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18 May 2007

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Subject: Post-Fire Erosion Recovery – Phase 2
Boeing Santa Susana Field Laboratory
Geosyntec Project: SB0363G

Dear Mr. Gallacher:

Geosyntec Consultants (Geosyntec) is pleased to provide The Boeing Company this Phase 2 study regarding post-Topanga-fire erosion recovery at the Santa Susana Field Laboratory (SSFL) (project site). The overall objective of the study is to assess the status of and time to recovery at the SSFL, from a hydrology and erosion perspective, subsequent to the September 2005 Topanga fire.

By destroying vegetation and causing soils to become hydrophobic, wildfires can increase stormwater runoff volumes, peak runoff flows, discharge frequencies, and sediment concentrations in stormwater discharges. This results in increased concentrations of sediment-associated pollutants such as TCDD and total metals. With respect to hydrologic effects on soils in particular, wildfires often also result in the deposition of a waxy or hydrophobic surface coating on burned soils, causing water repellency, which leads to increased surface runoff and, in turn, increased soil erosion. Therefore, the study focused on measurable parameters that directly impact these stormwater-related conditions of concern, most notably vegetation type and cover, which affect soil stability and erosion potential, and soil water repellency, which affects runoff rates and volumes.

For this study, vegetative coverage (particularly coverage by perennials, such as chaparral, which have the greatest stabilizing effect on soils due to their more extensive root coverage and increased evapotranspirative demand and canopy interception capabilities) and soil hydrophobicity (or water repellency) were measured quantitatively to assess the watershed's recovery from the Topanga fire. The term "recovery" is defined, for the purposes of this analysis, as vegetation and soil hydrophobicity conditions that are statistically indistinguishable from conditions in comparable unburned areas. Both vegetative coverage and soil hydrophobicity characteristics that are statistically similar to unburned areas are necessary for post-Topanga-fire soil erosion potential and sediment yields to be considered equivalent to pre-Topanga-fire conditions. If one of these factors (vegetative coverage or soil hydrophobicity) are not statistically similar between burned and unburned areas, then the burned areas would be expected to produce greater sediment yields than unburned areas. Hence, for recovery to occur, it is necessary for both the vegetative cover to return to pre-fire levels, particularly of the perennial woody-stemmed species, and for soil hydrophobicity to be broken down to its respective pre-fire levels.

Phase 1 of the study, which was completed in March 2007, was an initial semi-quantitative assessment of the site's likely recovery time based on a literature review and reconnaissance-level survey of conditions at the project site. The initial findings from the Phase 1 study indicated that watershed recovery time following a fire is highly variable and dependant upon many factors. Literature reviewed generally indicates that cumulative watershed recovery could occur within four to eight years. Both the soil and the vegetative conditions must be restored to pre-fire conditions for a watershed to be considered "recovered" in the context of natural erosion control and sediment yield.

Phase 2 of the study, conducted in March through April 2007, included a quantitative site survey of existing vegetation and soil hydrophobicity. The survey was conducted in the spring, when a large percentage of annuals and perennials were identifiable. The Phase 2 quantitative survey sought to refine the estimated recovery time range from the Phase 1 study based on further literature review and a detailed field assessment of current conditions (one and a half years, or two complete wet seasons[1] since the fire). The Phase 2 site survey found that soil water repellency is at or near a recovered state, and vegetation is expected to recover in five to ten years after the fire.

As part of the Phase 2 study, a comprehensive site-wide soil survey was conducted by Geosyntec, in which soil water repellency was measured at 33 onsite burned and 33 unburned reference locations, and statistically compared to investigate remaining fire effects on soil infiltration capacity at the site. No statistical differences were observed between burned and unburned test locations at most areas tested for this study, therefore supporting the general conclusion that soil water repellency has recovered almost completely in most areas of the site.

[1] However it should be noted that rainfall during the most recent wet season (October 2006 – April 2007) totaled only 5.9 inches at the onsite Los Angeles County rain gauge #300 (2260 ft elevation), or the 2nd lowest on record for the previous Ventura County onsite gauge #249 (1910 ft elevation). Gauge #249 had a 36 year period of record (1959-1977, 1986-2002). Gauge #300 was installed in January 2001 and remains in operation.

This finding is consistent with literature reviewed, which indicates that soil water repellency, in general, recovers between one and three years after a fire. Wright Water Engineers, Inc. (WWE) provided peer review for this study. The final report for this study will be provided separately upon completion.

Also as part of the Phase 2 study, a post-fire site-wide vegetation survey was performed by Western Botanical Services, Inc. (WBS). WBS' May 2007 report, which is entitled "Phase 2 Post-Fire Vegetation Recovery Report," is provided with this letter. Data from this March to April 2007 field survey confirm that there is a statistically significant difference in total vegetative cover, perennial cover, and litter between burned (SSFL) and unburned chaparral (onsite and offsite locations) in the study area. Burned areas on the project site have not fully recovered from the 2005 Topanga fire in terms of vegetation and litter cover. Recovery, for purposes of the vegetation assessment, was defined as the burned areas achieving similar perennial and/or woody plant cover as is currently found in unburned reference areas (e.g., nearby offsite "control" area). Based on WBS' observations and analysis of data, vegetative recovery at the SSFL site was reported to be consistent with chaparral recovery patterns documented in literature, and anticipated recovery of vegetative cover to pre-fire conditions is therefore expected to occur 5 to 10 years post-fire, or between 2010 and 2015. Chaparral and other perennial species that dominate the SSFL site are particularly important in the context of natural erosion control due to their deeper and more expansive root systems and their provision of more permanent and seasonally reliable ground cover than annual species (e.g., grasses and forbs).

Furthermore, an evaluation of vegetative cover by major watershed (i.e., areas draining to outfalls 001, 002, 008, 009, 011, and 018) demonstrated generally consistent recovery rates with the exception of the watershed for outfall 002, where observed perennial cover percentages were higher than in the other watersheds.

Both soil hydrophobicity recovery and vegetative recovery are necessary to reduce erosion and sediment yield potential to pre-fire conditions. Based on the findings from these two studies, and the fact that both the soil and the vegetative conditions must be restored to pre-fire conditions for a watershed to be considered "recovered" in the context of natural erosion control and sediment yield, total recovery at the site is expected to occur between 5 and 10 years from the time of the fire, or 2010 to 2015.

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Should you have any comments or questions regarding the above-referenced information, or the reports that are attached, please do not hesitate to contact us.

Sincerely,

Ronald S. Johnson, PE
Associate

Brandon Steets, PE
Project Manager

Attachments: Post-Fire Vegetation Recovery Assessment Report, prepared by WBS

Copies to:
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Phase 2 Post-Fire Vegetation Recovery Assessment Report

Boeing Santa Susana Field Laboratory

Prepared for:

Geosyntec Consultants

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Contact: Brandon Steets, Project Manager

May 18, 2007

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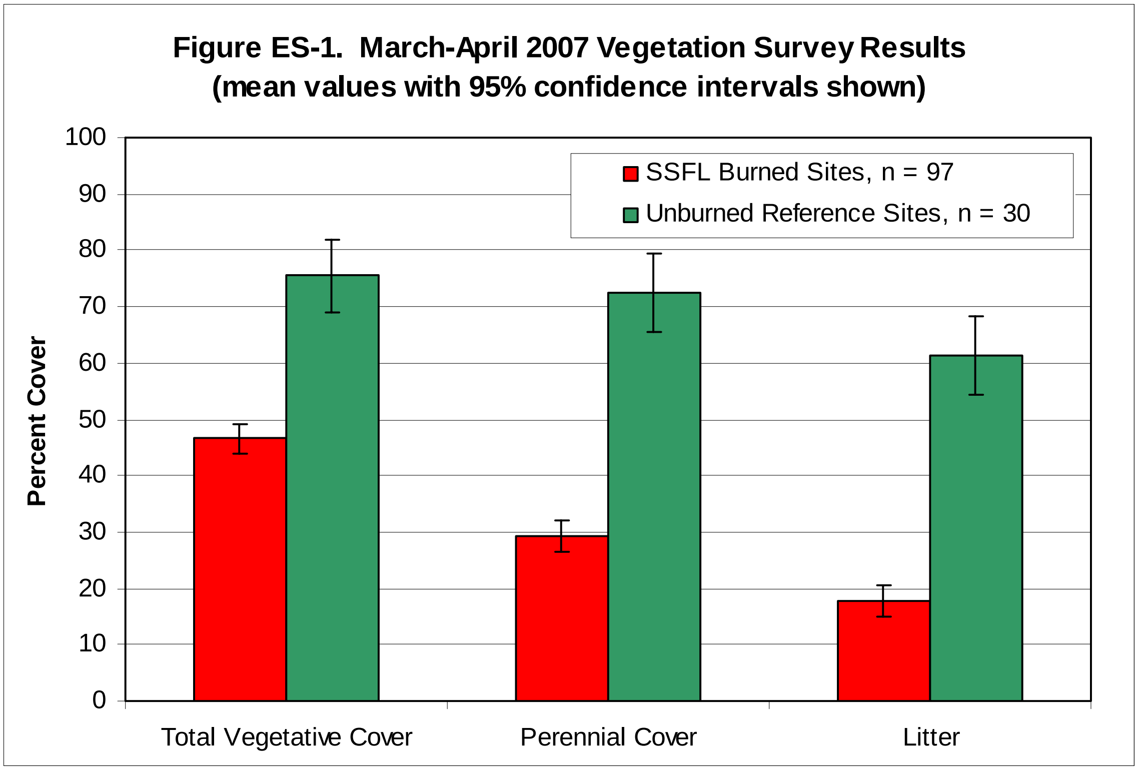
Executive Summary

In September of 2005, a wildfire burned the majority of The Boeing Company's (Boeing) 2800 acre Santa Susana Field Laboratory (SSFL) greatly reducing vegetative cover throughout the site. Prior to the fire, on-site vegetation and Best Management Practices (BMPs) installed by Boeing were relied upon to minimize discharge of sediment and sediment-associated pollutants regulated under Boeing's NPDES permit. The loss of vegetation following the fire resulted in increased storm flows and erosion, making it more difficult for Boeing to meet its NPDES discharge limits. The purpose of this study was to document the state of vegetation regrowth at the SSFL approximately 18-months following the fire, and to estimate the amount of time until the vegetation could be considered recovered (in an erosion control context) relative to pre-fire conditions.

Post-fire vegetation recovery requires regrowth of various vegetation cover classes. Following a fire, annual species (such as many grasses) may recover relatively quickly, but they provide less erosion control than perennials associated with mature chaparral and scrub, which are slower to recover. The potential for increased post-fire erosion continues until these perennial species have recovered. To determine the current level of recovery at the SSFL, the study compared total vegetative cover and several categories of vegetative and abiotic cover (perennials, annuals, woody, litter and unvegetated soils) in burned areas of the site with vegetative cover in comparable unburned areas both on-site and off-site. The study shows that neither total vegetation, nor any other relevant cover category, has returned to pre-fire conditions. The study further concludes that based on the recovery measured to date, as well as on chaparral recovery literature reviewed, vegetation at the SSFL will likely recover to near pre-fire conditions in five to ten years from the date of the fire, or 2010 to 2015.

The overall objective of the study was to assess the status of and time to recovery of chaparral and scrub at the project site subsequent to the September 2005 Topanga fire. Chaparral and scrub represent the dominant vegetation types at the SSFL. These plant communities, when developed, represent an important natural vegetation-based means of erosion control at the site. In plant communities dominated by perennial species, perennials generally provide better erosion control than annual species due to their better developed root systems, greater canopy cover, biomass, and litter production. Burned chaparral/scrub communities on the entire project site were combined and evaluated together by calculating average mean cover values (with confidence intervals). In addition, a comparison of burned and unburned transects (pairwise comparison) revealed statistically significant effects of burning on all three response variables (perennial plant cover, total vegetative cover, and litter cover). Specifically, perennial plant cover differed by significantly more than 30 percent cover between burned and unburned transects, total vegetative cover differed by significantly greater than 20 percent cover, and ground cover by litter (independent of the vegetation layer) differed by significantly more than 30 percent cover. In other words, all of these cover values were significantly higher on unburned transects than on burned transects, by at least 20-30 percent cover. This difference between burned and unburned chaparral is also evident in the overall aggregated transect datasets, as shown in Figure ES-1 below.



Note: "n" = number of samples

Vegetative cover was also evaluated by watersheds (identified for watersheds draining to outfalls 001, 002, 008, 009, 011, and 018). Overall, mean total vegetative cover, perennial cover, and litter were similar between watersheds, with the exception of the watershed draining to outfall 002, where mean cover for perennial and exposed bare ground are both higher than in the other watersheds, but still substantially different than those cover percentages measured in unburned (reference) areas. The higher perennial cover in the outfall 002 watershed is likely due to less historic disturbance and reduced invasion by introduced species. Total vegetative cover, perennial plant cover, litter cover and exposed bare ground were analyzed independently of other parameters and are shown in Table ES-1 below.

Table ES-1. SSFL Vegetation Transect Survey Results: Percent Cover by Cover Category (mean percentages shown, +/- 95% confidence intervals)

Burned Status	Watershed/ Outfall	Number of Samples	Total Vegetative Cover	Total Perennial Plant Cover	Litter Cover	Exposed Bare Ground (unvegetated soil)
Burned	001	20	44.0 ± 5.6	22.9 ± 5.7	18.6 ± 5.5	26.1 ± 6.8
Burned	002	22	46.9 ± 6.3	39.3 ± 6.6	14.1 ± 7.9	36.9 ± 7.7
Burned	008	8	40.0 ± 9.5	28.3 ± 13.0	24.8 ± 10.6	28.6 ± 9.7
Burned	009	21	49.1 ± 5.6	29.9 ± 5.1	18.5 ± 5.8	26.5 ± 5.3
Burned	011	7	47.7 ± 15.9	26.4 ± 14.9	22.9 ± 19.6	23.4 ± 13.1
Burned	018	17	49 ± 6.0	25.5 ± 6.5	15.0 ± 4.8	28.8 ± 7.3
Unburned	**All unburned areas**	**30**	**75.5 ± 6.4**	**72.5 ± 7.0**	**61.4 ± 7.0**	**4.9 ± 2.2**

An evaluation of the data collected in the phase 2 study confirms that there is a statistically significant difference in total vegetative cover, perennial cover, and litter between burned (on the project site) and unburned chaparral (onsite and offsite locations) in the study area. This result indicates that the burned areas, in general, throughout the project site have not fully recovered with regards to vegetation cover and litter layer from the effects of the 2005 Topanga fire. Additional evidence to support this conclusion was also provided as means and confidence intervals of biotic and abiotic cover parameters for all burned and unburned transects. Native cover, total vegetative cover, woody cover, perennial cover, and litter cover are all higher in unburned areas than burned areas; while introduced species cover, annual cover, herbaceous cover and bare ground cover are higher in burned areas than unburned areas.

Based on this field data, the unburned mature chaparral mean total vegetative cover is dominated by woody species (an indication of recovery). Currently, the average cover by woody plants on the burned areas combined is approximately one-fifth of that of the unburned mature chaparral. The average cover of litter within the burned areas is approximately one-half that of the unburned mature chaparral litter cover. This reduced cover by woody species and litter increases the potential for increased erosion to occur.

The data from this study can be used to set target cover goals for recovery. The control for this study consists of onsite and offsite unburned areas chosen to best represent the pre-fire conditions of burned areas onsite. Since there is no data available to assess the chaparral conditions that existed prior to the fire, we assumed that vegetation cover (perennial and woody) and litter cover were similar to the reference unburned mature chaparral on- and offsite. Target cover goals for recovery based on the data collected from these reference areas could be based on the 95 percent confidence intervals calculated for these parameters in the unburned reference areas. Recovery could thus be assessed when the burned areas reach the levels exhibited by the reference unburned areas in terms of the range of cover values shown above in Table ES-1 for all unburned areas.

Given these metrics for assessing recovery, we estimate that the burned chaparral and scrub vegetation will likely recover within five to ten years following fire, or between 2010 and 2015. Based on the status of the burned areas 18 months following the 2005 fire, the regeneration patterns on the burned areas are consistent with most literature reviewed on development and recovery of chaparral following fires.

Purpose and Scope

This Phase 2 Post-Fire Vegetation Recovery Assessment Report (Report) is meant to provide quantitative field survey data and analysis results to support preliminary literature review-based findings that were presented in the Phase 1 reconnaissance survey report for the project site (WBS February 2007). In preparing this Report, vegetation field data collected between March 26 and April 12, 2007, were used to evaluate the recovery of vegetation subsequent to the Topanga fire, which burned most of the project site in September and October of 2005. Vegetative "recovery" is defined by measurable site-specific metrics and is based on statistical comparisons between burned and unburned (control) areas on or near the project site. This information will assist the Los Angeles Regional Water Quality Control Board (LARWQCB) staff in supporting decisions regarding interim relief from final numeric discharge limits and defining an associated compliance schedule for SSFL as it recovers from the effects of fire on erosion.

More specifically, this post-fire vegetation study has two principal goals: 1) to determine whether burned chaparral and coastal sage scrub habitats within the project site differ significantly from unburned reference areas (onsite and offsite) in terms of perennial plant cover and litter cover (i.e., two cover types believed to serve as a reliable vegetation-based metric for natural watershed erosion control); and 2) to quantify measurable recovery parameters in burned areas throughout the project site for the purpose of assessing the vegetation recovery thus far.

Introduction

The 2005 Topanga fire burned nearly all of the approximately 2,850 acres within the SSFL, located in the Simi Hills of Ventura County (Figure 1). To better understand the existing site conditions and to develop the sampling design for the follow-up (Phase 2) quantitative assessment surveys, Western Botanical Services Inc. (WBS conducted a reconnaissance-level (Phase 1) botanical survey in February 2007. This survey included qualitative comparisons of dominant vegetative cover in areas burned during the 2005 Topanga fire to similar small onsite remnant areas that did not burn.

Following the Phase 1 vegetation assessment, it was determined that Phase 2 sampling would focus on the chaparral and coastal sage scrub plant communities (see descriptions below) since these plant communities dominate steep slopes throughout the project site. These perennial species are particularly important in the context of natural erosion control due to their deeper and more expansive root systems and their provision of more permanent and seasonally reliable ground cover than annual species (e.g., grasses and forbs). A Phase 2 work plan was developed to quantitatively assess vegetation and litter cover in burned and unburned chaparral and coastal sage scrub in and around the project site (WBS 2007). Since the majority of the project site burned during the 2005 fire, unburned chaparral and coastal sage scrub transect locations are very limited. The sampling design outlined in the work plan and described in this report, was developed to compare burned and unburned sites including transect locations offsite. This Phase 2 vegetation assessment in burned and unburned chaparral and scrub habitats provides important baseline information on vegetative recovery within the SSFL.

Project Location

Draft Phase 2
Post-Fire Vegetation Recovery
Assessment Report

Geosyntec consultants

Boeing Santa Susana Field Laboratory Ventura, CA

Figure **1**

Santa Barbara

04-May-2007

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Chaparral

Chaparral and coastal sage scrub are common plant communities in California, dominating slopes and hilltops throughout the State. Chaparral occupies over 550,000 acres in Los Angeles County and over 320,000 acres in Ventura County (see http://www.californiachaparral.com/awheresthechaparral.html). Chaparral is the predominant plant community on the project site.

Chaparral in Southern California is adapted to the Mediterranean climate and consists of an association of *sclerophyllous* woody plants having thick, leathery leaves and growing approximately 5-10 feet tall. It is adapted to summer drought, mild, wet winters, and naturally recurring fire disturbance, every 25-50 years on average. Chaparral is typically dominated by scrub oak (*Quercus berberidifolia*), chamise (*Adenostoma fasciculatum*) and other thick-leaved species including *Ceanothus* and manzanita species (*Arctostaphylos spp)*, all of which are typically deep-rooted; however, species composition and dominance varies by location. The understory is typically very sparsely vegetated or not vegetated, consisting mostly of leaf litter. Coastal sage scrub (sometimes called "soft chaparral") often intergrades with chaparral in Southern California, and therefore, scrub species with softer leaves are often found within areas classified as chaparral. This variation in species composition is represented within the unburned chaparral on the project site and adjacent properties, as there are pure stands dominated by typical chaparral species as well as other areas that consist of a mix of chaparral and coastal sage scrub-type species.

The association of species occurring in chaparral communities is quite diverse, and community composition is thought to be shaped by biotic and abiotic characteristics of the site. Examples of these factors include slope aspect, elevation, water availability, soil type, frequency and type of disturbance (e.g., natural such as fire and landslides, human induced), herbivory, and soil microbial communities. The effects of these and other factors on plant communities are described in more detail below and in the discussion section of this report.

The Importance of Fire in Chaparral

Fire is an important natural disturbance in chaparral ecosystems. Chaparral communities are dynamic and adapted to fire, and many chaparral-associated plant species require fire disturbance to persist. The state of recovery following a fire can be evaluated by looking at the predominant life stages as the community develops back to its mature form, which is dominated by woody shrubs. Hanes (1971) notes that chaparral succession "is not a series of vegetational replacements, but a gradual ascendance of long-lived species present in the pre-fire stand."

A typical fire return interval in healthy mature chaparral is between 20-35 years (Hanes 1971). Following a fire, it can take 20 to 30 years for chaparral to return to its pre-fire physiognomy or natural form and structure (Hanes 1971). In the absence of fire for 20 years, chaparral shrubs begin to senesce. Without fire, a large proportion of non-sprouting shrubs eventually die and the community becomes non-productive (Wright and Bailey, 1982).

Chaparral is adapted to repeated fires, with many dominant shrub species responding by crown sprouting following the fire. Seeds of many chaparral plant species also require heat, ash, and/or charate (product of burned vegetation) to germinate.

Chaparral Recovery after Fire

Most studies concerning vegetation cover changes over time in chaparral following a fire did not continue for more than four years (e.g. Christensen & Muller 1975, Keeley & Keeley 1981, Guo 2001, Guo 2003, Safford & Harrison 2004). However, patterns of regeneration (e.g. biomass, vegetative cover, species diversity) are fairly consistent among the literature reviewed. For example, total vegetative cover is generally high in the first two years following a fire; reported values are from 11 to 85 percent (Guo 2001, Grace & Keeley 2006, Keeley & Keeley 1981, Horton & Kraebel 1955, Robichaud *et al* 2000). Total vegetative cover fluctuates (increases and decreases) during the second and eighth years following a fire. Reported values are from 48 to 79 percent (Keeley & Keeley 1981, Horton & Kraebel 1955, Hanes 1971); this fluctuation depends on location and weather patterns, and is primarily the result of changes in cover by annual species. Only two of the studies referenced in this Report looked at vegetation more than four years following a fire. Hanes (1971) reported total vegetative cover of 97 percent in chaparral nine to twenty-one years post-fire, 107 percent after 22 to 40 years, and 126 percent after 40 years (total vegetative cover, in some calculation methods, can exceed 100 percent as leaves and branches intersect and overlap, allowing for multiple species to be noted at individual measurement points along a survey transect). Horton & Kraebel (1955) reported total vegetation cover ranges of 18 to 65 percent (absolute cover, not including overlapping vegetation) between six and twenty years post-fire and that total vegetative cover in most chaparral types decreased after 10 to 17 years post-fire.

Literature also reveals similar results for changes in species composition, species diversity and species richness, responsible for increasing cover during the first eight years follow a fire. Species richness is greatest in the second year, with the presence of annuals and forbs being the biggest contributors; species richness then declines through the fourth year, as perennial species begin to dominate the cover (Guo 2001; Grace & Keeley 2006). The increasing vegetation cover over time following a fire, resulting in high biomass production (Grace & Keeley 2006), is comprised of differing life forms during the each of the first five years. During the first to third growing seasons following a fire, the chaparral community is typically comprised of resprouting woody vegetation and post-fire adapted annual and forb species. During the second to fourth year, seedlings of fire adapted perennials are prevalent amongst the annual forbs and grasses. Studies have shown that the vegetative cover during this time can increase from approximately 65 percent total cover (overlapping vegetation) in the first/second year, to almost 150 percent cover (overlapping vegetation) in the fifth year (Grace & Keeley 2006).

Based on the literatures reviewed, the rate of recovery is somewhat consistent and predictable but varies depending on the location of the plant community (e.g. coastal versus inland, San Bernardino and Los Angeles Counties versus Ventura County). The rate of recovery for chaparral communities is greatest immediately following a fire through three to six years post-fire (Hanes 1971, Keeley & Keeley 1981, Guo 2001). Recovery then slows down through the eighth year (Hanes 1971). By the fifth year following a fire, chaparral resprouts and seedlings dominate the vegetative cover (Hanes 1971), and stands of chaparral are expected to recover to 50 percent of the pre-burn biomass by the eighth year (Wright & Bailey 1982). Between 18 and 23 years following a fire, chaparral continues to grow but begins to level off by the time it is 20 to 25 years old. At approximately 37 years old, many chaparral plants (e.g. chamise) stop growing and senescence begins. The chaparral community then declines until the next fire.

The effects of slope angle, aspect, elevation, and distance from coast on the rate of recovery of chaparral and coastal sage scrub communities have also been repeatedly studied. Aspect, or the direction the slope is facing, was found to have the greatest influence on rate of recovery (Hanes 1971, Guo, 2001). For example, the rate of succession was found to be slowest on south-facing slopes below 3,000 feet elevation; the fastest rate of succession was found to be on north-facing slopes above 3,000 feet elevation (Hanes 1971). Additionally, the north-facing slopes tended to have fewer, if any, coastal sage scrub species present in the chaparral communities, compared to south-facing chaparral communities. In these north-facing areas, the dominant resprouting shrubs and seedlings were primarily responsible for the rapidly closing cover.

Three studies reported estimates of chaparral community recovery time following a fire. Safford & Harrison (2004) estimated that woody cover and richness of chaparral within their study area would take approximately four to five years to recover; this estimation was an extrapolation from their collected field data. Horton & Kraebel (1955) reported chaparral reaching peak total cover values between nine to fourteen years following a fire. Hanes (1971) suggests that chaparral does not reach pre-fire physiognomy until 10-20 years following a fire. The study by Safford & Harrison (2004) was carried out in Northern California, where precipitation is greater; therefore this short time frame for recovery is probably less directly applicable to the SSFL study area than the studies by Hanes (1971) and Horton and Kraebel (1955), which were carried out in the San Gabriel and San Bernardino Mountains.

Factors Affecting Regeneration after Fire

To gain a more in-depth understanding of the dynamics of fire-dependent chaparral and scrub communities, and factors that may influence their regeneration following a fire, we conducted an extensive literature review of studies related to post-fire recovery in chaparral. This review also included those studies that focused on changes in vegetation cover over time following fire.

Many studies have evaluated biotic and abiotic factors that may influence the regeneration and recovery of chaparral communities following a fire. Plant community composition and rates of recovery can be affected by a multitude of factors, including the following: slope, aspect, elevation, latitude, soil type, soil moisture, soil nutrients, ambient climate (precipitation, fog, etc.), litter (organic material), soil microbial activity, light availability, competition between plants, allelopathy (chemical inhibition between plant species), time since last fire, species composition prior to fire, seed banks, reproduction strategy of dominants, herbivory, and fire intensity (soil heating, hydrophobicity, etc.). Some of these factors are discussed in general terms below.

Elevation

Studies assessing the effects of elevation on chaparral growth and composition included chaparral communities ranging in elevation from 900 to 6,500 feet. Two studies that looked at elevation effects on vegetative cover in chaparral determined that higher elevation chaparral communities typically had greater vegetative cover than chaparral at lower elevations and these communities could be expected to recover more slowly than chaparral at higher elevations (Hanes 1971, Keeley & Keeley 1981). Guo (2003) also found that biomass production was higher in early years following a fire at higher elevations than at lower elevations. Each of these studies incorporated very broad elevation ranges (i.e., at least several thousand feet of elevation difference); however, elevation is less likely to affect growth and composition within the much more restricted elevation range found within the SSFL study area.

Aspect

The literature indicates that aspect is an important factor shaping recovery trajectories and rates of growth in post-fire chaparral, and notable differences in species richness, total cover, biomass, and species composition in chaparral in north-facing versus south-facing slopes have been documented. (Hanes 1971, Keeley & Keeley 1981). North-facing slope receive less sunlight, and are thus generally cooler and have greater moisture than south-facing slopes. Guo (2003) determined that early post-fire total vegetative cover and biomass production in chaparral was higher on north-facing slopes. Species composition is also different on north-facing and south-facing slopes. South-facing slopes are often comprised of more drought-tolerant species than north-facing slopes, where larger-leaved species that prefer more moist soil and are more adapted to lower light conditions are more prevalent. Introduced annual species are typically less abundant on north-facing slopes than south-facing slopes (Keeley 1991 and 1992, Meentemeyer 2001).

Slope (Incline)

Hanes (1971) found that slope, aspect, and elevation all affect species composition in chaparral, thus influencing succession. Of these three variables, slope (or incline) was found to be the least important (Hanes 1971).

Soil Type

Soil type influences vegetative cover and species diversity in chaparral; this is most likely a result of availability of soil nutrients, soil moisture retention, and soil depth (e.g. Christensen 1973, Meentemeyer *et al.* 2001, Safford and Harrison 2004). Some species have narrower requirements for growth than others. For example, a study that examined the growth and distribution of bigberry Manzanita (*Arctostaphylos glauca*) and chamise noted that chamise cover was highest on rocky soils and more evenly distributed throughout the study site, where bigberry Manzanita cover was highest on rocky soils where there were narrow temperature and soil moisture fluctuations (Meentemeyer *et al.* 2001). Additionally, the number of herbaceous perennials decreases on sandy soils, but increases with rock cover (Keeley *et al.* 2005). Soil type is thus a complex variable affecting post-fire recovery of chaparral vegetation.

Soil Moisture Retention

Soils have different water holding capacities, which are primarily determined by texture (i.e., percent silt, sand, and clay). Soil moisture also differs between slope aspects due to differing amounts of solar radiation and rates of plant evapotranspiration. Soil moisture and water holding capacity can affect rates of vegetation regeneration, with higher soil moisture generally facilitating faster plant growth and thus faster vegetation recovery.

Soil Nutrients

Soil nutrients related to growth in chaparral plant communities, particularly following fires has been studied by Christensen (1973) and DeBano (1989). In general, unburned chaparral communities are typically low in nitrogen and phosphorous. Plants continually use available nitrogen as they grow. When the vegetation burns, the nitrogen contained in the plant biomass is released into the soil and becomes readily available in the ash as ammonium and nitrate through the first year following the fire (DeBano 1989). In the first spring after a burn, high levels of available nitrogen result in rapid resprouting of perennials, germination, and growth of many species, including mostly annuals. Subsequent to this time, nitrogen returns to pre-fire levels (DeBano 1989).

Available Moisture/Precipitation

California chaparral communities receive on average approximately 26-36 inches of precipitation per year, primarily during October through April (DeBano 1989). Growth patterns of native plants in California parallel precipitation patterns, predominantly germinating and growing during the winter and spring months. The amount of moisture available (e.g., rainfall, fog) is an important factor in determining what species germinate and how much they grow and reproduce during each growing season (Keeley and Keeley 1981). Seasonal precipitation has been found to be an important variable in vegetation cover and biomass in chaparral recovery after fire with increase cover by annual plants (Keeley & Keeley 1981, Grace & Keeley 2006).

Time Since Last Fire/Fire Frequency

The normal burn frequency for chaparral communities is once every 30 to 40 years (Keeley *et al.* 2001). Since 1927, 23 large fires (300 acres or more) have overlapped with the footprint of the 2005 Topanga Fire discussed below (Cal. Dept. of Forestry and Fire Protection 2005). In the project vicinity, fire perimeter data maps indicate that approximately 20 fires have occurred over the last 58 years, with some burns overlapping at differing intervals (California Dept. of Forestry/FRAP 2007). In general, the majority of the SSFL has burned every 21 to 25 years. Several smaller portions of the project site, mostly along the southeast, northeast and western boundaries, have burned at more frequent intervals throughout the last few decades.

Fire frequency (i.e., how often a patch of vegetation can be expected to burn over some defined period of time) affects plant communities by altering vegetative cover, density and species diversity, particularly during the first few years following a fire when there is a shift from a woody perennial dominated community to an herbaceous dominated community (Hanes 1971, Keeley 2000). Frequent fires maintain shrub dominance in chaparral communities; however, if fires occur too frequently, plant community type conversion can occur due to depletion of the seed bank and plant stress (Riaño *et al.* 2002). For example, Franklin *et al.* (2004) found that in chaparral habitats that burned more frequently, the cover of obligate seeder species, such as hoary-leaved ceanothus *Ceanothus crassifolius*) increased and the resprouter species, such as mountain mahogany (*Cercocarpus betuloides*) decreased in mature stands (greater than 30 years old).

Since the amount of growth during the active years following a fire can depend on the amount of available moisture, the relationship between precipitation and accumulated fuels (dead plant material) has also been reviewed. Keeley (2001) suggests that precipitation, by affecting primary productivity, also affects the rate of fuel productivity (accumulation of dead plant materials that act as fire fuels). This effect of precipitation on fire regime is supported by Krausmann's (1981) findings that there is a positive correlation between precipitation and fire occurrence within the chaparral type north of the San Diego County border.

Litter (Organic Matter)

As plant species in the chaparral community mature, organic matter or litter accumulates below and around the plants. Litter is comprised of decomposing dead leaves, bark and stems. In mature chaparral, litter can accumulate to over four inches in depth.

Litter affects plant establishment in chaparral communities by both promoting and inhibiting germination, depending on conditions and plant species. Plant establishment in mature chaparral has been found to be significantly positively correlated with depth and biomass of the litter layer (Keeley 1992). Litter can inhibit germination of some species that are UV dependent, while organic matter on the soil surface can increase moisture retention, reducing soil heating temperatures and making conditions more favorable for other species.

In other situations, the accumulation of post-burn litter from some plant species can be hydrophobic (Hubbert *et al.* 2006). Water repellency or hydrophobicity can result from accumulation of litter containing chemicals that repel water (Hubbert *et al.* 2006). The presence of litter appears to have complex effects on post-fire recovery of chaparral, because it can both facilitate and inhibit growth of resident plants. Litter most likely promotes the later stages of chaparral succession because species adapted to growth in mature chaparral communities are less inhibited by a litter layer.

When covering bare soils, mature (unburned) litter provides significant erosion control benefits, particularly on sloped surfaces where it can protect exposed soils from direct raindrop impacts and runoff flow shear stresses.

Soil Food Web

Microbial activity in soils, including bacteria, fungi, and invertebrates is highly complex. These organisms define the soil food web, whereby nutrients are recycled and made available to higher plants. DeBano (1989) looked at the presence of microbial activity in burned and unburned sites. He reported an increase in microbial activity as nutrients became more available in the soil. It is unclear how microbial activity and interactions in the soil food web influence rates of post-fire recovery of chaparral.

Light and Solar Radiation

Light availability and solar radiation influence germination, growth, and patterns of species composition and dominance in chaparral. Light is an important germination cue for many plant species, in particular many coastal sage scrub species that occur in chaparral (Meentemeyer *et al.* 2001). For example, Keeley (1987) found that California buckwheat (*Eriogonum fasciculatum*), Yerba Santa (*Eriodictyon crassifolium*), and black sage (*Salvia mellifera*), which are common in chaparral communities following fire, germinated readily in the absence of fire. These species were all found to exhibit germination inhibition in the absence of light. This is most likely responsible for a portion of the seed of these species staying in the seed bank (in the soil) until fire or other disturbance clear the mature vegetation canopy allowing more light to reach the soil.

For most species, the light-stimulated germination increases the chance of seedling establishment in open sites created by fire and other types of disturbance.

Solar radiation relates to the amount of time an area is exposed to sunlight each day and may be an important factor in species that require heat treatment for seed germination. Christensen *et al.* (1975) suggested that species such as California deerweed (*Lotus scoparius*) and California morning glory (*Calystegia macrostegia*), which show increased germination rates with heat treatment, may benefit from soil heating by fire and increased soil temperatures during summer months.

Solar radiation differences between slope aspects were found to be the greatest influence on species abundance in chaparral communities by Meentemeyer *et al.* (2001). Keeley (1991, 1992) suggests that invasive annual species often require more light, and therefore may not be as abundant on north-facing slopes as south-facing slopes (see section above on Aspect). Solar radiation is responsible for differences in vegetation development on slopes with different aspects; however, the critical factor for differences in vegetation recovery is slope aspect.

Competition between Plants

Following a fire, competition between plants for light, nutrients, and moisture can shape species diversity and cover. For example, abundant annual plant cover after a fire may inhibit shrub seedling recruitment and growth (Keeley *et al.* 2005), thereby resulting in slower recovery. In burned chaparral communities where surviving resprouting perennials are present, competition may not be as an important factor in the regeneration of dominants. As chaparral communities mature, woody perennial species replace and outcompete annual species, thus resulting in decreased cover of annuals as the community develops over time (Horton *et al.* 1955, Christensen and Muller 1975, Keeley and Keeley 1981). Although competition is an important factor during the early post-fire years of recovery, it becomes less important as the community matures and perennial plant cover increases.

Allelopathy

In a phenomenon known as allelopathy, certain plant species produce chemicals that inhibit the germination of other species. This process is common among many California chaparral and scrub species. In particular, chamise and bigberry manzanita both produce allelopathic chemicals that are washed from their leaves and deposited on the soil surface (Christensen and Muller 1975). These chemicals were found to inhibit germination of some annual species including the introduced species prickly lettuce (*Lactuca serriola*) and tocalote (*Centaurea melitensis*), and a native species, the common cryptanth (*Cryptantha intermedia*) (Christensen and Muller 1975). These chemicals were not found to affect seed germination of other native species including the California deerweed and the California morning glory.

Allelopathy by introduced annual species may also be responsible for influencing the regeneration of perennial cover. For example, black mustard (*Brassica nigra*) has been reported to inhibit the development of native species such as black sage, laurel sumac, and California buckwheat (Horton and Kraebel 1955).

Allelopathy is likely one factor responsible for the absence of some annual species in mature chaparral communities. Since fires typically consume the litter layer containing these allelopathic chemicals, annual species can become established during the early years following a fire until the leaf litter containing these chemicals redevelops.

Allelopathy is one important factor in shaping mature chaparral; however, literature has not reported allelopathy to be critical in the recovery of chaparral, but rather, a characteristic in reducing competition among perennial and annual species.

Reproductive Mode of Dominants and Species Composition Prior to Fire

The effects of fire on species diversity during recovery in chaparral communities depend largely on what species were present in the plant community prior to the fire. For example, if an area was dominated by woody resprouting species before the fire, the majority of those woody plants are expected to survive and resprout, resulting in similar species composition and abundance after the fire. However, if an area that burns is dominated by plant species that do not resprout, but rely on reseeding for regeneration, the distribution of woody species is expected to be somewhat different in the early years following a fire. Recently burned areas may exhibit differences in species diversity than that of pre-fire conditions; however, species diversity is expected to return to that of pre-fire conditions at maturity (Keeley *et al.* 1992).

The reproductive modes of dominants and species composition prior to the fire are important factors that affect the rate of recovery of chaparral vegetation. Resprouting plants may grow back more quickly than reseeded plants and are less like to compete with introduced and annual plants.

Herbivory

Herbivory (animal browsing) plays a role in plant species establishment in newly burned and in established unburned chaparral communities. After fires resulting in high mortality of wildlife, newly germinating plants often thrive during the first years, until the herbivores re-inhabit the area (Christensen & Muller 1975). Animal browsing can play a major role in limiting herbaceous species establishment under mature chaparral (Christensen & Muller 1975). Similar to allelopathy, herbivory affects seedling survival and establishment during early post-fire years and also in mature chaparral. However, it is not considered an important factor when estimating the rate of recovery of chaparral vegetation.

Fire Intensity/Severity

The rate of regeneration of vegetation following a fire may be dependent on fire severity, the amount of vegetation burned in the overstory (the uppermost layer of vegetation that forms a plant community) and understory (the vegetation that occurs below the overstory), heating of the soil, proportion of area burned, and fire interval length, etc. (DeBano *et al.* 1998). DeBano *et al.*(1998) classified fire severity into categories according to the following table below.

Table A: Visual factors used to evaluate fire intensity (excerpted from DeBano *et al.* 1998)

Severity	Litter Present Following Fire	Ash Present Following Fire	Percent canopy biomass consumed	Diameter (inches) charred plant stems remaining
Low	Yes (10-15% of pre-fire litter lost)	Gray ash	40	<0.2 (most with leaves)
Moderate	No	None	40-80	0.2-0.5
Severe	No	White ash	90	0.5+

Low Severity (soil temperature estimated at 225 degrees Celsius at the soil surface and 125 degrees Celsius at 2.5 cm depth) – charred leaf litter, grayish ash most like present immediately following the fire, but soon became inconspicuous (DeBano *et al.* 1998).

Moderate Severity (maximum soil temperature at mineral surface at almost 430 degrees Celsius, and 200 degrees Celsius at 2.5 cm depth) – bare soil present as leaf litter and fine woody material was consumed by fire. Ash is inconspicuous immediately after the fire. Between 40 and 80 percent of the plant canopy is consumed by the fire; remaining charred twigs would be greater than 0.6 to 1.3 cm in diameter (DeBano *et al.* 1998).

High Severity (surface soil temperatures just over 700 degrees Celsius and nearly 250 degrees Celsius at 2.5 cm deep) – Fluffy white ash layer present following the fire as a result of the main stems of trees and shrubs that burned (DeBano *et al.* 1998).

Fire severity can affect the rate of recovery in extreme cases where fire severity is so high that the excess heat kills seed in the soil and underground roots and crowns of perennial chaparral species. Detailed fire severity data for the 2005 Topanga fire was not available and a large percent of the shrub species observed on the burned areas are resprouting. Therefore, fire severity is not considered an important factor in determining rate of recovery for this project.

Soil Heating and Charate

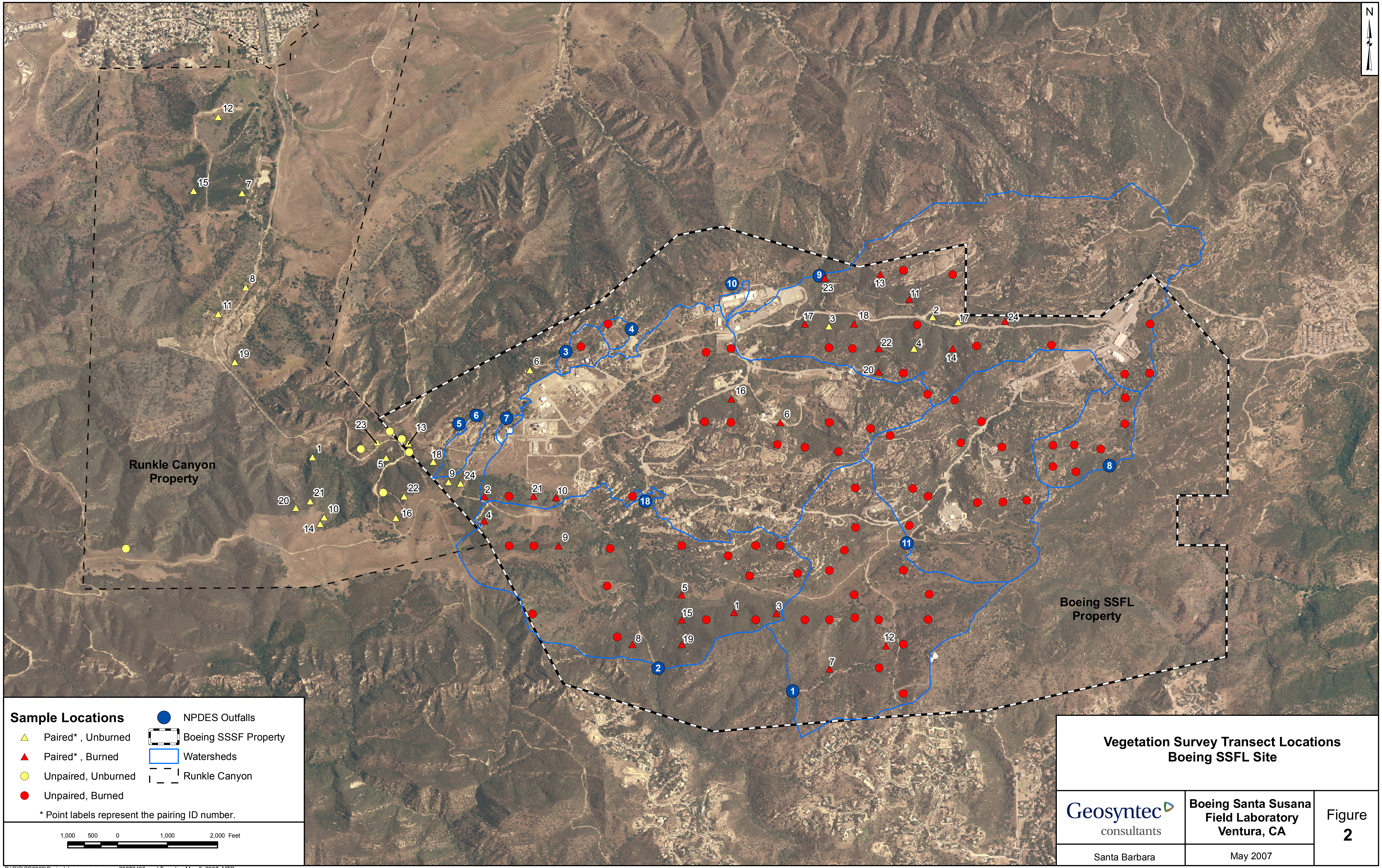
Soil heating is based on the amount of heat reflected into the soil during a fire and is a result of combustion rate, amount of aboveground biomass, and litter consumed (DeBano 1989). Soil heating has the greatest affect on components associated with organic matter in the upper soil layer, including soil structure, cation exchange capacity, and available nutrients (DeBano 1989).

Some plant species are adapted to fire such that they require soil heating and/or the presence of charate (product of burned vegetation). For some plants, soil heating and charate treatment is not necessary but may increase germination (Keeley 1987). Examples of charate-stimulated species include Eastwood Manzanita (*Arctostaphylos glandulosa*), bristly matilija poppy (*Romneya trichocalyx*), ashy silk tassel (*Garrya flavescens*), Virgin's bower (*Clematis lasiantha*), skunkbrush (*Rhus trilobata*), Yerba Santa and chamise. Examples of heat-stimulated species include *Ceanothus spp*., sugarbush (*Rhus ovata*), chamise, chaparral bush mallow (*Malacothamnus fasciculatus*), and white sage (*Salvia apiana*). Soil heating and charate treatment of seed for germination are factors that explain the regeneration mode of fire-adapted species in chaparral and are not specifically linked to rates of recovery of chaparral vegetation.

Study Site Description

The study site is located on undeveloped areas within the SSFL (approximately 2,850 acres; Figure 2). The study site is located within Ventura County.

Offsite unburned reference (or "control") areas were also selected within Runkle Canyon located immediately adjacent to and west of the northern half of the SSFL site (Figure 2). When developing the Phase 2 work plan (WBS 2007), and after observing that the majority of the project site had burned, we determined that additional representative unburned chaparral sampling areas were necessary to meet the criteria of the study design. The small amount of chaparral on the project site that did not burn (less than 15 acres) was almost entirely located on north-facing slopes in the same area on the site, and therefore did not adequately represent the range of characteristics of the entire project site. Potential unburned sampling locations near the SSFL were very limited due to the great extent of the 2005 fire in the project vicinity. Therefore, unburned areas were identified immediately adjacent to the project site with chaparral and scrub vegetation types. Due to the proximity and comparable vegetation habitats, these offsite areas were expected to exhibit similar geographic and environmental conditions as the project site. Unfortunately, the majority of the sedimentary rock lands formation both within and adjacent to the project site were either burned in the 2005 fire or located within developed areas. Permission to access adjacent properties was also a deciding factor for choosing the Runkle Canyon control study area.



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The study site lies in the Santa Susana Hills/Simi Hills that run in an east-west direction, and is characterized by steep slopes, the majority of which face and drain to the north and south. Slope steepness is variable throughout the site, with the majority of the project site comprised of steep slopes. More gentle slopes are located within the canyon bottoms, the largest of which is located in an east-west direction within the northern half on the SSFL. Since chaparral and scrub vegetation types spatially dominate the project site, and especially steeper slopes within the project site, sampling was conducted in these vegetation types to provide cover estimates that represent the majority of the area and that most clearly address the major study goals.

Soils on the study site consist of several types of loam and sedimentary rock lands. Sampling locations were mostly on sedimentary rock lands and Gaviota rocky sandy loam with a few transects in other loamy soil types, including Saugus sandy loam, Calleguas-Arnold complex and Zamora loam (USSCS 1970). Sedimentary rock lands is the dominate soil type on the SSFL site, occupying the interior of the site, the northwestern corner, and outcroppings elsewhere. Sedimentary rock lands are virtually absent from the offsite control area within Runkle Canyon, which is characterized by mostly loam soils.

Two vegetation datasets were used for mapping vegetation classes for this field survey effort – a United States Forest Service (USFS) Geographical Information System (GIS) shapefile dataset that is based on remote sensing analysis and was used to map offsite vegetation classes, and a MWH Americas, Inc. GIS shapefile dataset that is based on site-specific surveys and was used to map onsite vegetation classes. All subcategories for chaparral and scrub identified on the USFS and MWH Americas, Inc. maps were are described as Chaparral/Scrub since chaparral and coastal sage scrub communities that burned are mostly indistinguishable at this stage of post-fire recovery. Chaparral/Scrub is the predominant general plant community, occurring in differing densities and species composition throughout the project site depending on soil type, aspect and age of disturbance, etc. USFS maps identified four chaparral types within the project site including Chamise, Foothill Mixed Chaparral, Northern Mixed Chaparral and Sumac Shrub. The MWH Americas, Inc. vegetation mapping (2005) identified five chaparral and coastal sage scrub types including Venturan Coastal Sage Scrub, Venturan Coastal Sage Scrub/Chaparral, *Baccharis* Scrub, Chaparral, and Chaparral/Coast Live Oak Woodland. These habitat types appear to be as described by Holland (1986) or of some combination thereof. A detailed description of chaparral/scrub and other plant communities observed on the project site are described in the Phase I Reconnaissance Report (WBS February 2007).

Northern Mixed Chaparral is shown on vegetation maps to occur mostly on northerly facing slopes and is characterized by numerous sclerophyllous-leaved shrub species with no or sparsely vegetated grasses and herbs. This classification most closely represents the stands of unburned chaparral remaining on the north facing slopes of the project site. These areas are dominated by mountain mahogany, holly-leaved cherry (*Prunus ilicifolia*), and toyon (*Heteromeles arbutifolia*). Chamise communities are stands of chaparral vegetation dominated by chamise; one unburned chamise stand was present at the far northwest corner of the project site. Foothill Mixed Chaparral is dominated by a somewhat even mix of various chaparral species, and an occasional coastal sage scrub type species. Sumac communities are areas dominated by laurel sumac; it is difficult to determine location of this habitat type since laurel sumac appears to be present in more than one plant community on the project site. Resprouting laurel sumac and chamise are present in most of the burned areas observed on the project site, but appear to be more abundant in areas described as chaparral on the MWH Americas, Inc. and USFS maps.

Many burned areas observed that had been classified as chaparral on the MWH Americas, Inc. and USFS maps were dominated by those chaparral species that are known to readily resprout after fires including laurel sumac, chamise, scrub oak, and toyon (Keeley *et al.* 2006). Species that are known to regenerate predominantly by seed following fires were also present, including hoary-leaved Ceanothus. It is possible that these species may have been dominant or co-dominant in the community prior to the fire, but are present only as seedlings now and thus are not highly visible from more than a few feet away.

Venturan coastal sage scrub is comprised of low, soft-wood shrubs, growing to approximately two to six feet in height. Dominant species often include California sagebrush, California buckwheat species, sage species (*Salvia* spp.), lemonade berry (*Rhus integrifolia*), and Our Lord's candle (*Yucca whipplei*). This habitat is also adapted to fire, with many scrub species commonly resprouting from their crown or recruiting from seed following a fire.

Lastly, much of the project site is situated on areas of sandstone rock outcroppings due to historical geologic uplifting. Although present, chaparral and other vegetation are sparse in areas of dense and large outcroppings.

Methods

This vegetation study has two principal goals: 1) to determine whether burned chaparral and coastal sage scrub habitats within the project site differ significantly from unburned reference areas (onsite and offsite) in terms of perennial plant cover and litter cover (i.e., two cover types believed to be a reliable vegetation-based metric for natural watershed erosion control); and 2) to quantify measurable recovery parameters in burned areas throughout the project site for the purpose of assessing the vegetation recovery thus far. This quantification of recovery parameters in burned areas, approximately 1.5 years after the fire, is essential for comparison with reference unburned areas and can provide useful baseline data for the same areas in later years as recovery progresses.

Point-intercept transect data were collected to determine vegetative and litter cover. Since vegetation regeneration was anticipated to vary with environmental factors (such as slope, aspect and elevation), diverse and representative scrub and chaparral transect locations were selected.

To statistically compare burned and unburned areas, GIS tools were used to pair burned and unburned transect locations to control locations for environmental factors (including slope, aspect, elevation, and basic soil type). Twenty-four pairings were made with all of the factors. Many additional (unpaired) transects were conducted throughout the project site to improve estimates of recovery parameters and to be able to assess values within different watersheds. Unburned areas were sampled less intensively (N=30) than burned areas (N=97) because cover was less variable in unburned areas. Also, a majority of unburned areas were located offsite where fewer areas were available to sample.

The methods for quantifying cover throughout burned areas will be discussed first. Our discussion of the statistical methods for comparing paired burned and unburned transects will follow since the statistical tests on burned and unburned paired transects uses a subset of the transect data collected throughout the burned project site.

Study Design

Using GIS tools, transect locations were randomly selected within the burned project site. Quantifying perennial cover and litter cover required extensive random vegetation sampling since perennial plant cover and litter cover was expected to vary greatly across the site. By randomly positioning sampling locations in scrub and chaparral habitats, a diverse, representative, and unbiased sample of these vegetation types was obtained. To achieve random sampling, a GIS map of the project area was created with an overlaid 150mX150m grid of possible sampling points. A subset of these possible sampling points was selected using a randomized procedure in GIS software. Criteria for rejection of potential transects were developed in order to focus sampling on the areas of interest and to increase sampling efficiency. Randomly selected intersection points were rejected if the following conditions existed:

1) the point fell in an area not previously mapped as a chaparral or scrub vegetation type;
2) the point fell on a rock outcrop (visibly apparent from the aerial photograph and/or as verified in the field); and
3) the point was inaccessible or could not be accessed safely due to barriers (e.g. cliffs, dense poison oak).

A total of 120 potential transect locations were randomly selected before field sampling. These points were converted into a GIS shapefile layer, mapped on an aerial photograph base, and their coordinates were uploaded into handheld Global Positioning System (GPS) units for location in the field. We anticipated sampling approximately 100 transects throughout the project site. Twenty additional locations were identified in the event that some locations would be rejected when field sampling was conducted. A total of 97 transects throughout the burned areas onsite were actually sampled due to accessibility limitations. Transects were 100 feet long and oriented uphill (see section on Field Methods).

There are two major advantages to random sampling. First, random sampling across chaparral and scrub vegetation in the project area is expected to result in a diverse and representative sample of these vegetation types across the project site. Second, a property of random sampling is that the number of points that fall into each distinct environment type (e.g., north facing versus south facing slopes) is roughly proportional to the area covered by these environment types in the project area, so that, in effect, it results in an area-weighted data collection.

Comparing Burned and Unburned Sites: Paired Sampling

In an ideal test for the effects of burning, transects on burned and unburned areas would be spatially independent. Specifically, instead of all sampling locations being grouped within one large burned area and one large unburned area, burned and unburned areas would be spatially interspersed across the same site (e.g., distributed like a checkerboard) to avoid extrapolation problems associated with "pseudoreplication" in statistical design (Hurlbert 1984). This would prevent the possibility that burned and unburned 'treatment' effects could be confounded with site effects or basic underlying differences between the two sites. Most of the project area within the SSFL and the surrounding offsite undeveloped areas burned during the Topanga Fire, so spatial interspersion of burned and unburned areas was not feasible. Thus, all burned transects were grouped together within the single burned area, and comparable unburned sites were selected for comparison.

Access for sampling was granted on a large adjacent unburned property just outside the western boundary of the project site (Figure 2). This area is characterized by similar topography and vegetation to the SSFL, although it does not contain soils mapped as sedimentary rock lands (USSCS 1970), a dominant soil type on the project site.

To control the potential for problems relating to lack of spatial interspersion discussed above, paired sampling was used to compare burned and unburned locations, controlling for environmental factors and enhancing the ability to detect and interpret differences between burned and unburned sites. Burned and unburned sampling locations were paired using GIS tools to control for environmental factors, including slope, aspect, elevation, and generalized soil types, since these factors have been found to influence distributions of plant communities as well as post-fire regeneration of chaparral (Hanes 1971, Guo 2001, Grace & Keeley 2006). This task required GIS intersections of soil type (USSCS 1970), elevation, slope, and aspect layers. Each layer was classified into categories and then layers were intersected into one combined layer with many classes, or “environmental types” based on these variables, with a total of 48 possible environmental type classes. By controlling for environmental variation within sampling locations, pairing transects by abiotic environmental type improves statistical power to detect the effects of burning and reduces the potential for spurious correlations while retaining a simple statistical model (see Statistical Analysis, below).

To select transect locations for comparing burned and unburned areas, a subset of the 97 transect locations within the burned project were used, and paired with environmentally matching unburned sampling locations. The unburned transect locations were chosen in environmental type combinations that were well represented in burned areas onsite and also available in the unburned areas offsite. The subset of transects within burned areas to be paired with unburned transects was randomly selected. Soils were classified into generalized categories of sedimentary rock lands and loams (predominantly Gaviota rocky sandy loam and Saugus sandy loam) based on Soil Conservation Service soil survey data for Ventura County (USSCS 1970). Since sedimentary rock land soils were not available in the offsite unburned areas, the transect pairings were constrained to loams with only one exception, where a small area of unburned sedimentary rock lands could be sampled onsite. Aspect was classified into four classes (North, South, East, and West), slope was classified as shallow, moderate and steep (corresponding to 0-10, 10-30, and >30 percent slope, respectively), and elevation was broken into two categories of low and high (below and above 1720 feet elevation). The environmental conditions for each of the final transect pairings are presented below (Table B).

Table B: Actual burned/unburned transect pairings and environmental type combinations

Transect Pair	Environmental “Type” ID	Aspect	Slope	Elevation	Soil type
1	3	North	steep	Low	Loam
2	5	North	moderate	High	Loam
3	5	North	moderate	High	Loam
4	6	North	steep	High	Loam
5	42	West	steep	High	Loam
6	12	North	steep	High	Sedimentary Rock Land
7	14	East	moderate	Low	Loam
8	15	East	steep	Low	Loam
9	17	East	moderate	High	Loam
10	18	East	steep	High	Loam

11	26	South	moderate	Low	Loam
12	27	South	steep	Low	Loam
13	29	South	moderate	High	Loam
14	18	East	steep	High	Loam
15	39	West	steep	Low	Loam
16	41	West	moderate	High	Loam
17	42	West	steep	High	Loam
18	6	North	steep	High	Loam
19	39	West	steep	Low	Loam
20	6	North	steep	High	Loam
21	6	North	steep	High	Loam
22	41	West	moderate	High	Loam
23	27	South	steep	Low	Loam
24	17	East	moderate	High	Loam

Field Surveys

Field Sampling Techniques

Timing

Vegetation sampling was conducted between March 26 and April 12, 2007. Optimum data collection is when vegetation peaks in biomass and when most plants are flowering, allowing optimum identification of plants to the species level. This sampling period was chosen partially to meet reporting deadlines. Due to the early timing of these surveys, many of the plant species, particularly annuals, were not at maximum biomass for the season, which may reduce cover estimates. Some of the annual forbs and grasses (herbaceous species) were unidentifiable due to lack of flowers or fruits. This early timing may affect estimates of cover, particularly annual cover (and total vegetation cover), under-representing peak vegetative cover for the second spring following the fire. Much additional growth of annual species, and some additional growth of perennial species is expected to occur before late spring of this growing season. This bias in results is most relevant when comparing values from this year to successive years or to values reported in the literature for the second year following a fire. However this timing issue is not expected to impact any of the key findings of this study (e.g., estimated time to recovery), particularly since perennial cover percentages, a primary metric used in this study to assess recovery, were unaffected by it.

Field Crews

Two field crews consisting of two field staff each performed vegetation sampling. Each crew included one WBS botanist/plant ecologist and one Geosyntec staff member to assist in data collection and documentation. Crew members included Jeannette Halderman (WBS Botanist/Plant Ecologist), Jennifer Burt (WBS Botanist/Plant Ecologist), Ryan Smith (Geosyntec Geologist), Elyse Warnecke (Geosyntec Geologist), and Geoff Frieman (Geosyntec Geologist). Each crew had one camera for photographing transects.

Vegetation and Litter Cover

Vegetative and litter cover was determined using the point-intercept method. This method entails recording the species present at points at each one foot interval (100 points) along each transect to determine cover by each species in the field. Using this method, the total number of points on which a specific species is vertically intersected divided by the number of points in a transect (100) provides an estimate of absolute cover. This method enables evaluation of vegetative cover and litter cover independently from overlapping species cover while also collecting useful information for evaluation of other parameters such as species composition, cover by woody species versus herbaceous species, cover by mulch, bare ground, diversity, etc. Absolute cover for various parameters (e.g., perennial vegetation cover) was calculated such that cover values for each of these parameters was not affected by species overlap or presence of other cover types.

The transect location for each sampling area was located using the uploaded latitude and longitude coordinates and a GPS hand-held unit. Each transect was oriented running upslope from the starting point (to reduce sampling bias and for purposes of measuring percent slope) by laying out a 100 foot tape as close to the ground as possible. If the predetermined transect location was not accessible or did not meet the pre-determined characteristics (e.g., crossed a road, located on unvegetated rock outcrop, inaccessible), but could be moved to a location immediately adjacent, the transect was re-located in the field. The revised GPS coordinates were recorded if the transect location was adjusted. The adjusted transect was moved to the closest location that met the characteristics of the chosen transect and was a minimum of 500 feet from another transect sampled.

To collect point-intercept data, a ¼” X 4’ fiberglass pin-stake was lined up with one side of the tape at a 90 degree angle at each foot along the tape. All plant species and abiotic elements (bare ground, rock, litter, mulch) touching the edge of the pin-stake nearest the tape (above and along the entire length of the pin-stake) was recorded. An example of the data forms used is included in Appendix A.

Specifics on data collection included:

1) Presence of litter was recorded when found at a sample point. Litter is defined as fallen dead and/or decaying plant biomass on the soil surface. For purposes of this study, litter was recorded even when found underneath standing vegetation, and was only recorded if it was part of a litter layer, as opposed to a single dead leaf or blade of grass surrounded by bare mineral soil. Cover of the soil surface by litter was assessed at each point on the transect. If soil was essentially completely covered by litter (or if visually projecting downward through dead annual thatch the soil was completely covered), “litter” was recorded. If some litter was present but bare soil was still showing, “sparse litter” was recorded. If most of the bare soil showed around the point, bare ground was recorded.
2) Wood fiber mulch was recorded when present at a sample point. Mulch was recorded if it was located on bare ground or litter, but not if found on top of rock. Mulch was applied hydraulically after the fire for erosion control.
3) Dead standing vegetative material was documented and noted as standing dead (last years’ vegetation), by species when identifiable. If dead branches were detached from the plant base they were recorded as litter.
4) The presence of rock was recorded when it was larger than one inch in diameter. “Rock small” was recorded for rocks greater than 1", but less than 6” in diameter; “rock large”

was recorded for rocks greater than 6" diameter. Rock was recorded even if sparse litter, broadcast mulch, or vegetation overlaid it.

5) Bare ground was recorded when the point intercepted mineral soil without the presence of rock (1" or larger) or litter as defined above. Bare ground was also recorded when it was present under vegetation.

Slope (Incline)

Percent slope (incline) was recorded for each transect location sampled using a clinometer (a hand-held instrument that measures angle of slope).

Aspect

The aspect of the slope was recorded for each transect using a hand-held compass. Slope aspect was recorded based on a compass reading of the transect direction (i.e., downhill slope direction) from the top of the transect (upslope end). Compass readings were adjusted by 14 degrees (http://www.ngdc.noaa.gov/seg/geomag/jsp/struts/calcDeclination) to account for magnetic declination from true North.

Elevation

The approximate elevation for each transect was determined from GPS coordinates and a site map of topographic contours.

Photos

Representative digital photographs of each transect were taken by field crews.

Data Analysis

Quantifying Recovery Values

All transect data collected throughout burned and unburned areas were used to estimate means and 95 percent confidence intervals around the means for various recovery parameters, including perennial plant cover and litter cover. Confidence intervals were calculated using a Student's t distribution, which assumes the data are normally distributed; however, in many instances the data do not meet this assumption. In these cases, a non-parametric confidence interval calculation approach is more appropriate. ProUCL statistical software (US EPA NERL 2006) was used to verify that non-parametric (i.e., standard bootstrap) confidence interval estimates were similar to the Student's t results. The standard bootstrap confidence intervals generally did not differ substantially from the Student's t confidence intervals, and when they did differ, the standard bootstrap confidence intervals were narrower than those reported by Student's t. Thus, for simplicity and consistency, only the Student's t confidence intervals are reported here and elsewhere in this report. All presented statistical analyses and confidence intervals were calculated using JMP 5.0.1a (SAS Institute Inc. 2002).

The transect data were compiled such that each point on a transect was given a score for presence/absence of each vegetation category and abiotic component, the values presented throughout this report are absolute cover values *independent* of all other parameters measured. For example, for a reported value of 40 percent perennial plant cover on a transect, this means that 40 of the 100 points on the transect had perennial plant cover present, regardless of other vegetation layers. The only parameter calculated in this report that is not independent of other vegetation and abiotic layers is the "Exposed Bare Ground" parameter, which consists of the number of points on a transect at which there was bare ground (i.e. not litter or rock), with no vegetation layer above. This parameter was calculated because exposed bare ground can be considered especially vulnerable to rainfall impact and thus erosion.

The datasets compiled from burned and unburned areas were assessed to determine which biotic and environmental factors were correlated with vegetation recovery parameters, including perennial plant cover, total vegetative cover, native species richness, and exposed bare ground. An exploratory recursive partitioning analysis (Urban 2002, Bourg *et al.* 2005) was also carried out to ascertain potentially important factors affecting perennial cover in burned areas. Bivariate correlations were performed between vegetation recovery parameters and environmental factors that were identified in this analysis or anticipated to be important in structuring post-fire recovery of the vegetation.

Testing Differences between Burned and Unburned Areas

To determine whether and to what extent the paired burned and unburned transects statistically differed for key vegetation recovery parameters (including perennial plant cover, total vegetative cover, and litter), a distribution test using the "test mean" function in the distribution platform of JMP 5.0.1a was performed on the absolute differences between paired burned and unburned transects for each of these variables. The distribution test is equivalent to a paired t-test or matched pairs test, except that the effect size (level of difference) can be specified as some number greater than zero. For example, one could test between the null hypothesis that there is no difference (zero difference) between burned and unburned pairs, versus an alternative hypothesis that there is a statistical difference (greater than zero difference) between pairs, but it is more biologically meaningful to statistically test for larger effect sizes. Thus, the distribution test was carried out for 10 percent cover differences, 20 percent cover differences, and 30 percent cover differences to determine at what effect size the burned and unburned pairs statistically significantly differ. A p-value less than 0.05 (the designated critical significance level or α) for a given effect size indicates that the paired burned and unburned transects differ by greater than that specified difference. Only paired transects were used in these tests, thus controlling for environmental variation in order to focus on the effects of burning. The GIS created environmental "types" that were used to pair transects for these analyses are somewhat artificial constructions, useful only for purposes of controlling for environmental variation, and were not considered in any other calculations or analyses presented in this report. Difference data were normally distributed and no data transformations were required to meet the statistical test assumptions. Confidence intervals for the mean differences between burned and unburned pairs were also estimated, with results corresponding to those of the statistical tests.

Results

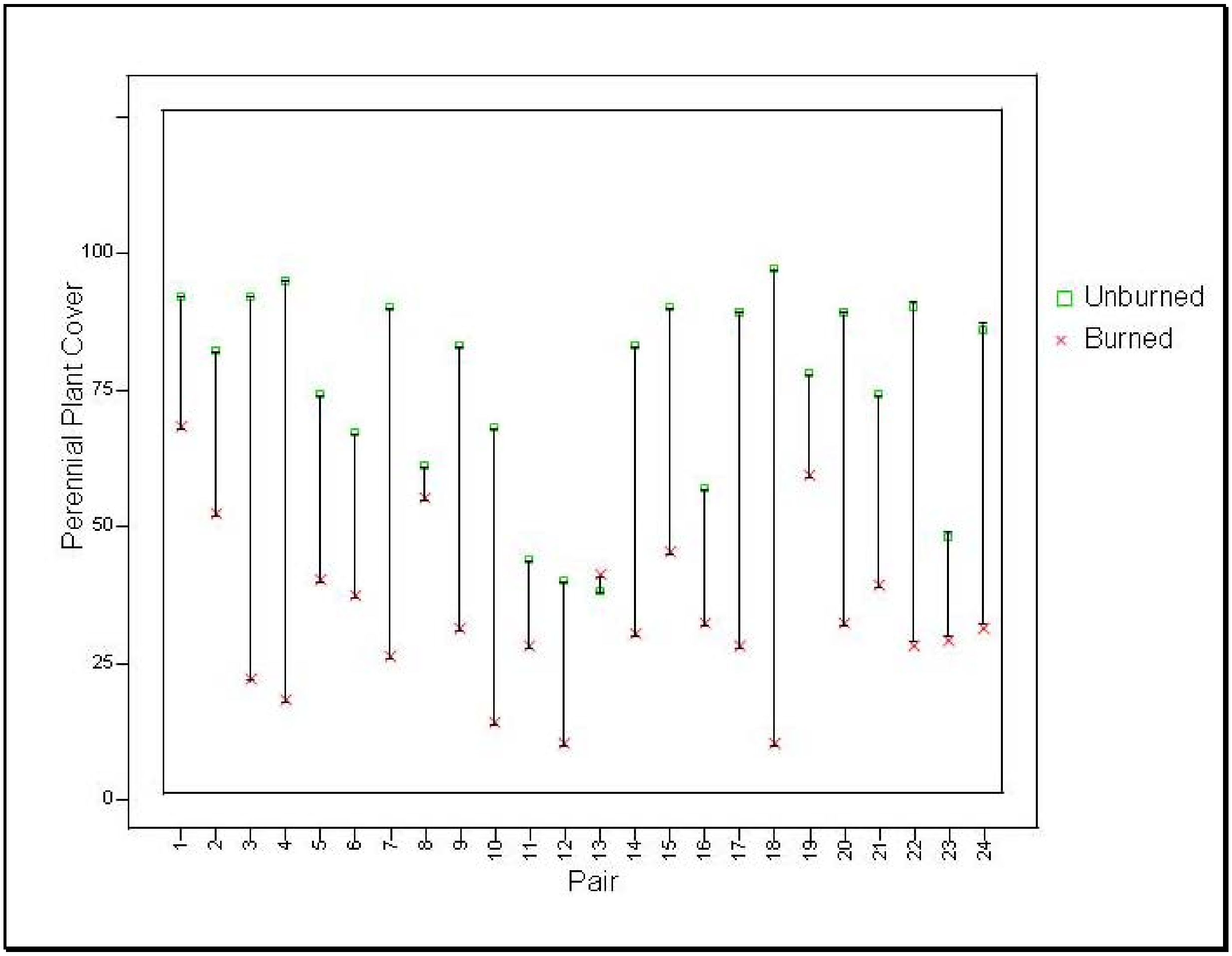
Testing Differences Between Paired Burned and Unburned Transects

A pairwise comparison of burned and unburned transects revealed statistically significant effects of burning on all three response variables (perennial plant cover, total vegetative cover, and litter cover). Specifically, perennial plant cover differed by significantly more than 30 percent between burned and unburned transects, total vegetative cover differed by significantly greater than 20 percent, and ground cover by litter (independent of the vegetation layer) differed by significantly more than 30 percent. In other words, all of these cover values were significantly higher on unburned transects than on burned transects, by at least 20-30 percent cover. Mean differences and confidence intervals for pairwise comparisons are presented in Table C, along with significance levels from tests conducted for 20 and 30 percent differences. Figure 3 graphically presents the difference between burned and unburned perennial cover for each pair (one burned and one unburned for each pair).

Table C: Mean differences in cover parameters (±95% confidence interval width) of paired burned and unburned transects (N=24 pairs).
P-values are presented for distribution test results; bolded p-values are those lower than the critical significance level of 0.05

Response Variables	Mean Difference ± 95% CI width	Significance at 20% difference	Significance at 30% difference
Perennial Cover	42.7 ± 9.6	**p<0.0001**	**p<0.0059**
Total Vegetative Cover	31.8 ± 8.7	**p<0.0051**	p<0.3341
Litter Cover	46.5 ± 11.6	**p<0.0001**	**p<0.0036**

Figure 3 - Perennial cover for burned and unburned transects by pairing
Symbols represent the actual perennial cover values; the line between the unburned and burned perennial cover symbols represents the pairwise difference in perennial cover.



Vegetation and Abiotic Cover across all Burned and Unburned Transects

Many transects were performed in both the burned and unburned areas that were not used in the paired statistical analyses discussed above. These additional transects were primarily conducted to obtain improved and more comprehensive estimates of recovery parameters throughout the project site. Means and confidence intervals presented hereafter refer to all performed burned (N=97) and unburned (N=30) transects conducted onsite and offsite, unless described otherwise.

A summary of the mean absolute cover values and 95 percent confidence interval widths for vegetation and abiotic parameters in all burned and unburned transects is provided in Table D below. All vegetation and abiotic layers were assessed and analyzed independently as described in the Methods section, except for "exposed bare ground", which is calculated as the amount of the transect at which there was exposed bare ground (e.g.., no litter layer or rock) *without* vegetative cover.

Table D: Absolute percent cover (mean ± width of 95 percent confidence interval) from all burned and unburned transects

Parameter	Burned (n=97)	Unburned (n=30)
Vegetation		
Native Cover	31.3 ± 2.9	72.7 ± 7.0
Introduced Species Cover	14.7 ± 2.8	2.2 ± 1.9
Annual Cover	16.9 ± 2.9	2.7 ± 2.0
Perennial Cover	29.3 ± 2.9	72.5 ± 7.0
Woody Cover	14.8 ± 2.1	70.9 ± 7.5
Herbaceous Cover (annual or perennial)	31.8 ± 2.8	6.4 ± 3.7
Total Vegetation Cover	46.6 ± 2.6	75.5 ± 6.4
Abiotic		
Bare Ground	46.2 ± 4.2	11.6 ± 3.4
Exposed Bare Ground (No Vegetation)	29.0 ± 2.9	4.9 ± 2.2
Litter	17.9 ± 2.8	61.4 ± 7.0
Litter Sparse	21.4 ± 2.7	23.7 ± 4.7
Large Rock	10.9 ± 2.2	3.0 ± 2.7
Small Rock	1.0 ± 0.4	0.4 ± 0.3
Mulch	3.8 ± 2.1	NA

Although the complete sets of burned and unburned transects are not perfectly matched in terms of environmental conditions (for example, sedimentary rock lands that did not burn were not available to sample although they are a dominant soil type in the burned areas onsite), comparing vegetation and abiotic parameters between all burned and unburned transects is illustrative of the conditions in those burned and unburned areas.

Total vegetative cover, native plant cover, perennial plant cover, woody plant cover, and litter are all much greater in unburned areas than in burned areas. Conversely, cover by annual plants and introduced plant species is higher in burned areas than in unburned areas. Cover by bare ground (absolute) and by exposed bare ground (without any vegetative cover) are also much higher in burned areas than in unburned areas. Large rock and small rock contribute higher cover on the burned areas than in unburned areas due to the predominance of sedimentary rock lands in the burned onsite areas.

Factors Affecting Cover within Burned Areas

Generalized Soil Type

Approximately half of the burned chaparral and scrub habitats onsite are found on sedimentary rock lands, which were essentially not available for comparison in unburned areas. Table E presents cover parameters from burned transects conducted in sedimentary rock lands and in loam soils for comparison. Total vegetative cover, perennial cover, native cover, and litter cover were analyzed independently of other parameters. Exposed bare ground is the cover by bare ground without overlaying vegetation. Loam soils sampled in burned areas included predominantly Gaviota rocky sandy loam, as well as Saugus sandy loam, Zamora loam, and Linne silty clay loam.

Table E - Absolute percent cover (mean ± 95% confidence interval width) in burned transects segregated by generalized soil types

Recovery Parameter	Sedimentary Rock Lands N=50	Loam Soils N=43
Vegetation		
Total Vegetative Cover	46.4 ± 3.7	47.8 ± 3.8
Perennial Cover	25.7 ± 3.6	33.3 ± 4.5
Native Cover	27.7 ± 3.6	35.3 ± 4.5
Introduced Species Cover	18.7 ± 3.9	11.2 ± 4.3
Abiotic		
Litter Cover	20.1 ± 3.6	16.2 ± 4.8
Exposed Bare Ground	24.6 ± 3.5	32.6 ± 4.7
Large Rock Cover	14.7 ± 3.0	7.4 ± 3.0

Native plant cover and perennial plant cover were lower in sedimentary rock land soils than in the loam soils, whereas introduced plant cover and litter were somewhat higher in sedimentary rock land soils. Sedimentary rock lands have a greater predominance of large rock outcropping than loam soils, thus explaining greater large rock cover in this soil type; however, total vegetative cover was not substantially different between sedimentary rock lands and loams.

Watersheds

Table F presents the means and confidence intervals for important recovery parameters in burned transects, summarized by National Pollutant Discharge Elimination Systems (NPDES) compliance outfall watershed, for the largest onsite watersheds. These average values were estimated from all burned transects conducted within each watershed.

Table F: Absolute percent cover (mean ± 95% confidence interval width) of burned transects by watershed.
Total vegetative cover, perennial plant cover, and litter cover were analyzed independently of other parameters. Exposed bare ground is the cover by bare ground without overlaying vegetation

Watershed/Outfall	N	Total Vegetative Cover	Total Perennial Plant Cover	Litter Cover	Exposed Bare Ground
001	20	44.0 ± 5.6	22.9 ± 5.7	18.6 ± 5.5	26.1 ± 6.8
002	22	46.9 ± 6.3	39.3 ± 6.6	14.1 ± 7.9	36.9 ± 7.7
008	8	40.0 ± 9.5	28.3 ± 13.0	24.8 ± 10.6	28.6 ± 9.7
009	21	49.1 ± 5.6	29.9 ± 5.1	18.5 ± 5.8	26.5 ± 5.3
011	7	47.7 ± 15.9	26.4 ± 14.9	22.9 ± 19.6	23.4 ± 13.1
018	17	49 ± 6.0	25.5 ± 6.5	15.0 ± 4.8	28.8 ± 7.3

Total vegetative cover is similar in all watersheds discussed, ranging from 40 to 49 percent total vegetative cover. Litter cover ranges from 15.0 to 24.8 percent with watershed 002 having the least litter cover (14.1 percent) and watershed 008 (24.8 percent) having the greatest cover by litter. Exposed bare ground within the watersheds 001, 008, 009, 011, and 018 ranges from 23.4 to 28.8 percent; watershed 002 has the highest amount of exposed bare ground.

Perennial cover in watersheds 001, 008, 009, 011, and 018 ranges from 22.9 to 29.9 percent, with watershed 002 being substantially higher at 39.3 percent. These results indicate that that vegetation in these watersheds have not fully recovered with regards to vegetation cover and litter layer from the effects of the 2005 Topanga fire.

Introduced Plants, Litter and Bare Ground

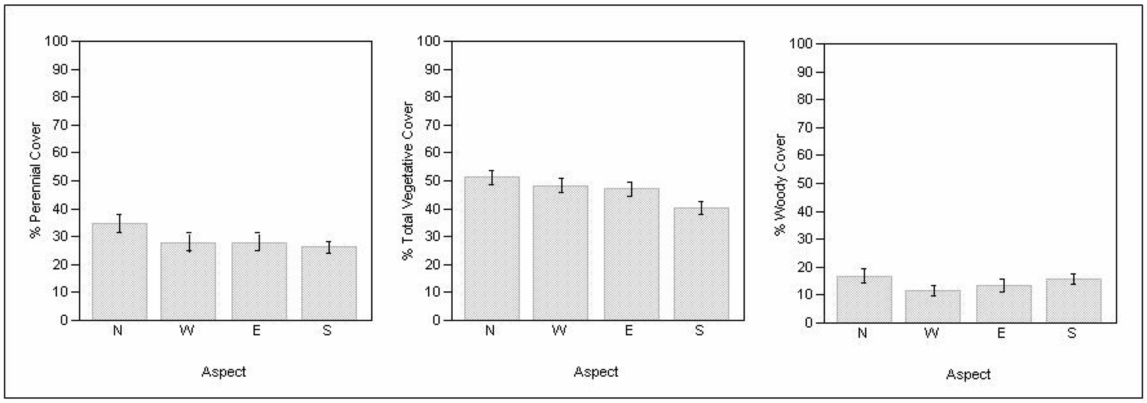
The exploratory recursive partitioning analysis revealed that cover by introduced plants may strongly influence perennial plant cover within burned areas, which agreed with field observations. Introduced plants compete with native plant species, potentially inhibiting germination and growth of natives, and introduced plant cover often increases after fire in many plant communities. In the burned transect dataset (N=97), introduced plant cover is significantly negatively correlated with perennial plant cover ($R = -0.55$, $p<0.0001$), native plant cover, ($R = -0.53$, $p<0.0001$), and woody plant cover ($R = -0.35$, $p<0.0005$). Native species richness (i.e., the number of native species present on a transect) is also significantly negatively correlated with introduced plant cover ($R = -0.2977$, $p<0.0031$). Much of the litter cover in the burned areas is thatch from introduced annual species, as evidenced by the strong positive correlation between introduced cover and litter ($R = 0.45$, $p<0.0001$) in burned transects.

It is important to note that since litter cover in recently burned areas is strongly related to introduced plant cover, high cover of bare ground is not necessarily an indicator of delayed recovery. In fact, bare ground in recently burned areas may indicate a healthy native community that has not yet been invaded by introduced annual species. Within burned transects (N=97), bare ground is significantly positively correlated with native plant cover ($R = 0.30$, $p<0.0025$), perennial plant cover ($R = 0.32$, $p<0.0016$), woody plant cover ($R = 0.22$, $p<0.0318$), and native species richness ($R = 0.26$, $p<0.0111$), and significantly negatively correlated with introduced plant cover ($R = -0.49$, $p<0.0001$). Areas observed and sampled in the field that had low cover of introduced plants did appear to be recovering better than areas without introduced plants, and exhibited higher native plant diversity.

Aspect, Elevation and Slope

Aspect appeared to exert some influence on recovery rates within the burned transects, with somewhat higher cover values on North-facing aspects than on all other aspects (Figure 4). Relativized aspect (as described in the Methods section, relativized aspects range from 0 – 180 and greater values indicate greater deviation from North-facing slopes) was negatively correlated with native plant cover ($R = -0.26$, $p<0.0113$), perennial plant cover ($R = -0.22$, $p<0.0280$), and total vegetative cover ($R = -0.36$, $p<0.0003$) on burned transects (N=97). Native species richness was also greater on North-facing slopes than on other aspects ($R = -0.27$, $p<0.0081$). These differences are represented but not completely obviously when looking at Figure 4, which is primarily provided for comparison with the results for the unburned chaparral (see section below).

Figure 4 - Perennial plant cover, total vegetative cover, and woody plant cover by aspect for all burned transects (N=97). Means ± standard error are shown.



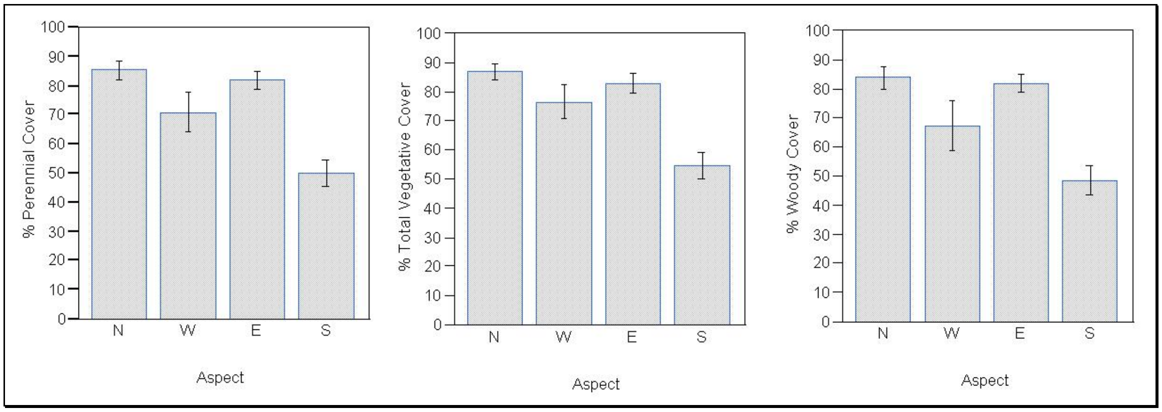
Elevation and slope do not appear to greatly affect recovery of vegetative and perennial cover in the burned areas on the project site. Burned areas sampled were fairly steep (burned transect slopes ranged from 8 to 72 percent slope, with a mean slope of 37 percent) and were within a fairly restricted elevation range (1600 to 2150 feet above sea level).

Factors Affecting Cover in Unburned Areas

The unburned chaparral and scrub habitats sampled are less variable than burned areas since these are mature plant communities that have not burned for 25-37 years. However, even with relatively low variability overall, mean perennial and total vegetative cover in mature unburned chaparral and scrub is affected by environmental factors, particularly slope aspect. These differences are important to note when comparing regenerating burned areas to unburned areas to assess recovery performance.

In unburned chaparral and scrub habitats sampled, many cover parameters are lower on south-facing slopes than on all other aspects. For example, total vegetative cover is negatively correlated with relativized aspect (where larger aspect values indicate more South-facing slopes; $R = -0.69$, $p<0.0001$), as is perennial plant cover ($R = -0.71$, $p<0.0001$), woody plant cover ($R = -0.66$, $p<0.0001$), and native richness ($R = -0.69$, $p<0.0001$). In other words, each of these parameters is lowest on South-facing slopes and higher as slope aspect becomes more North-facing in unburned areas. Categorizing aspect into North-, South-, East- and West-facing slopes for unburned transects shows clear trends by aspect for multiple cover parameters (Figure 5) that should perhaps be taken into account when assessing recovery performance of burned areas over time.

Figure 5- Perennial plant cover, total vegetative cover, and woody plant cover by aspect for all unburned transects (N=30) Means ± standard error are shown



Litter cover in unburned areas is more representative of vegetation development and maturity than it is in recently burned areas. Within unburned areas, litter cover is strongly correlated to perennial and woody plant cover, and not correlated with introduced species cover, which is dissimilar from the patterns observed in the burned areas. In these mature chaparral and scrub communities, the developed litter layer is composed primarily of leaves, bark and branches dropped from native woody shrubs rather than thatch from introduced annual plants.

Shrub Regeneration in Burned Areas

Strategies that perennial plant species use to recover from fires include crown sprouting, seeding, and branch sprouting. Plants that are adapted to fire are classified as "obligate resprouters", "facultative seeders", or "obligate seeders". Obligate resprouters are plants that depend on resprouting from their underground root systems (including some bulbous plants) and lower stems or burls (lignotuber) to survive after a fire. Facultative seeders both resprout and produce seeds that germinate after a fire. Obligate seeders are destroyed in the fire and depend on seedlings to replace their populations. The seeds of many of obligate seeder species are fire dependent, meaning their seeds require some fire cue (heat, charred wood, smoke) to germinate. Primary evidence of post-fire vegetation regeneration on the project site included presence of crown sprouts and seedlings.

Table G summarizes the presence of species by life form (e.g., perennial/woody, perennial/herbaceous) in the burned and unburned paired transects for comparison. Regeneration type (e.g. resprouter, seeder) is listed for species when that information was available.

Table G: Species present in paired burned and unburned transects

Plant Species	Introduced (I)/Native(N)	Regeneration Type	Present in Unburned	Present in Burned
Perennial/Woody				
Adenostoma fasciculatum	N	R, S	X	X
Arctostaphylos glauca	N	S	X	
Artemisia californica	N	R, S	X	X
Baccharis pilularis	N			X

Ceanothus crassifolius	N	S	X	X
Ceanothus thyrsiflorus	N		X	X
Cercocarpus betuloides	N	R	X	X
Clematis sp.	N		X	
Encelia californica	N	S	X	
Eriodictyon crassifolium	N	R	X	X
Eriogonum fasciculatum	N	S	X	
Galium angustifolium	N	R		X
Gutierrezia sp.	N	S*	X	X
Hazardia squarrosa	N	S	X	X
Helianthus gracilentus	N			X
Heteromeles arbutifoia	N	R	X	X
Lonicera subspicata	N	S*	X	X
Malacothamnus fasciculatus	N	S		X
Keckiella cordifolia	N	R	X	
Malosma laurina	N	R	X	X
Mimulus aurantiacus	N	S	X	X
Nicotiana glauca	I	S		X
Quercus agrifolia	N	R	X	X
Prunus ilicifolia ssp. *ilicifolia*	N	R	X	X
Rhus ovata	N	R	X	
Rhamnus ilicifolia	N	R	X	
Ribes malvaceum	N	R	X	X
Salvia apiana	N	S		X
Salvia leucophylla	N	R	X	X
Salvia mellifera	N	S	X	X
Sambucus mexicana	N	R	X	X
Toxicodendron diversilobum	N	R		X
Yucca whipplei	N	R,S	X	X
Perennial/Herbaceous				
Acourtia microcephala	N		X	X
Antirrhinum multiflorum	N			X
Calystegia macrostegia	N	S		X
Calochortus sp.	N			X
Chlorogalum pomeridianum	N		X	X
Dicentra ochroleuca	N	S		X
Dichelostemma capitatum ssp. *Capitatum*	N			X
Eriophyllum confertiflorum var. *confertiflorum*	N	S		X
Helianthemum scoparium	N	S		X
Lessingia filaginifolia	N		X	X
Lithophragma affine	N		X	
Lotus scoparius	N	S		X
Malacothrix saxatilis var. *tenuifolia*	N			X
Marah macrocarpa	N	R	X	X
Melica imperfecta	N	R		X
Mirabilis californica	N	S	X	X
Nassella lepida	N	R	X	
Paeonia californica	N	R	X	X
Pentagramma triangularis	N		X	
Ranunuculus californicus	N		X	

Phacelia ramosissima	N		X	
Sanicula crassicaulis	N		X	
Solanum xanti	N		X	X
Symphorocarpus mollis	N	R	X	
Venegasia carpesoides	N		X	X
Zigadenus fremontii	N			X
Annual				
Antirrhinum kelloggii	N	S		X
Avena barbata	I	S		X
Brassica nigra	I	S	X	X
Brassica tournefortii	I	S	X	X
Bromus diandrus	I	S	X	
Bromus hordeaceus	I	S		X
Bromus madritensis rubens	I	S	X	X
Centaurea melitensis	I	S	X	X
Claytonia parviflora	N	S	X	X
Conyza canadensis	N	S		X
Cryptantha intermedia	N	S		X
Erodium botrys	I	S		X
Erodium cicutarium	I	S		X
Eucrypta chrysanthemifolia	N	S	X	X
Galium aparine	N	S	X	
Gnaphalium californicum	N	S	X	X
Hesperocnide tenella	N	S	X	
Hirschfeldia incana	I	S		X
Lactuca serriola	I	S		X
Nemophila menziesii	N	S	X	
Phacelia cicutaria	N	S		X
Pholistoma aurium	N	S	X	
Silene gallica	I	S		X
Silybum marianum	I	S		X
Sonchus asper ssp. *asper*	I	S		X
Stellaria media	N	S	X	X
Vulpia myuros	I	S	X	X

Species are organized by life form. Documented post-fire recovery strategies (Meentemeyer *et al* 2001; Franklin, Janet et al, 2004; Hanes, Ted L., 1971) include resprouters (R) and seeders (S); some species regenerate by both resprouting and seeding after fire. * Indicates potential regeneration strategy based on information documented for closely related species in California.

Appendix B contains a list of all plant species observed throughout the study area, both within and outside the transects.

Discussion

Fire is important to the continued existence of chaparral plant communities in California. The occurrence of fire in the project area has been frequent over the past 60 years, burning some areas of the project site more frequently than others. Fire frequency is one of the many factors that can influence species diversity and potential recovery of chaparral and scrub plant communities. In order to better understand fire frequency throughout the study areas, we reviewed burn history maps and assessed the onsite and offsite study areas by watershed. The watersheds within the project site are shown in Figure 2 and are discussed by outfall number, with an emphasis on the watersheds of outfalls 001, 002, 008, 009, 011, and 018. Outfall watersheds 001, 002, 008, and 009 were selected because these watersheds do not have structural treatment BMPs (not including hydromulch) and rely primarily on natural vegetation[1] to control erosion and sediment migration offsite. Outfalls 011 and 018 were added because these drain to 001 and 002, respectively, and collectively with the other watersheds, make up the majority of the site. Runkle Canyon is also included in the table as it is the major offsite unburned control area that was investigated in the study.

Table H - Summary of fires by outfall watershed over the last 60 years (California Department of Forestry/FRAP 2007).

Fire Year (Name)	**Watershed**						
	Runkle Canyon	**001**	**002**	**008**	**009**	**011**	**018**
1949 (Simi Hills)		X	X	X	X	X	X
1950		X (east portion)					
1966 (Black Canyon Fire)				X (1/2)		X	X
1967 (Devonshire-Parker)	X	X (east & south portion)	X (all but middle)	X (east portion)			
1967 (Palmer Fire)		X	X (all but middle)	X (east portion)			
1970 (Clampitt Fire)	X	X	X	X	X	X	X
1981 (Oat Fire)					X (east edge)		
1982 (Hall Fire)	X				X (east edge)		
2005 (Topanga)		X	X	X	X	X	X
Total Fires	3	6	5	6	5	4	4

Overall, four to six fires burned portions of any given watershed ranges over the past 60 years. However, three fires burned the entire area within each of the watersheds during that same time period. This is similar to the offsite Runkle Canyon area which also burned three times in the last 60 years.

Entire or large portions of some watersheds on the project site burned a minimum of three times between 1949 and 1970 (21 years); this is more frequent than the 20-30 year average burn cycle documented in literature. Fire has been less frequent over the last 35 years, and more consistent

[1] It should be noted that Boeing also has implemented distributed post-fire erosion and sediment control BMPs throughout these watersheds, including hydromulch, straw waddles, and ash vacuuming (within the stream channels).

with the stated average fire regime for chaparral, as the watersheds have burned once (2005) following the 1970 fire, with the exception of small portions along the eastern edge of watershed 9, and for Runkle Canyon, that burned in 1982 (25 years ago).

Increased fire frequency may affect recovery rates by reducing the amount of perennial resprouters, reducing the seed bank of chaparral dominants and other species, and enhancing persistence of herbaceous species, thereby slowing the recovery of the dominant chaparral community.

The recent history of fire frequency onsite is thus fairly typical for chaparral in Southern California, and the reference unburned areas in Runkle Canyon exhibit fire history since the last fire similar to most of the project site. In this respect, Runkle Canyon is an appropriate control for the burned areas onsite, as it approximates pre-burn conditions at SSFL.

Significance Differences between Burned and Unburned Areas

The focus of this evaluation is how chaparral and scrub communities on the project site are recovering, approximately 18 months following the fire, relative to what is expected based on the scientific literature reviewed. An evaluation of burned and unburned paired data clearly shows that the burned areas currently are significantly different than the unburned areas for all factors tested including total vegetative cover, perennial cover, and litter cover. The greater total vegetative and perennial cover (measured) and height (visually observed) of vegetation in the unburned areas is obvious when visually comparing mature stands of chaparral in the study areas that are of similar age (25-37 years old) as the burned areas were at the time of the 2005 fire (Figure 6). The difference in litter cover (higher in unburned) is also apparent (Figure 7).

Vegetation by Seeding Species within Burned Areas

Vegetative cover in recently burned areas (Figure 8) on the project site is dominated by non-woody annual and perennial species (both native and introduced) that thrive on disturbed areas where light is abundant. For many of these species, light is one factor that limits their presence in mature chaparral, and seeds stored in the soil do not germinate until conditions are favorable. Examples of these herbaceous species throughout the burned areas include foxtail chess (*Bromus madritensis rubens*), ripgut brome (*Bromus diandrus*), softchess brome, shortpod mustard (*Hirschfeldia incana*), caterpillar phacelia (*Phacelia cicutaria*), black mustard, slender wild oats (*Avena barbata*), red-stemmed filaree, long-beaked filaree, tocalote, chaparral nightshade (*Solanum xantii*), and common Eucrypta (*Eucrypta chrysanthemifola*). Some woody perennial species present within burned areas that also have light-stimulated seed germination include California buckwheat, black sage, and Yerba Santa.

Other species that are common soon after a fire have seeds that require or benefit from soil heating and charate. The primary regeneration strategy for most of these species is by seed, with the exception of chamise and Yerba Santa. These two species also readily resprout following fire. For some of the species requiring soil heating for germination, solar radiation during summer months on exposed soils may be sufficient to stimulate germination. For other species, soil heating and charate may not necessarily be required for germination, but may increase germination rate. California morning glory and California deerweed, both known to be stimulated by soil heating, are common and abundant in cover throughout the burned areas.

North an d North/Northeast Facing Slopes Unburned Chaparral(Off-site)
N 34.24683º, W 118.72957º

Unburned South/Southwest Facing Chaparral/Scrub (On-site)
N 34.22748º, W 118.71989º

FIGURE 6

Western Botanical Services, Inc.

Boeing Santa Susana Field Laboratory
Representative Unburned Chaparral

SOURCE:

Litter in burned chaparral (north-facing slope onsite)
N 34.23609º, W 118.68747º

Litter in unburned chaparral (north-facing slope onsite)
N 34.23651º, W 118.68645º

Western Botanical Services, Inc.

FIGURE 7

SOURCE:

Boeing Santa Susana Field Laboratory
Representative Litter Cover in Burned and Unburned Chaparral

Burned North/Northeast Facing Slopes Chaparral (Watershed 2)
N 34.21959º, W 118.70588º

Burned South/Southwest Facing Chaparral/Scrub (Watershed 2)
N 34.21724º, W 118.70461º

FIGURE 8

Western Botanical Services, Inc.

Boeing Santa Susana Field Laboratory
Representative Burned Chaparral

SOURCE:

Perennial woody species known to be stimulated by soil heating but are not as abundant include chaparral bush mallow (*Malacothamnus fasciculatus*), hoaryleaf ceanothus, blue blossom (*Ceanothus thysiflorus*), and white sage (*Salvia apiana*). The seed of chamise and Yerba Santa, both of which regenerate by seed and resprouting, is also stimulated by charate. These two species often dominate areas where they are present on the burned sites due to their post-burn reproductive strategies.

Vegetation by Resprouting Species within Burned Areas

The woody cover (averaging 14.8 percent cover across the burned project site) in the burned areas on the project site includes perennial species that are expected to become the dominants as the chaparral recovers from the fire. Most of these woody species regenerate by resprouting quickly following a fire and are therefore abundant, with reprouts ranging in height from two to seven feet (visually estimated). The most common woody perennial species contributing the most cover include chamise, Yerba Santa, and laurel sumac. Chamise is common in all areas except the southwestern portion and the northeastern portions of the project site. Laurel sumac is common throughout the site but is higher in cover in the southern half of the project site. Yerba Santa is higher in cover in middle and northern portions of the project site. Other resprouters, including California bay (*Umbellaria californica*), poison oak (*Toxicodendron diversilobum*), Southern honeysuckle (*Lonicera subspicata* var. *denudata*), holly-leaved cherry (*Prunus ilicifolia*), and Mexican elderberry (*Sambucus mexicana*) are more common in the middle and northern portions of SSFL, but these species contribute less cover than chamise, Yerba Santa, and laurel sumac.

Introduced Species and Competition

Introduced species cover and perennial cover are negatively correlated within the burned areas; (e.g., on average, the greater the vegetative cover by introduced species, the lower the perennial cover). Introduced species on the project site average 14.7 percent cover and are nearly all annual herbaceous forbs and grasses. The most common introduced species include tocolate, foxtail chess, ripgut brome, softchess brome, red-stemmed filaree, storkbill filaree, shortpod mustard, and black mustard. These introduced annuals often have an advantage on establishment following disturbance, allowing them to aggressively compete with native annual and perennial species for light, nutrients, and space. Introduced species are usually eventually outcompeted by native species in chaparral, and constitute a small percentage of vegetative cover in mature chaparral included in this study. Introduced species cover in unburned chaparral and scrub is approximately 2.2 percent.

Introduced cover and litter within the burned areas are highly positively correlated and much of the litter present within the burned areas are dead plant stalks and leaves from last years annual plant communities, primarily tocalote, black mustard, and *Bromus* spp. We also observed that a large amount of litter included residual dead plant branches of perennial California morning glory and a few native annual species including caterpillar phacelia.

Cover by Slope Aspect

Previous studies on chaparral communities by others found that biomass, species diversity, and vegetative cover is typically higher on north-facing slopes. Consistent with this finding, north-facing slopes of the burned areas on the project site have somewhat greater vegetative cover, perennial cover, native cover, and species richness than burned slopes of all other aspects (south, east, and west) on the project site.

Species composition of the north-facing transects is also consistent with references cited, since more moisture-loving and shade tolerant perennial species such as California bay, toyon, poison oak, and Mexican elderberry are present on north-facing slopes, and are not common or are absent from south-facing slopes.

Comparison by Watersheds

We reviewed the cover value results for vegetative cover, total perennial cover, litter cover, and exposed bare ground for burned areas in the watersheds draining to outfalls 001, 002, 008, 009, 011, and 018. Mean absolute cover values for total vegetative cover, total perennial cover, litter cover, and exposed bare ground are fairly similar across watersheds; the greatest differences are found in watershed 002 and are discussed below.

Outfall 002 watershed has the highest cover by exposed bare ground (36.9 percent) compared to the other watersheds. However, this watershed also has the greatest perennial plant cover (39.3 percent) compared to other watersheds, and is quite a bit higher than the second highest watershed average (29.9 percent). This finding is consistent with the positive correlation found site-wide between perennial plant cover and bare ground.

Evaluating this elevated perennial cover in the outfall 002 watershed, we determined that the greatest contributors to the perennial cover (in order of descending cover, ranging from 17 percent to 1 percent) are: California morning glory, California deerweed, laurel sumac, white ear-drops (*Dicentra ochroleuca*), wild cucumber (*Marah macrocarpa*), and black sage. The remaining perennial cover is comprised of a mix of predominantly native species that primarily regenerate by seed and are considered temporary species observed during the first few years following a fire (e.g., Yerba Santa, chaparral bush mallow, chaparral nightshade, peak rush-rose, common eucrypta). Some of these species (e.g., California buckwheat, saw-toothed goldenbush, California wishbone bush (*Mirabilis californica*), California aster (*Lessingia filaginifolia*), California melic (*Melica imperfect*), and Our Lord's candle (*Yucca whipplei*)) often also characterize mature stands of coastal sage scrub. Hoaryleaf ceanothus (which regenerates by seed only), toyon, and holly-leaved cherry, which are all co-dominants in mature chaparral, contributed less than 0.5 percent cover each.

Annual cover is lowest in the outfall 002 watershed (approximately 7 to 8 percent). Half of the annual cover in this watershed is by the native caterpillar phacelia. The remaining cover by annuals is comprised of introduced species such as red-stemmed filaree, shortpod mustard, and prickly lettuce. Consequently, watershed 002 contains very little cover by introduced species as compared to other watersheds discussed. Watersheds draining to outfalls 001 and 018 exhibit the most cover by annual species (approximately 20 to 24 percent), which is predominately comprised of introduced species (e.g., foxtail chess, ripgut brome, shortpod mustard, rattail fescue). Native annuals are also present in these watersheds but represent much lower cover than that found in the outfall 002 watershed.

Evaluation of Bare Ground

Bare ground cover is greater in burned areas with higher native plant cover (including perennial woody and non-woody species), and native species richness, and less in areas with greater introduced species cover. It is important to note that since litter cover in recently burned areas is strongly related to introduced plant cover, high cover of bare ground is not necessarily an indicator of delayed recovery. In fact, bare ground in recently burned areas may indicate a healthy native community that has not yet been invaded by introduced annual species. Areas observed and sampled in the field that had low cover of introduced plants did appear to be recovering better (more native species were present) than areas without introduced plants, and exhibited higher native plant diversity. There appears to be more bare ground in areas with less introduced species because the introduced annuals are not occupying the bare areas between the reestablishing native species.

Water Availability/Precipitation

The importance of precipitation and soil moisture on establishment and survival of plant species is widely documented. Sampson (1944) suggested that weather conditions in the seasons following a fire and availability of seed in the soil are critical in determining the kind of cover that develops. Therefore, the amount and frequency of precipitation and soil moisture is an important factor determining the rate of recovery of burned vegetation.

Compared with an annual average rain total of 17.3 inches based on the formerly-onsite Ventura County rain gauge #249 (1910 ft elevation, period of record of 1959-1977 and 1986-2002), the 5.9 inches total for the most recent rain season (i.e., October, 2006 through April, 2007), according to Los Angeles County rain gauge #300 (located onsite at 2260 ft elevation), is far below normal. This recent rain year total would be the second driest on record for the former Ventura County rain gauge, which has a period of record of 36 years.

Time to Recovery

When estimating time to vegetative recovery, it important to consider that "[C]haparral succession is not a series of vegetation replacements, but a gradual ascendance of long-lived species present in the pre-fire stand" (Hanes 1971). Therefore, for the purposes of this report, time to vegetative recovery is defined as returning to a similar plant community (e.g., chaparral/scrub) with similar perennial cover to pre-fire conditions, and at a similar stage of succession. The burned areas of the project site are in the early stages of succession. In order to evaluate the progress of vegetative recovery at SSFL, we compared vegetative cover estimates for burned areas of the project site with those reported in the literature for studies of chaparral communities of similar age.

In order to gain the understanding of chaparral succession necessary to assess time to recovery of burned chaparral on the project site, we reviewed available literature related to post-fire recovery of chaparral. Most of the references we reviewed focused on early succession of chaparral during the first four to five years following a fire. We also found and reviewed numerous studies assessing the characteristics of older mature chaparral. Only a few references, however, reported changes in chaparral vegetation during intermediate growth stages (i.e., older than four or five years) of chaparral.

Hanes (1971) and Horton & Kraebel (1955) provide the most complete information on changes in vegetative cover of chaparral from early succession through senescence. Horton & Kraebel (1955) studied chaparral in San Bernardino County (see Figure 9). They reported two peaks in total vegetative cover -- one early peak between two and four years following a fire and another later peak between 14 and 17 years following a fire. The abundance of annual and herbaceous growth following a fire is responsible for the early peak in cover; the second peak is a result of growth of perennial woody species. Total vegetative cover declined or senesced after 17 years. Hanes (1971) also reported rapid growth of vegetative cover during the first two to eight years following a fire, then a decline after 20 years.

Figure 9 - Changes in total vegetation cover over 24 years following fire from Horton and Kraebel (1955).
All sites burned at different times; this graph is standardized by years since burn. The presented "Cover Density - Percent" parameter is equivalent to the total vegetative cover parameter used in this study.

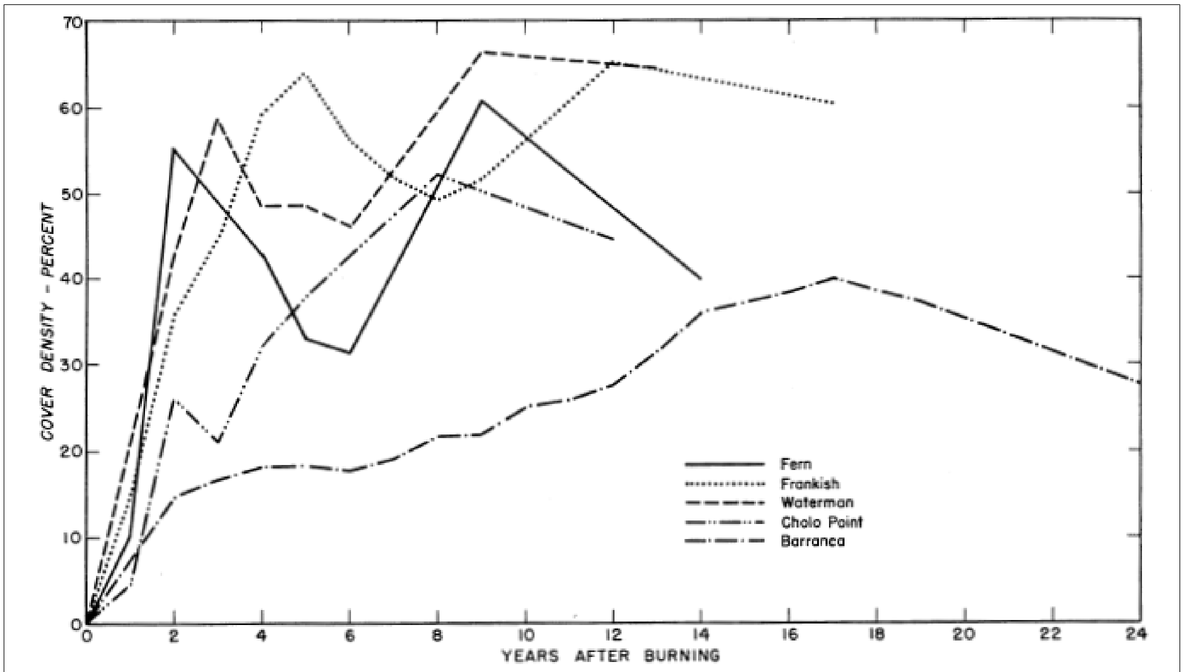


FIG. 10. Development of vegetative cover on the various burns.

Numerous studies on post-fire recovery of chaparral and sage scrub communities indicate that vegetation on the project site should be expected to resprout and seed at a high rate for the first five years following the fire. Overall, total vegetation cover of burned areas on the project site is consistent with literature on recovery during the first two years following a fire. Generally, in reviewed studies of post-fire chaparral recovery, the years subsequent to a fire are defined by the number of wet seasons since the fire (i.e., not necessarily calendar years), and vegetation sampling is conducted in the spring of each year. Thus, the data from this study are comparable with data reported in other studies for two years following a fire, with the exception that the field surveys for this study were conducted a little earlier in the spring than in most studies reviewed. Total vegetative cover for chaparral two years following fire has been reported to range between 11 to 85 percent (Guo 2001, Horton & Kraebel 1955, Keeley & Keeley 1981, Robichaud *et al.* 2000). The current mean total vegetative cover within the burned areas is 46.6 percent, which is consistent with these findings. Patterns of regeneration of annual, herbaceous, and perennial plants are also consistent with the literature.

Similarly, the burned vegetation appears to be regenerating as would be expected during the first two years following a fire. Resprouting is occurring at a high rate throughout the burned areas onsite. Many of the obligate and facultative resprouters present, such as laurel sumac, chamise, toyon, holly-leaved cherry, scrub oak, Yerba Santa, lemonadeberry, and mountain mahogany have resprouted from one to 10 feet in height.

In areas where resprouting is not as prevalent, it is likely that standing dead (burned) shrubs are those that reproduce by seed following fire rather than resprouting. Seedlings of perennial obligate seeders, observed on the burned areas, include hoary-leaved ceanothus, chamise, California deerweed, California sagebrush, and California buckwheat. Many of the South/Southwest- and West-facing burned slopes are dominated by California morning glory, which is consistent with a study conducted on the recovery of chaparral following the 2003 Santa Monica Mountain fire (Guo 2003).

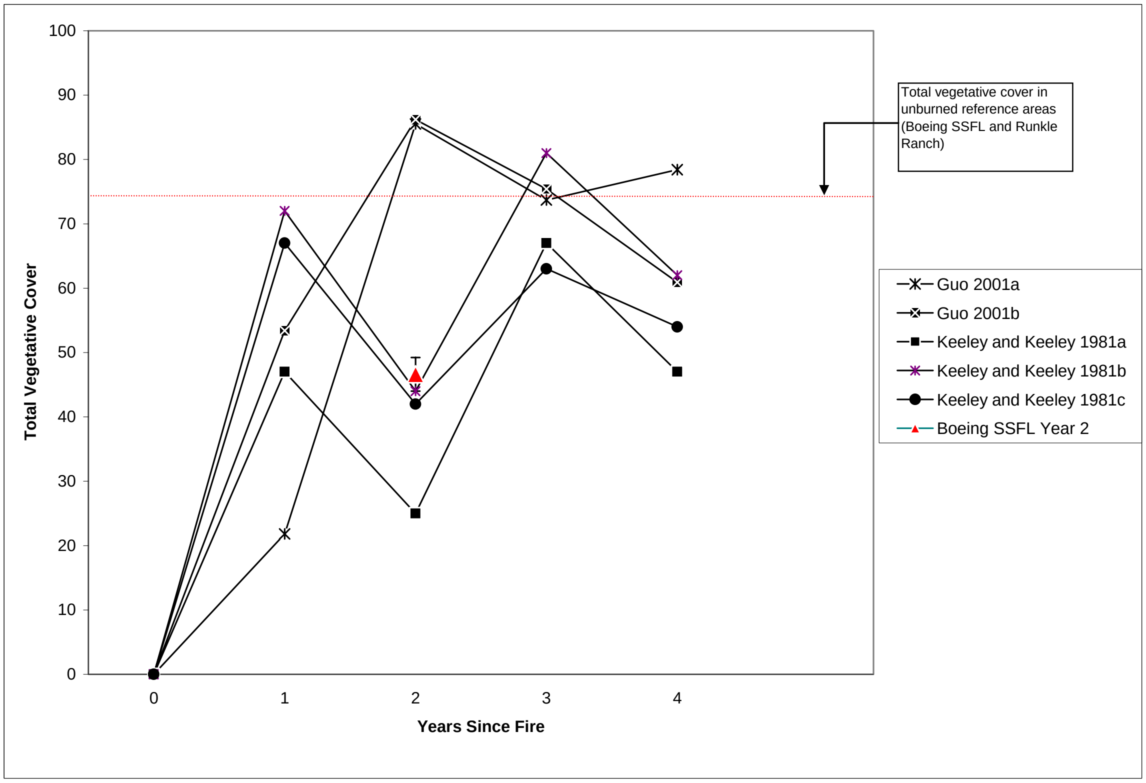
The abundance of annual and herbaceous species on the project site is also consistent with literature which describes vegetation likely to be observed within two years following a fire (see Figure 10). For example, the residual thatch (remnant dead plant stalks) of annual native forbs (such as phacelia and horseweed) are from the first year's growth following the fire in many of the burned areas. Many of the herbaceous species (native and introduced, annual and perennial) observed within the burned areas are considered "temporary" by literature, and are not present in mature chaparral. This was found to be the case in the current study, as temporary species observed on the burned areas (but not in mature chaparral) include California morning glory, common eucrypta, caterpillar phacelia, slender wild oats, Kellogg's snapdragon (*Antirrhinum kelloggii*), prickly lettuce, milk thistle, softchess brome, golden yarrow, and chaparral snapdragon (*Antirrhinum multiflorum*).

Perennial woody species (e.g., chamise, laurel sumac, mountain mahogany, black sage, hoaryleaf ceanothus, toyon, holly-leaved cherry, purple sage) that are common in the mature chaparral within the project vicinity are present and regenerating within the burned areas as expected for the first two years following a fire. Reviewed literature indicates that woody shrub cover ranges from 15 to 30 percent (Keeley *et al*. 2006) and 10 to 20 percent (Horton and Kraebel 1955) in the first year following a fire. Second year post-fire woody cover values are 18 to 29 percent (Keeley & Keeley 1981) and 42 to 45 percent (Safford & Harrison 2004). The current mean woody cover within the burned areas of the project site is 14.8 percent, which is basically consistent with the range of reported cover values for two years after a fire, though it is slightly lower than reported values from other studies (Figure 11). This estimated value of woody cover may be slightly lower than other reported estimates due to the early timing of our surveys.

To further evaluate the progress of vegetative recovery on the project site, we graphically compared the total vegetative cover and perennial and woody cover of the burned areas with cover values of chaparral of the same age reported in available scientific literature. These comparisons are shown in Figures 10 and 11, below.

Figure 10 - Changes in total vegetative cover over time from studies tracking post-fire recovery of chaparral in California

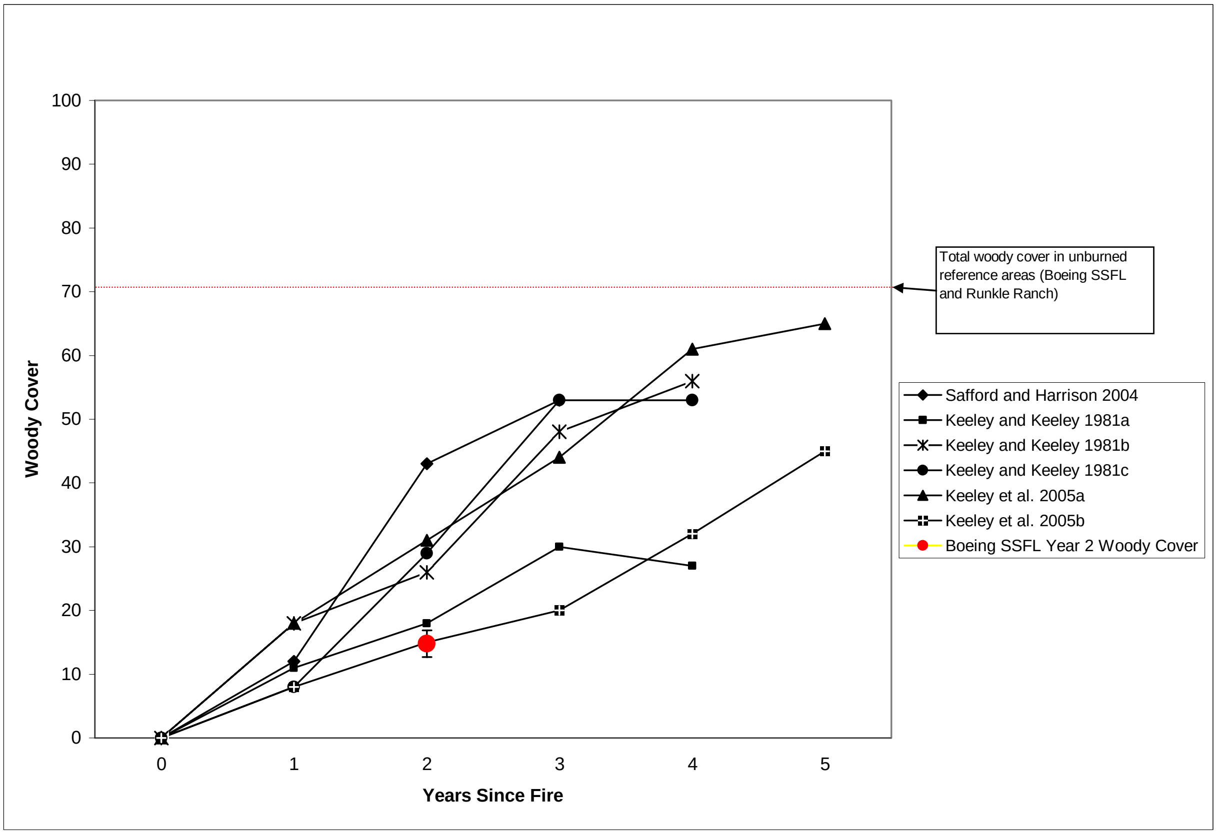
Error bars on the estimate for burned chaparral from Boeing SSFL represent the 95% confidence interval. [2]



[1] Values from Guo (2001) are directly from a table contained therein; Guo 2001a and 2001b represent South- and North-facing slopes, respectively. Values from Keeley & Keeley (1981) were estimated from a graph contained therein; the a, b, and c designations represent different sites within that study. Mean total vegetative cover from the current study of burned and unburned chaparral from the SSFL and adjacent Runkle Ranch are graphed for comparison.

Figure 11 - Changes in woody cover over time from studies tracking post-fire recovery in chaparral in California

Error bars on the estimates for burned chaparral from Boeing SSFL represent the 95% confidence intervals[2]



[2] The a, b, and c designations for Keeley & Keeley (1981) represent different sites within that study. The a and b designations for Keeley *et al*. (2005) represent woody cover in interior chaparral and sage scrub communities, respectively. Interior (i.e. not coastal) sites in that study included one located at Chatsworth (close to the project site). Woody cover values from Safford & Harrison (2004), Keeley & Keeley (1981), and Keeley *et al.* (2005) were estimated from graphs contained therein. For comparison, mean woody cover estimates from the current study of burned and unburned chaparral from the Boeing SSFL and adjacent Runkle Ranch are graphed.

It is likely that the recovery of the chaparral vegetation will follow reported growth patterns assuming no catastrophic events occur (e.g., extreme weather, extreme natural and human disturbances). Based on the literature, vegetative recovery occurs most rapidly during the first six years of regrowth and less rapidly thereafter. Woody cover is expected to continue to increase rapidly (Guo 2001, Keeley & Keeley 1981, Guo 2003, Keeley *et al*. 2006, Hanes 1971) and linearly (Keeley *et al*. 2006) through the fourth or fifth year. Woody cover reported for four to five years following a fire differs between the two references reviewed -- Keeley & Keeley (1981) reported woody cover ranging from 28 to 55 percent, compared to 70 to 85 percent reported by Keeley *et al*. (2005). These differences are likely due to variations in site and community characteristics and thus represent the difficulty of predicting cover over time in chaparral communities.

One of the key challenges when estimating time to recovery is evaluating whether the pre-fire age of the chaparral (or some other age) should be used as the reference for recovery. Based on ecological studies of chaparral communities, chaparral begins to senesce (decline) between 17 to 20 years following a fire (Horton & Kraebel 1955). Since the pre-fire chaparral/scrub on the project site was between 25 to 37 years old, it is considered to be in a senescent (declining) state. References (Hanes 1971) reports that older chaparral communities decline in woody cover during the senescent years. Based on these references, it is likely that the pre-fire perennial cover was likely in a state of decline, and therefore, may suggest that the perennial cover could have been higher in previous years. Because we do not know the pattern of vegetative cover of the life of the pre-fire chaparral, we do not know what the perennial cover was at the prime growth stage of the chaparral on site. Therefore, we make a necessary assumption that the growth rates and composition during the early years following a fire will continue to parallel that of what is reported in literature, and perennial woody species cover may peak between 14 and 17 years following a fire (based on Hanes 1971 and Horton & Kraebel 1955). This peak range is an estimated average for all chaparral sites considered in these long-term studies, and is likely to be somewhat different for the project area, which exhibits different geographical and environmental factors (e.g. closer to the coast) than that of the San Bernardino study areas (Hanes 1971, Horton & Kraebel 1955).

The control for this study consists of onsite and offsite unburned areas that reasonably represent the pre-fire conditions of burned areas onsite, including vegetation composition and age . The parameters for recovery are those values currently exhibited by these reference areas, although these cover values may be lower than the peak cover values for the same sites before senescence.

Based on a literature review and the current vegetative cover of the chaparral on the burned project areas, we estimate the time to vegetative recovery, as determined by perennial woody cover, for the project site to be within 5 to 10 years[3], with the expectation that species diversity and composition will be somewhat different than that of the senescing mature chaparral (onsite and offsite) that represents the pre-fire conditions.

A review of the literature indicates that the time frame for vegetation recovery is broad (five to twenty years) and that the establishment and growth of vegetation depends on many factors such as vegetation type, soil conditions, fire severity and climatic conditions. Furthermore, although chaparral continues to change over time in terms of species diversity, composition, and physiognomy, the erosion control afforded by chaparral vegetation is likely achieved prior to plant community maturity and senescence. Vegetative recovery of chaparral is not necessarily tied to the peak vegetative cover of chaparral, but rather to the development of a healthy stand of vegetation, dominated primarily by perennial woody species, which is likely to develop prior to the peak in vegetative cover reported by Horton & Kraebel (1955). Given that vegetation recovery is defined for this site as the development of a healthy stand of vegetation, and based on having similar values for perennial cover and litter cover as exhibited in the reference unburned areas, we estimate that the burned chaparral and scrub vegetation will likely recover within five to ten years The earliest estimated time of vegetative recovery (five years) is based on estimates by Keeley *et al*. (2006) and Safford & Harrison (2004).

The assessment of time to recovery of the site was made based on field data, field observations, and assumptions formulated through the review of available literature. However, there were few studies available that actually follow trajectories of post-fire recovery in chaparral for more than four years, so there is inherent uncertainty in our estimates of probable time to recovery. Future assessments could be conducted which focus on a re-evaluation of a subsample of burned areas

[3] This estimate is based on the assumption that weather patterns are somewhat normal over the next decade, and the absence of any catastrophic events on the burned areas.

(not unburned areas) of the project site in the spring of successive years to determine the rate at which the perennial and woody species cover is changing over time at this site. These additional assessments of vegetative cover would help to reduce the uncertainty inherent in the timeline-related conclusions of this report.

Conclusions

The overall objective of the study was to assess the status of and time to recovery of chaparral and scrub at the project site subsequent to the September 2005 Topanga fire. Chaparral and scrub represent the dominant vegetation types at SSFL, and these plant communities, when developed, will represent an important natural vegetation-based means of erosion control at the site. Burned chaparral/scrub communities on the entire project site were combined and evaluated together by calculating average mean cover values (with confidence intervals). We determined that cover values for native cover, perennial cover, and total vegetative cover are highest on north-facing slopes. We also evaluated vegetative cover by watersheds (identified for watersheds draining to outfalls 001, 002, 008, 009, 011, and 018). Overall, total vegetative cover, perennial cover, and litter cover were similar between watersheds, with the exception of the watershed draining to outfall 002, where perennial cover and exposed bare ground cover are both higher than in the other watersheds. This watershed appears to be on a slightly accelerated trajectory of recovery, and has most likely benefited from less historic disturbance and reduced invasion by introduced species.

An evaluation of the data collected for this Report in March and April 2007 confirms that there is a statistically significant difference in total vegetative cover, perennial cover, and litter cover between burned (on the project site) and unburned chaparral (onsite and offsite locations) in the study area. This result indicates that the onsite burned areas have not fully recovered with regards to vegetation cover and litter cover from the effects of the 2005 Topanga fire. Additional evidence to support this conclusion was also provided as means and confidence intervals of biotic and abiotic cover parameters for all burned and unburned transects. Native cover, total vegetative cover, woody cover, perennial cover, and litter cover are all higher in unburned areas than burned areas; while introduced species cover, annual cover, herbaceous cover and bare ground cover are higher in burned areas than unburned areas. In plant communities dominated by perennial species, perennials generally provide better erosion control than annual species due to their better developed root systems, greater canopy cover, biomass, and litter production.

Based on these field data, the unburned mature chaparral mean total vegetative cover is dominated by woody species. Currently, the average cover by woody plants on the burned areas combined is approximately one-fifth of that of the unburned mature chaparral. The average cover of litter within the burned areas are approximately one-half than that of that of the mature (i.e., unburned) chaparral litter cover. We recommend that future studies focus on changes in perennial and/or woody cover values, rather than total vegetative cover in determining how the site is recovering, since post-fire total vegetative cover is comprised largely of temporary annual and herbaceous species that greatly vary (both increasing and decreasing) in cover two to eight years following a fire (Horton & Kraebel 1955).

A review of available literature on the estimated time of recovery to pre-fire vegetation conditions for chaparral provides somewhat variable estimates, which are affected by a number of abiotic and biotic factors. In post-fire recovery of chaparral, the available scientific literature strongly emphasizes life-form (perennial or annual, woody or herbaceous), regeneration mode (resprouters, seeders), density, and cover of pre-fire dominant species. Available moisture and nutrients, fire frequency, and presence of introduced and annual species following a fire are also important factors that affect the rate of recovery.

The control for this study consists of onsite and offsite unburned areas chosen to best represent the pre-fire conditions of burned areas at the project site. Since there is no data available to assess the chaparral conditions that existed prior to the fire, we assume that vegetation cover (perennial and woody) and litter cover were similar to the reference unburned mature chaparral on and offsite. Target cover goals for recovery based on the data collected from these reference areas could be based on the 95 percent confidence intervals calculated for these parameters in the unburned reference areas. Recovery could thus be assessed when the burned areas reach the levels exhibited by the reference unburned areas in terms of perennial cover (65.5 to 79.5 percent cover), woody cover (63.4 to 78.4 percent cover), and cover of the ground surface by litter (54.4 to 68.4 percent cover; values calculated from those presented in Table D).

Given these metrics for assessing recovery, we estimate that the burned chaparral and scrub vegetation, with its related litter, will likely recover within five to ten years following fire, or between the years 2010 and 2015. Based on the status of the burned areas 18 months following the 2005 fire, the regeneration patterns on the burned areas are consistent with most literature reviewed on development and recovery of chaparral following fires.

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Glossary

abiotic – non-living elements that impact the growth, composition, and structure of the plant community (e.g., soil, climate, topography).

absolute cover (percent) - total distance covered by a plant species on one transect divided by total distance of transect.

allelopathy – the effects of chemicals produced by one plant reducing the germination or growth of another plant.

annual – plant species that completes life cycle (germination through death) in one year or growing season; these plants are typically not woody.

Chaparral - a shrub-dominated plant community found primarily in California, that is shaped by a Mediterranean climate (mild, wet winters and hot dry summers) and wildfire.

charate – product of burned vegetation.

dicot – the subgroup of flowering plants that generally have one to many of the following characteristics: two cotyledons (first leaf that grows from a seed), flower parts in 4's, 5's, or spirals, pinnate or palmate leaf venation, stem veins in rings.

disturbed area – an area that has been temporarily changed in average environmental conditions that causes a pronounced change in ecosystem structure that lasts longer than the change in the environment. Disturbances may be natural or anthropogenic. Examples include fire, grazing, construction, flood, landslide, drought. Ecosystem changes include altered populations or physiological behavior of difference species as they respond to the stressful conditions imposed by the disturbance.

forb - any broadleaf plant that does not have a woody stem.

introduced plants –plant species that are not native to location of discussion (typically used when discussion State and/or Country).

mean – also referred to as the "average", the mean is the sum of the observations divided by the number of observations.

litter – the dead organic matter (fallen leaves, stems and bark) that accumulated below and around plants

monocot – the subgroup of flowering plants that generally have one to many of the following characteristics: one cotyledon (first leaf that grows from a seed), flower parts in 3's, parallel leaf venation, stem veins scattered.

perennial – plant species that live more than two years or growing seasons.

plant community – a collection of plant species that live together on a relatively uniform area of land.

plant crown – top of the plant root system that is present at or just below the soil surface.

riparian habitat – plant communities that live in the area that interfaces between land and a flowing surface water body. Plant species that live in plant communities are often hydrophilic or "water-loving" (e.g. willows, sycamore trees, cottonwood trees).

ruderal – a plant species that is first to colonize a disturbed area. Disturbance can be from natural (e.g. wildfire, landslides, flooding) or man-made causes (e.g. construction, agriculture). Ruderal species may often persist for a few years to decades depending on level of disturbance to the topsoil layer.

scrub – low-lying, woody shrub vegetation.

standing dead – dead branches, elevated off the ground, that are attached to a present live or dead plant crown.

standard deviation – It is defined as the square root of the variance. The standard deviation is the most common measure of statistical dispersion, measuring how widely spread the values in a data set are. If the data points are close to the mean, then the standard deviation is small. Conversely, if many data points are far from the mean, then the standard deviation is large. If all the data values are equal, then the standard deviation is zero.

total cover (percent) – total distance covered by all plant species divided by total distance of transect. Total cover is interchangeable with absolute cover when talking about one plant species.

understory – young trees, shrubs, grasses, and forbs that grow under the large shrubs or tall trees in a forest, woodland, or scrub habitat.

APPENDIX A – DATA FORM

Aspect (degrees, uncorrected)____________________ **Date__________________**

Transect # **Incline_(%)____________________________________** **Data Collected by: _____________________________**

Burned/Unburned (circle one) **GPS Coords: N** **Photo #**

Mulched? ______________________________ **GPS Coords: W** **"Abiotic" - L=litter; LS=litter sparse; M=applied mulch;**

Avg. Height Veg (ft)_______________________ **GPS Elevation (ft):** **R<=rock smaller than 6"; R>=rock larger than 6"; B=bare**

SD=standing dead (dead mature branches)

Transect Location Notes/Miscellaneous Observations (e.g. information on physical conditions of site and presence of other species/seedlings not encounted along transect)

Point along transect (feet)	Abiotic	Species encountered	Point along Transect (feet)	Abiotic	Species Encountered
0			50.0		
1.0			51.0		
2.0			52.0		
3.0			53.0		
4.0			54.0		
5.0			55.0		
6.0			56.0		
7.0			57.0		
8.0			58.0		
9.0			59.0		
10.0			60.0		
11.0			61.0		
12.0			62.0		
13.0			63.0		
14.0			64.0		
15.0			65.0		
16.0			66.0		
17.0			67.0		
18.0			68.0		
19.0			69.0		
20.0			70.0		
21.0			71.0		
22.0			72.0		
23.0			73.0		
24.0			74.0		
25.0			75.0		
26.0			76.0		
27.0			77.0		
28.0			78.0		
29.0			79.0		
30.0			80.0		
31.0			81.0		
32.0			82.0		
33.0			83.0		
34.0			84.0		
35.0			85.0		
36.0			86.0		
37.0			87.0		
38.0			88.0		
39.0			89.0		
40.0			90.0		
41.0			91.0		
42.0			92.0		
43.0			93.0		
44.0			94.0		
45.0			95.0		
46.0			96.0		
47.0			97.0		
48.0			98.0		
49.0			99.0		
			100.0		

APPENDIX B

VASCULAR PLANT SPECIES OBSERVED

The following vascular plant species were observed in the study area by biologist(s) Jeannette Halderrman during site surveys conducted on February 5-9, 2007 and March 26 through April 11, 2007.

* Introduced, nonnative species

PTERIDOPHYTA		**FERNS AND FERN-ALLIES**	
Polypodiaceae		**Wood Fern Family**	
	Pentagramma triangularis		Goldenback fern
	Polypodium californicum		California polypody fern
Pteridaceae		**Brake Family**	
	Pellaea sp.		Coffee fern
Selaginellaceae		**Spike-moss Family**	
	Selaginella bigelovii		Bigelow's spike-moss
ANGIOSPERMAE: DICOTYLEDONAE		**DICOT FLOWERING PLANTS**	
Aizoaceae		**Carpet-weed Family**	
*	*Carpobrotus aequilateralus*		Sea-fig
Apiaceae		**Carrot Family**	
	Apiastrum angustifolium		False parsley
	Sanicula crassicaulis		Pacific sanicle
Anacardiaceae		**Sumac Family**	
	Malosma laurina		Laurel sumac
	Rhus integrifolia		Lemonade berry
	Rhus ovata		Sugar bush
	Toxicodendron diversilobum		Poison oak
Asteraceae		**Sunflower Family**	
	Acourtia microcephala		Sacapellote
	Ambrosia psilostachya		Western ragweed
	Artemisia californica		California sagebrush
	Artemisia douglasiana		Mugwort
	Baccharis pilularis		Coyote bush
	Baccharis salicifolia		Mulefat
	Brickellia californica		California brickellbush
*	*Carduus pycnocephalus*		Italian thistle

*	*Centaurea melitensis*	Tocalote
*	*Conyza bonariensis*	Flax-leaved horseweed
	Conyza canadensis	Common horseweed
	Encelia californica	California encelia
	Eriophyllum confertiflorum var. *confertiflorum*	Golden yarrow
	Gnaphalium bicolor	Bicolored cudweed
	Gnaphalium californicum	California everlasting
	Gnaphalium sp.	Gnaphalium
	Gutierrezia sp.	Matchweed or snakeweed
	Hazardia squarrosa	Saw-toothed goldenbush
	Helianthus gracilentus	Slender sunflower
	Hemizonia minthornii	Santa Susana tarplant
	Heterotheca grandiflora	Telegraph weed
	Heterotheca sessiliflora	Golden aster
*	*Lactuca serriola*	Prickly lettuce
	Lessingia filaginifolia	California aster
	Malacothrix saxatilis var. *tenuifolia*	Cliff malacothrix
	Microseris sp.	Microseris
*	*Senecio vulgaris*	Common grounsel
*	*Silybum marianum*	Milk thistle
*	*Sonchus asper* ssp. *asper*	Prickly sow-thistle
*	*Sonchus oleraceus*	Common sow thistle
	Venegasia carpesoides	Canyon sunflower
Boraginaceae		**Borage Family**
	Amsinckia menziesii	Fiddleneck
	Cryptantha intermedia	Common cryptanth
Brassicaceae		**Mustard Family**
*	*Brassica nigra*	Black mustard
*	*Brassica tournefortii*	Asian mustard
*	*Hirschfeldia incana*	Shortpod mustard
Caprifoliaceae		**Honeysuckle Family**
	Lonicera subspicata var. *denudata*	Southern honeysuckle
	Sambucus mexicana	Mexican elderberry
	Symphoricarpos mollis	Creeping snowberry
Caryophyllaceae		**Pink Family**
*	*Silene gallica*	Common catchfly
*	*Stellaria media*	Common chickweed
Chenopodiaceae		**Goosefoot Family**
*	*Salsola tragus*	Russian-thistle

Cistaceae	**Rock-Rose Family**
Helianthemum scoparium	Peak rush-rose
Convolvulaceae	**Morning-glory Family**
Calystegia macrostegia	Morning-glory
Crassulaceae	**Stonecrop Family**
Dudleya lanceolata	Lance-leaved dudleya
Dudleya pulverulenta ssp. *pulverulenta*	Chalk dudleya
Cucurbitaceae	**Gourd Family**
Marah macrocarpus	Wild cucumber
Ericaceae	**Heath family**
Arctostaphylos glauca	Bigberry manzanita
Euphorbiaceae	**Spurge Family**
Eremocarpus setigerus	Doveweed
Fabaceae	**Legume Family**
Astragalus brauntonii	Braunton's milk-vetch
Lotus salsuginosus	Coastal lotus
Lotus scoparius	California deerweed
Lotus strigosus	Strigose bird's-foot trefoil
Lupinus sp.	Lupine
Trifolium sp.	Trifolium
Vicia sp.	Vetch
Fagaceae	**Beech Family**
Quercus agrifolia var. *agrifolia*	Coast live oak
Quercus berberidifolia	California scrub oak
Geraniaceae	**Geranium Family**
* *Erodium botrys*	Long-beaked filaree
* *Erodium cicutarium*	Red-stemmed filaree
Grossulariaceae	**Gooseberry Family**
Ribes indecorum	White-flowered gooseberry
Ribes malvaceum	Chaparral currant
Hydrophyllaceae	**Waterleaf Family**
Eriodictyon crassifolium	Thick-leaved yerba santa
Eucrypta chrysanthemifolia	Common eucrypta
Nemophila menziesii	Baby blue-eyes
Phacelia cicutaria	Caterpillar phacelia
Phacelia ramosissima	Branching phacelia
Pholistoma aurium	Fiesta flower

Lamiaceae		**Mint Family**	
*	*Marrubium vulgare*		Horehound
	Salvia apiana		White sage
	Salvia columbariae		Chia
	Salvia leucophylla		Purple sage
	Salvia mellifera		Black sage
	Salvia spathacea		Hummingbird sage
	Trichostema lanatum		Woolly blue-curls
Lauraceae		**Laurel Family**	
*	*Persea americana*		Avocado
	Umbellularia californica		California bay laurel
Malvaceae		**Mallow Family**	
	Malacothamnus fasciculatus		Chaparral bush mallow
Myrtaceae		**Myrtle Family**	
*	*Eucalyptus spp.*		Gum
Nyctaginaceae		**Four O'clock Family**	
	Abronia maritima		Red sand-verbena
*	*Bougainvillea* sp.		Bougainvillea
	Mirabilis californica		California wishbone bush
Onagraceae		**Evening Primrose Family**	
	Epilobium sp.		Willow-herb
	Camissonia californica		California sun-cup
Paeoniaceae		**Peony Family**	
	Paeonia californica		California peony
Papaveraceae		**Poppy Family**	
	Dendromecon rigida		Bush poppy
	Dicentra ochroleuca		White ear-drops
	Eschscholzia californica		California poppy
Platanaceae		**Sycamore Family**	
	Platanus racemosa		Western sycamore
Polygonaceae		**Buckwheat Family**	
	Eriogonum sp.		Buckwheat
	Eriogonum fasciculatum		California buckwheat
	Pterostegia drymarioides		Threadstem
*	*Rumex crispus*		Curly dock

	Portulacaceae	**Purslane Family**
	Claytonia parviflora	Miner's lettuce
	Primulaceae	**Primrose Family**
*	*Anagallis arvensis*	Scarlet pimpernel
	Ranunculaceae	**Buttercup Family**
	Clematis sp.	Virgin's bower
	Ranunculus californicus	California buttercup
	Rhamnaceae	**Buckthorn Family**
	Ceanothus crassifolius	Hoaryleaf ceanothus
	Ceanothus thyrsiflorus	Blue blossom
	Rhamnus ilicifolia	Holly-leaved redberry
	Rosaceae	**Rose Family**
	Adenostoma fasciculatum	Chamise
	Cercocarpus betuloides var. *betuloides*	Mountain mahogany
	Heteromeles arbutifolia	Toyon
	Prunus ilicifolia ssp. *ilicifolia*	Holly-leaved cherry
	Rosa californica	California rose
	Rubiaceae	**Bedstraw Family**
	Galium angustifolium	Narrow-leaved bedstraw
	Galium aparine	Goose grass
	Rutaceae	**Rue Family**
*	*Citrus* sp.	Citrus tree
	Salicaceae	**Willow Family**
	Salix laevigata	Red willow
	Salix lasiolepis	Arroyo willow
	Saxifragaceae	**Saxifrage Family**
	Lithophragma affine	Woodland star
	Scrophulariaceae	**Figwort Family**
	Antirrhinum kelloggii	Kellogg's snapdragon
	Antirrhinum multiflorum	Chaparral snapdragon
	Keckiella cordifolia	Heart-leaved bush-penstemon
	Mimulus aurantiacus	Bush monkey flower
	Scrophularia californica	California figwort
	Solanaceae	**Nightshade Family**
*	*Nicotiana glauca*	Tree tobacco
	Solanum xanti	Chaparral nightshade

Urticaceae	**Nettle Family**
Hesperocnide tenella	Western nettle
Verbenaceae	**Vervain Family**
Verbena lasiostachys	Western verbena
ANGIOSPERMAE: MONOCOTYLEDONAE	**MONOCOT FLOWERING PLANTS**
Cyperaceae	**Sedge Family**
Cyperus sp.	Umbrella-sedge
Scirpus sp.	Bulrush
Juncaceae	**Rush Family**
Juncus sp.	Rush
Liliaceae	**Lily Family**
* *Agave americana*	American century plant
Calochortus sp.	Calochortus
Chlorogalum pomeridianum	Wavy-leaved soap plant
Dichelostemma capitatum ssp. *capitatum*	Blue dicks
Yucca whipplei	Our Lord’s candle
Zigadenus fremontii	Death camas
Poaceae	**Grass Family**
Acnatherum aridum	Mormon needlegrass
Acnatherum coronatum	Giant needlegrass
* *Avena barbata*	Slender wild oat
* *Bromus diandrus*	Ripgut grass
* *Bromus hordeaceus*	Soft chess
* *Bromus madritensis* ssp. *rubens*	Foxtail chess
* *Lamarckia aurea*	Goldentop
Leymus condensatus	Giant wild-rye
Melica imperfecta	California melic
Muhlenbergia rigens	California deergrass
Nassella lepida	Foothill needlegrass
Poa secunda ssp. secunda	One-sided bluegrass
* *Polypogon monspeliensis*	Rabbitfoot grass
* *Vulpia myuros*	Rat-tail fescue
Typhaceae	**Cat-tail Family**
Typha sp.	Cat-tail

Taxonomy and scientific nomenclature conform to Hickman (1993). Common names for each taxa generally conform to Roberts (1998), although Abrams (1923, 1944, 1951) and Abrams and Ferris (1960) are used, particularly when species specific common names are not identified in Roberts (1998).