a stronger influence in CSS shrubland boundary movement.

CHAPTER 6

CONCLUSIONS

Wildfire frequency data for the Cheseboro and Palo Comado Canyon areas provide a valuable set of geographic information that has been used as a lens through which to study the spatial movement of CSS shrubland boundaries over two distinct historical time periods. The number of times a portion of land has burned and the temporal variations in disturbance cycles have implications for the vegetative cover that is able to establish and persist in a given location. Current research in the field of CSS post-fire recovery and CSS regeneration capabilities reveals differing opinions regarding the effect that disturbance has on the persistence of CSS stands. This study attempts to provide additional information about the impact of fire frequency on CSS stand dynamics by analyzing stand boundary changes over time in areas with documented fire frequencies.

It was expected that areas with increased fire frequencies would exhibit retreating CSS shrubland boundaries. This research revealed, however, that boundary shifts were not correlated directly with fire frequencies documented for the site. The portions of the study area that experienced the most dramatic CSS coverage loss, however, were those with the highest frequency. This observation may reveal that the use of FRAP fire perimeter data (2005) is better applied to analyses conducted at a coarser geographic scale than that used in this analysis. While observations of CSS/grassland boundary shifts were not necessarily consistent with high fire frequencies, the dramatic loss in CSS cover within the study area is directly correlated with high fire frequencies. This conflicting condition may indicate that other characteristics of wildfire play a more important role in promoting or inhibiting the establishment of CSS. Specifically, the duration of time between fires (fire return interval) and the amount of heat generated form individual fires (fire intensity) may be better indicators of the whether CSS stands are able to establish and persist, or whether they are converted to grasslands as CSS shrub species are less tolerant to high-intensity fires (Keeley, Fotheringham, and Baer-Keeley 2005). Additionally, grazing, either by itself or in combination with repeated fires, may also play a crucial role in the dynamics of CSS coverage over time.

The inconsistencies between observed conditions and expected outcomes noted during the analysis of site data included in this study may also be explained by limitations in the data sets used in interpreting landscape cover change and fire frequencies. The fire history data (FRAP 2005) utilized in this analysis only contains fires of a certain size as determined by the responsible agency. Consequently, small wildfires or intentional burning by ranchers attempting to increase available forage for cattle may not have been included in the database. Fire perimeters generally encompass the final extent of the burn area and do not account for un-burned portions existing within the perimeter itself, while the accuracy of fire perimeters is difficult to ascertain (FRAP 2005). The georeferencing procedures used in aligning the 1929 aerial photo set may also account for slight variations observed along shrub stand boundary edges and may explain the static or advancing boundaries observed in certain portions of the study area. However, considerable changes in CSS coverage throughout the study area would be observable despite any georeferencing errors.

While limitations exist in the data sets used in this study, the inclusion of fire history data provides a further level of analysis in the field of CSS research. As previous studies have addressed the effects of various forms of disturbance on CSS recovery, the effect of fire frequency has not been adequately addressed. While it has been argued that increased fire activity will promote the conversion of CSS to grassland (Westman 1981a; Zedler et al. 1983; Keeley and Keeley 1984), the data generated during this study reveal that direct correlations between fire frequency and the extent of CSS coverage can not be made for this particular study site. Analysis of fire free periods, however, revealed that shorter intervals affect the capability of CSS to expand at the expense of grasslands. This finding correlates nicely with existing research (Zedler et al. 1983; Keeley and Keeley 1984; Westman and O'Leary 1986; Keeley 1987; Giessow and Zedler 1996; DeSimone and Zedler 1999) that focuses on the recovery techniques of individual shrub species that comprise CSS. Additional research is warranted in this field, specifically in regard to the effect of wildfire heat intensity on the recovery of CSS. The use of thermal satellite imagery or more detailed fire perimeter data in analyzing fires burning in CSS habitat can provide additional insight into the effect of wildfire on CSS stand characteristics.

The results of this study provide another piece of information in the growing field of coastal sage scrub research. The adaptation of CSS species to disturbance regimes affects their ability to persist in the landscape of Southern California, while shifting land use priorities in this region will affect the overall distribution of this habitat type in the future. The inclusion of fire frequency data in the analysis of CSS stand boundary fluctuations presented in this study provides a valuable landscape variable through which to view such changes. Current research in this field indicates that increased disturbance frequencies will result in the loss of CSS coverage over time. While the dramatic loss of CSS coverage observed in portions of the study area correlates well with fire frequency data, fluctuations of CSS boundaries in other areas do not correlate well with fire frequency data. Additionally, field sampling data is inconsistent with expected outcomes for CSS stand boundary advancement or retreat given certain fire frequencies.

The analysis of CSS stand conditions at two different scales reveals inconsistencies with expected outcomes. Consequently, fire frequency may play less of a role in determining CSS shrubland dynamics than other components of fire history, such as fire return interval and fire intensity, although further research is necessary to better support such a hypothesis. Short durations between burns in the study area did result in conversion of CSS cover to grass cover, supporting such an argument. Also, the geographic scale at which analyses are conducted may dictate findings. For example, the high frequency of fires was directly correlated with the dramatic loss of CSS in the north-east portion of the study area, while field sampling results for areas with higher frequencies in the south-west portion of the study area were inconclusive. Consequently, the fire frequency data utilized in this analysis may be more applicable to analyses conducted at coarser geographic scales than that presented in this study.

The information presented in this study utilizes valuable fire history data for Southern California in interpreting the dynamic nature of coastal sage scrub boundaries over time. The presence of CSS in the landscape is strongly influenced by disturbance regimes, namely wildfire. Increases in fire frequencies and decreases in fire free periods in CSS as a result of anthropogenic influences serve to threaten this habitat type in Southern California. This study provides a better understanding of one component of wildfire disturbance that affects CSS shrubland dynamics by analyzing change over two distinct time periods. This study also creates an opportunity for future study in the field of CSS research by providing a baseline of CSS cover change within the Cheseboro and Palo Comado Canyon areas in the Santa Monica Mountains of Southern California. Additionally, the inclusion of field sampling provides an opportunity for further study by documenting species composition change since the Freudenberger et al. study of 1987. Finally, while the understanding of CSS shrubland dynamics is not complete, this study provides one of the only analyses of multiple time period changes documented for a specific study site in Southern California.

APPENDICES

APPENDIX A

INDIVIDUAL TRANSECT DATA

TABLE 1. Transect 1 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Eriogonum cinereum*			1		1			1		2										
2	*Eriogonum cinereum*						1		2				2								
3	*Eriogonum cinereum*							1	2	1	5	1									
4	*Eriogonum cinereum*						1		2	1	3		1								
	Salvia mellifera					2															
5	*Eriogonum cinereum*									1	3		2								
	Salvia mellifera						2	1	2												
6	*Eriogonum cinereum*						2		2		2										
	Salvia mellifera							1			1		1								
7	*Eriogonum cinereum*						1			2	2										
	Salvia mellifera							2		1	1										
8	*Eriogonum cinereum*							1	2	1	2										

Slope (percent): 70
Aspect (degrees): 180
Date: 12/17/2005
Soil: coarse, medium to large rock fragments (> 2"), sandy

Fire Frequency: 4
Fire-free Period: 8
Most Recent Fire: Boundary I Fire, 1995

TABLE 2. Transect 2 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Haplopappus venetus*		3	6	2	3	1		1		2										
2	*Haplopappus venetus*		2	6	3	2	1	3		5	3										
	Salvia leucophylla										2										
3	*Haplopappus venetus*				1	2	3	3		3	4										
	Salvia leucophylla										2				1						
4	*Haplopappus venetus*			2		3	1	3	1		2										
	Salvia leucophylla								1		3					2					
5	*Haplopappus venetus*		5	2	2	3	2		2	2											
	Salvia leucophylla									1			3	1			2		1		1
6	*Haplopappus venetus*			3	3	2	1		1												
	Salvia leucophylla									2		1		1	1						
7	*Haplopappus venetus*		4	2	3	2	1														
	Salvia leucophylla										1	2	2		1			1			1
8	*Haplopappus venetus*		2	2	4	2		1													
	Salvia leucophylla									2		1	1	1			1	1			

Slope (percent): 26
Aspect (degrees): 10
Date: 12/17/2005
Soil: coarse, medium to large rock fragments (> 2"), sandy

Fire Frequency: 3
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

TABLE 3. Transect 3 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Artemisia californica*								1							2					
2	*Artemisia californica*										1		1			2	1				
3	*No shrubs, all grass*																				
4	*Artemisia californica*										1		2		2						
	Salvia mellifera										1										
5	*Artemisia californica*			1		2	2				1			1	1	2					
	Salvia mellifera							1	1		1	1	2		2						
6	*Artemisia californica*										2		2								
	Salvia mellifera										2				1	2	1				
	Haplopappus venetus																				3
7	*Artemisia californica*										1	2			1						
	Salvia mellifera										2						2		1		
8	*Artemisia californica*								1			3		1			1				
	Salvia mellifera										2		2			2		1			

Slope (percent): 45
Aspect (degrees): 245
Date: 12/17/2005
Soil: coarse, few rock fragments, sandy

Fire Frequency: 3
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

TABLE 4. Transect 4 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Haplopappus venetus*					2	1	2			1										
2	*Haplopappus venetus*						2	1	1	1											
	Artemisia californica										3		1								
	Salvia leucophylla												1								
3	*Artemisia californica*									1	4	2	2		2						
4	*Artemisia californica*									2	3	1	2			2	1				
	Haplopappus venetus						1		1												
5	*Artemisia californica*									1	2	3	2		1						
	Haplopappus venetus							1	1	2											
6	*Artemisia californica*							1		2	2		2	1							
	Haplopappus venetus					1	1		1												
7	*Artemisia californica*									1	1	2	2		1						
	Haplopappus venetus							2	1	1											
	Salvia leucophylla																2				
8	*Artemisia californica*									2		3		2	1						
	Haplopappus venetus								1	1		2									
	Salvia leucophylla												1		1		4				

Slope (percent): 37
Aspect (degrees): 310
Date: 12/18/2005
Soil: coarse, sandy, rock fragments generally less than 1 inch

Fire Frequency: 4
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

TABLE 5. Transect 5 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Haplopappus venetus*										1										
2	*Haplopappus venetus*										2										
3	*Haplopappus venetus*					1					3										
4	*Haplopappus venetus*				1	1				1	2		1								
	Artemisia californica												1		1						
5	*Artemisia californica*										1			1		1		1			
	Salvia leucophylla																	1			1
6	*Artemisia californica*											1	1			1	1				
	Haplopappus venetus										1	3									
	Salvia leucophylla									1	1	1									
7	*Artemisia californica*														1	1	2				
	Salvia leucophylla															1		1	1		1
8	*Artemisia californica*															2		1	1		
	Salvia leucophylla											1				1		1	1		2

Slope (percent): 32
Aspect (degrees): due north
Date: 12/18/2005
Soil: coarse, few small rock fragments

Fire Frequency: 4
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

TABLE 6. Transect 6 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Eriogonum cinereum*						1														
	Marrubium vulgare					1	4	1													
2	*Marrubium vulgare*	1	1		2	2	3	1													
3	*Marrubium vulgare*		1		1				1												
	Artemisia californica															2					
4	*Marrubium vulgare*					1		1													
	Haplopappus venetus								1												
	Artemisia californica															1					
5	*Marrubium vulgare*	2	1	1		1	1														
	Eriogonum cinereum					1			2		1										
6	*Salvia leucophylla*								1		1		1		1						
	Eriogonum cinereum					2		1			2										
	Artemisia californica										2					1					
7	*Artemisia californica*											1	1	1							
	Salvia leucophylla												1	2		2					
8	*Artemisia californica*										1					2					
	Malacothamnus fasciculatus																				2
	Eriogonum cinereum									1	2										

Slope (percent): 45
Aspect (degrees): 25
Date: 12/18/2005
Soil: coarse, rock fragments greater than 2 inches

Fire Frequency: 4
Fire-free Period: 9
Most Recent Fire: Toth Fire, 1994

TABLE 7. Transect 7 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Eriogonum cinereum*									2	2	2									
	Haplopappus venetus								2												
2	*Eriogonum cinereum*								1												
	Salvia leucophylla								1		1		1			1					
3	*Salvia leucophylla*										2								2		1
	Malacothamnus fasciculatus																				1
4	*Eriogonum cinereum*									1	2										
	Artemisia californica													1							
	Salvia leucophylla									1											
5	*Eriogonum cinereum*					2			2	1			1								
	Artemisia californica									1	1										
6	*Eriogonum cinereum*						1	1	1		1										
	Artemisia californica										3	1		1							
7	*Eriogonum cinereum*										1	1									
	Artemisia californica						1						1						1		
	Malacothamnus fasciculatus																				1
8	*Artemisia californica*										1	1	1	2	1						
	Malacothamnus fasciculatus																				3

Slope (percent): 20
Aspect (degrees): 310
Date: 12/19/2005
Soil: coarse, rocky, rock fragments greater than 3 inches

Fire Frequency: 2
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

TABLE 8. Transect 8 data.

Quadrat Number	Species	Quantity of Shrubs by Shrub Height (cm)																			
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
1	*Salvia leucophylla*								1	1	2		1								
2	*Artemisia californica*							1	2	2	1										
3	*Salvia leucophylla*								1			1	1	1							
	Artemisia californica									1	1	1		2		1					
4	*Salvia leucophylla*					1					1										
	Artemisia californica										2		2								
5	*Salvia leucophylla*			1																	
	Artemisia californica									1	2	1	1								
6	*Salvia leucophylla*						1		1												
	Artemisia californica									2	2		2								
7	*Salvia leucophylla*										1			1		1					
8	*Artemisia californica*										1	2	2		1						

Slope (percent): 42
Aspect (degrees): 115
Date: 12/19/2005
Soil: coarse, rocky, rock fragments greater than 2 inches

Fire Frequency: 2
Fire-free Period: 21
Most Recent Fire: Dayton Canyon Fire, 1982

APPENDIX B

TRANSECT PHOTOGRAPHS

FIGURE 1. Transect 1, Photograph 1.

FIGURE 2. Transect 1, Photograph 2.

FIGURE 3. Transect 2, Photograph 1.

FIGURE 4. Transect 2, Photograph 2.

FIGURE 5. Transect 3, Photograph 1.

FIGURE 6. Transect 3, Photograph 2.

FIGURE 7. Transect 4, Photograph 1.

FIGURE 8. Transect 5, Photograph 1.


FIGURE 9. Transect 6, Photograph 1.


FIGURE 10. Transect 6, Photograph 2.

FIGURE 11. Transect 7, Photograph 1.

FIGURE 12. Transect 7, Photograph 2.

FIGURE 13. Transect 8, Photograph 1.

FIGURE 14. Transect 8, Photograph 2.

REFERENCES

REFERENCES

Axelrod, D. 1978. The origin of coastal sage vegetation, Alta and Baja California. *American Journal of Botany*. 65:1117-1131.

Bowler, P.A. 1990. Coastal sage scrub restoration I: the challenge of mitigation. *Restoration and Management Notes*. 8(2): 78-82.

Bowler, P.A. 2000. Ecological restoration of coastal sage scrub and its potential in habitat conservation plans. *Environmental Management*. 26(1): 85-96.

Callaway, R.M. and Davis, F.W. 1993. Vegetation dynamics, fire, and the physical environment in coastal central California. *Ecology*. 74(5): 1567-1578.

DeSimone, S.A., and Zedler, P.H. 1999. Shrub seedling recruitment in unburned Californian coastal sage scrub and adjacent grassland. *Ecology*. 80(6): 2018-2032.

Fire and Resource Assessment Program (FRAP) 2005. California Department of Forestry and Fire Protection. On-line: http://frap.cdf.ca.gov/. Accessed 5 May 2005.

Freudenberger, D.O., Fish, B.E., and Keeley, J.E. 1987. Distribution and stability of grasslands in the Los Angeles Basin. *Bulletin of the Southern California Academy of Sciences*. 86: 13-26.

Giessow, J. and Zedler, P. 1996. The effects of fire frequency and firebreaks on the abundance and species richness of exotic plant species in coastal sage scrub. In: Lovich, J., Randall, J., and Kelly, M. (eds.). Proceedings: California Exotic Pest Plant Council Symposium, Volume 2, 1996. San Diego, California, October 4-6, 1996.

Helms, J.A., ed., *The Dictionary of Forestry.* Bethesda: The Society of American Foresters, 1998.

Hobbs, E.R. 1986. Characterizing the boundary between California annual grassland and coastal sage scrub with differential profiles. *Vegetatio*. 65: 115-126.

Keeley, J.E. 1987. Role of fire in seed germination of woody taxa in California chaparral. *Ecology*. 68(2): 434-443.

Keeley, J.E. 2002a. Fire management of California shrubland landscapes. *Environmental Management*. 29(3): 395-408.

Keeley, J.E. 2002b. Native American impacts on fire regimes of the California coastal ranges. *Journal of Biogeography*. 29: 202-320.

Keeley, J.E., Fotheringham, C.J., and Morais, M. 1999. Reexamining fire suppression impacts on brushland fire regimes. *Science*. 284: 1829-1832.

Keeley, J.E., and Fotheringham, C.J. 2001. Historic fire regime in Southern California shrublands. *Conservation Biology*. 15(6): 1536-1548.

Keeley, J.E., Fotheringham, C.J., and Baer-Keeley, M. 2005. Determinants of postfire recovery and succession in Mediterranean-climate shrublands of California. *Ecological Applications*. 15(5): 1515-1534.

Keeley, J.E. and Keeley, S.C. 1984. Postfire recovery of California coastal sage scrub. *The American Midland Naturalist*. 111(1): 105-117.

Kirkpatrick, J.B. and Hutchinson, C.F. 1980. The environmental relationships of Californian coastal sage scrub and some of its component communities and species. *Journal of Biogeography*. 7: 23-38.

Leak, W.B. and Graber, R.E. 1974. A method for detecting migration of forest vegetation. *Ecology*. 55:1425-1427.

Levin, M. 1985. Park service buys $8-million recreation area tract. *Los Angeles Times*. January 11, 1985.

Malanson, G.P. 1984. Fire history and patterns of Venturan subassociations of Californian coastal sage scrub. *Vegetatio*. 57: 121-128.

Maslach, W.R. 2000. Historical land use of the lower Las Virgenes Valley, central Malibu Creek watershed, 1500 – 2000. M. S. thesis, California State University, Northridge.

Minnich, R.A. 1983. Fire mosaics in Southern California and northern Baja California. *Science*. 219:1287-1294.

Minnich, R.A. 1987. Fire behavior in Southern California chaparral before fire control: the Mount Wilson burns at the turn of the century. *Annals of the Association of American Geographers*. 77(4): 599-618.

Minnich, R.A. and Scott, T.A. 2005. Wildland fire and the conservation of coastal sage scrub. On-line: http://ecoregion.ucr.edu/review/cssfirex.pdf. Accessed 4 April 2005.

Moritz, M.A. 2003. Spatiotemporal of controls on shrubland fire regimes: age dependency and fire hazard. *Ecology*. 84(2): 351-361.

Moritz, M.A., Keeley, J.A., Johnson, E.A., and Schaffner, A.A. 2004. Testing a basic assumption of shrubland fire management: how important is fuel age? *Frontiers in Ecology and the Environment.* 2(2): 67-72.

Natural Resources Conservation Service (NRCS), United States Department of Agriculture 2002. Soil Survey for Ventura Area, California. On-line: http://soils.usda.gov/. Accessed 14 March 2006.

O'Leary, J.F. and Westman, W.E. 1988. Regional disturbance effects on herb succession patterns in coastal sage scrub. *Journal of Biogeography*. 15: 775-786.

Pinol, J., Beven, K., and Viegas, D.X. 2005. Modelling the effect of fire-exclusion and prescribed fire on wildfire size in Mediterranean ecosystems. *Ecological Modelling*. 183: 397-409.

Rodrigue, C.M. 2004. The construction of scrub in California and the Mediterranean borderlands: climatic and edaphic climax or anthropogenic artifact? *American Geophysical Union*, San Francisco. 16 December 2004. (Biogeosciences, Paper no. B41B-0113).

Swetnam, T.W., Allen, C.D., and Betancourt, J.L. 1999. Applied historical ecology: using the past to manage the future. *Ecological Applications*. 9(4): 1189-1206.

Thomas, T.W. 1986. Population structure of the valley oak in the Santa Monica Mountains National Recreation Area. *Symposium on multiple-use management of California's hardwood resources.* November 12-14, 1986, San Luis Obispo, California. 335-340.

Trabaud, L. and Galté, J. 1996. Effects of fire frequency on plant communities and landscape pattern in the Massif des Aspres (southern France). *Landscape Ecology*. 11(4): 215-224.

Vogl, R.J. 1976. An introduction to the plant communities of the Santa Ana and San Jacinto Mountains. Pages 77-98 in J. Latting, ed. Plant communities of Southern California. Special Publication 2, California Native Plant Society.

Wells, M.L., O'Leary, J.F., Franklin, J., Michaelsen, J., and McKinsey, D.E. 2004. Variations in a regional fire regime related to vegetation type in San Diego County, California. *Landscape Ecology*. 19: 139-152.

Westman, W.E. 1981a. Diversity relations and succession in Californian coastal sage scrub. *Ecology.* 62(1): 170-184.

Westman, W.E. 1981b. Factors influencing the distribution of species of Californian coastal sage scrub. *Ecology*. 62(2): 439-455.

Westman, W.E. and O'Leary, J.F. 1986. Measures of resilience: the response of coastal sage scrub to fire. *Vegetatio*. 65: 179-189.

Zedler, P.H., Gautier, C.R., and McMaster, G.S. 1983. Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. *Ecology*. 64(4): 809-818.