**Restoration of *A. fasciculatum* at Rocky Canyon Granite
Quarry, San Luis Obispo, CA**

A Thesis
presented to
the Faculty of California Polytechnic State University,
San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Biological Sciences

by
Catherine Lorene Roy
August 2009

© 2008
Writer's Full Name
ALL RIGHTS RESERVED

COMMITTEE MEMBERSHIP

TITLE: Restoration of *A. fasciculatum* at Rocky Canyon Granite Quarry, San Luis Obispo, CA

AUTHOR: Catherine Lorene Roy

DATE SUBMITTED: August 2009

COMMITTEE CHAIR: V L Holland, Professor Emeritus

COMMITTEE MEMBER: Andrew Schaffner, Professor

COMMITTEE MEMBER: Matthew Ritter, Associate Professor

ABSTRACT

Restoration of *A. fasciculatum* at Rocky Canyon Granite Quarry, San Luis Obispo, CA
Catherine Lorene Roy

The objective of this study was to assess the above-ground factors affecting the establishment and recovery of the dominant chaparral shrub *Adenostoma fasciculatum* (chamise) on the Rocky Canyon granite mine.

Attempts to restore the California chaparral have been challenging and few successful efforts have been documented. However, the California chaparral can fully recover from fire in as little as 10-15 years. Factors affecting chamise seedling establishment were tested by planting chamise seed in forty eight 1square meter plots managed to test the effects of interspecific competition with native postfire vegetation, post-mining volunteer vegetation, and intraspecific only competition. Plots were managed and observed from December 2004 to May 2006. Half of the 48 plots were summer irrigated throughout the first growing season to test the addition of water on growth and survivability. Nearly all chamise seedlings exposed to competition from either native or non-native vegetation perished within the first summer. Seedlings in plots where interspecific competition was removed experienced significantly higher germination and higher survival. Seedlings in the irrigated plots with competition removed, grew on average 18cm taller and had 27% more coverage per plot than non-irrigated with competition removed. They were also 4 times more likely to survive. The results of this study clearly show that chamise seedlings are not strong competitors when exposed to either native herbaceous post-fire vegetation or non-native weedy vegetation. Restoration of chamise at Rocky Canyon will require removal of all competing species during the first year of establishment. Irrigation is not required for successful germination and establishment but will result in higher survival and faster growth.

Keywords: *Adenostoma fasciculatum*, chamise, restoration, fire, competition, mine, establishment

ACKNOWLEDGMENTS

I would like to acknowledge my appreciation to my advisor, Dr. VL Holland for introducing me to Rocky Canyon, encouraging me along the way, and patiently editing my paper. I would like to acknowledge Dr. Andrew Schaffner for providing his statistical expertise in the study layout and results, and Dr. Matt Ritter for his enthusiasm and support.

I would also like to acknowledge Union Asphalt for their funding for this project, cooperation, and genuine interest in restoration that made this research possible.

My Father, Dr. Gail Billings patiently and thoughtfully edited my paper while my loving Mother, Lorene Billings cared for my rambunctious toddler so I could finish this work. Eric Roy my husband has donated many hours of manual labor setting up the study and has supported me along the way. Stephanie Scolari's research in chamise seed germination at Rocky Canyon provided a base for this research and her input at the beginning of the study was invaluable.

TABLE OF CONTENTS

	Page
LIST OF TABLES (if applicable)	vii
LIST OF FIGURES (if applicable)	viii
CHAPTER	
I. INTRODUCTION	
Purpose of Study	1
Study Site	1
Revegetation and Restoration	2
Climate	4
Soils	6
California Chaparral	8
Fire and Succession in the Chaparral	10
Factors Effecting Post-fire Shrub Establishment	15
Restoration Challenges	17
II. MATERIALS AND METHODS	20
III. RESULTS	
Germination	27
Mortality	32
Growth	37
IV. DISCUSSION AND CONCLUSIONS	
Reasons for inability to compete	44
Inter-specific vs. Intra-specific Competition	43
Effects of Additional Summer Water	48
Three Year Follow-up 2008	48
Herbivory	51
Effects of Precipitation During the Study	52
Comparison of the Rocky Canyon Quarry Restoration Project to the Post-fire Environment.....	53
Suggested Restoration Strategies for Rocky Canyon Chaparral	54
Conclusions	59
BIBLIOGRAPHY.....	62
APPENDICES	
A. Distribution of Chaparral in California	65
B. List of Herb Species, Treatments, and Amounts Planted with Planted with Chamise in Post-fire Herb Plots.....	66
C. Study Layout.....	67
D. Species germinated in Volunteer plots.....	68
E. Germination and Mortality Data for Each Plot.....	69

LIST OF TABLES

Table		Page
1.	Number of plots per treatment type.....	22
2.	Native herb species planted in herb plots with chamise.....	23
3.	Monthly mean values for bare and bare irrigated plots.....	39

LIST OF FIGURES

Figure	Page
1.Monthly average maximum and minimum temperatures with extreme temperatures at RCQ from 1901 to 2007.....	5
2. Average annual precipitation by growing season for Paso Robles from 1993 to 2008.....	6
3. Total Chamise germinated in all the three seed treatments.....	28
4. Total Chamise germinated in all treatments irrigation included.....	29
5. Mean number of new chamise seedlings germinated in the bare, volunteer, and herb plots.....	30
6. Herb plot "M" in April 2005.....	31
7. Volunteer plot "5" in April.....	32
8. Final Survivorship of chamise in all treatments.....	34
9. Timing and season of chamise mortality.....	35
10. Volunteer plot 20.....	36
11. Herb irrigated plot "S".....	36
12. Bare plot "2".....	37
13. Mean Area and height for all chamise in the bare plots that were irrigated and not irrigated.....	40
14. Images comparing bare plot "2" (top two pictures) and bare-irrigated plot "T".....	41-43
15. Dense competition in bare-irrigated plot.....	47
16. Images of a bare-irrigated plot (top) and a bare plot (bottom) in spring 2008.....	50-51
17. Image of an herb plot in July 2005.....	

Purpose of Study

The objective of this study was to assess the factors affecting seed germination and establishment of chamise on mined slopes. I examined the ability of chamise to compete with native post-fire herbaceous and weedy post-mining plant species to discover how to enhance seed germination and seedling establishment, and understand seed timing on disturbed sites in Rocky Canyon Quarry. I also examined the effects of addition of summer irrigation on growth and survival of chamise seedlings. I attempted to discover a successful method to efficiently re-establish chamise on the mined slopes of Rocky Canyon and to create a native chaparral community that would be self-sustaining and blend in with the undisturbed native chaparral communities surrounding the site. This information will contribute significantly to restoration of chaparral communities on this and other mines and quarries.

Study Site

Rocky Canyon Quarry (RCQ) is a 200-acre granite mine quarry located in San Luis Obispo County approximately two miles east of Atascadero. It is situated in the Santa Lucia Mountains at elevations that range from 1,000 to 1,600 ft. Rocky Canyon is an east-to-west trending valley with Rocky Canyon Creek, a seasonal creek, flowing through it toward the Salinas River. The terrain is relatively flat along Rocky Canyon and along Rocky Canyon Creek; however, steep, granite hillsides border

the canyon and creek on both its north and south sides. Prior to mining, the native vegetation of RCQ consisted of chamise-dominated chaparral on the steep, dry slopes, foothill woodland in the valleys and moist north and east facing slopes, and riparian woodland along Rocky Canyon Creek. Coastal scrub is also on the site but is a minor component of the overall vegetation cover. This study is directed at establishing chamise on one of the mines' steep Southwest facing slopes that has been reclaimed by grading and topsoil replacement.

Revegetation and Restoration

Historically, there were few regulations requiring re-vegetation of old mines and quarries. As a result, several areas mined in the 1940s remain mostly barren and un-vegetated (Holland, 1993). Even at RCQ, early attempts to re-vegetate mined sites consisted of planting non-native pines (*Pinus* spp.) on the flat terraces between barren vertical cliffs that had been mined. However, restoration efforts have changed significantly in the last 20 years. The Surface Mining and Reclamation Act (SMARA) of 1975, required RCQ to restore and re-vegetate mined areas to a vegetation cover that is structurally and functionally similar to their native, pre-disturbance condition (Bernstein, 1999).

In 1993, V. L. Holland developed a Restoration and Re-vegetation Plan for RCQ that has been implemented for the quarry since that time. In general, the plan requires mine operators to remove all vegetation and

topsoil from each site prior to mining and stockpile it for future use. Then, after excavating the granite, operators must redistribute the stockpiled soil and plant materials over the slopes to a depth of at least 4 inches (10 centimeters). These slopes are then hydroseeded with a mixture of native grasses, forbs, and shrubs. Container stock plants are also planted in some locations on the slopes to supplement the seeding.

The design of the quarry, after mining, has resulted in a series of steep, mined granite slopes separated by flat terraces that extend downslope from the top to the bottom of the hill. The steepness of the slopes varies, but most slopes are approximately 2:1.

The re-vegetation goals of RCQ are: (1) replace topsoil, (2) control erosion, (3) promote natural succession from surrounding areas, (4) enhance recovery by seeding with native plant species and establishing native vegetation that is genetically and ecologically compatible with surrounding vegetation in composition and structure, and (5) reestablish self-sustaining native plant communities that naturally blend with the surrounding native vegetation (Holland, 1993).

Since 1993, V. L. Holland and many Cal Poly students have worked with Union Asphalt to successfully meet the restoration and re-vegetation requirements at RCQ. This work has been sponsored by grants provided to Cal Poly by Union Asphalt.

Climate

RCQ has a semi-arid Mediterranean climate characterized by hot, dry summers and cool, moist winters. Average summer high temperatures are near 90°F, and average low temperatures near 50° (Figure 1). Fall and winter are dramatically cooler with average high temperatures of 65°F and average low temperatures 35°F. Almost all precipitation occurs during the fall and winter and generally peaks near the end of winter. The Morro Group (1995) estimated that RCQ averages 18 inches of precipitation annually based on county precipitation maps. However, precipitation totals can differ significantly from one year to the next. Figure 2 shows the average precipitation from 1993 to 2008 at the Paso Robles weather station. Since RCQ does not have an active weather station; current weather data was obtained from the nearest stations in Santa Margarita, Atascadero, and Paso Robles.

Figure 1. Monthly average maximum and minimum temperatures with extreme temperatures at RCQ from 1901 to 2007 (NOAA WRCC, 2007).

Figure 2. Average annual precipitation by growing season for Paso Robles from 1993 to 2008. RCQ has similar precipitation patterns; so these data are useful in showing the various dry and wet years over the last 15 years (NOAA WRCC 2008b, The Weather Channel, 2008a). During restoration at RCQ (December 2004 to May 2006) annual precipitation was higher than average.

Soils

The soils of RCQ have not been studied in detail. The United States Department of Agriculture Soil Conservation Service (1983) roughly mapped San Luis Obispo County. In 1992, the Soil and Plant Laboratory Inc. of San Ramon, California completed soil evaluations for the Oak Woodland Restoration site at RCQ (Morro Group, 1995). The details of both surveys are included below.

The Soil Conservation Service identified coarse sandy loams derived from decomposed granite between 1,000 and 2,500 feet in the area of Rocky Canyon Quarry. Three groups of coarse sandy loam were found: (1) Vista, (2) Cieneba, and (3) Cieneba-Andregg. These three groups are closely related and occur together frequently. The Conservation Service determined that these soils have low water holding capacity and low fertility. They are all moderately permeable, can accumulate 2 to 6 inches of water per hour, and have very low available water capacity. Organic matter is less than 1% for all three. These are generally used for rangeland, but Cieneba is poorly suited for this purpose (USDA, 1983).

Soil samples collected from the oak woodland plots were analyzed by The Soil and Plant Laboratory in 1992. These soils developed on decomposed granite that was used to shape the oak woodland plots. Soil development had occurred for two years when these samples were taken. Results differ somewhat from the native soils described by the Soil Conservation Service (1983). While the Soil Conservation Service found native soils have a pH from 5.6 to 7.1, the Soil and Plant Laboratory found a pH of the soils on the decomposed granite between 4 and 4.7. The Soils Conservation Service did not identify any soils near the region of RCQ with pH less than 5.6. Organic levels were within the range described by Soil Conservation Service, but they were quite low (0.3%).

California Chaparral

The California chaparral is a dynamic and diverse plant community that has been of interest to botanists and ecologists for many years. Chaparral covers roughly 9% of the state of California and is distributed from the Baja peninsula to Southern Oregon (See Appendix A), (Holland and Keil 1995). It is home to a high number of California endemic plant species, many of which are rare plants.

Chaparral is defined as dense shrublands dominated by sclerophyllous shrubs reaching 2-4 m in height. These communities range from having a high diversity of shrub species to stands dominated by one or two shrubs. The dominant shrubs are evergreen, with small sclerophyllous, heavily cutinized leaves (Cooper 1922). There is usually little to no understory in the mature chaparral (Hanes 1977). The term "hard" chaparral is used to differentiate chaparral dominated by tall, stiff, woody vegetation from the closely associated coastal scrub or coastal sage scrub. Most of the dominant plants in coastal scrub are comparatively soft-stemmed shrubs that undergo significant dieback during the summer drought. For this reason, coastal scrub is sometimes referred to as "soft chaparral" as opposed to the "hard chaparral" or "true chaparral" (Holland and Keil 1995). At Rocky Canyon both hard and soft chaparral are present, although hard chaparral is most common on the steeper, drier slopes.

Chaparral communities are typically found in areas with Mediterranean climates described by wet mild winters followed by hot

summers with prolonged summer drought (Hanes 1977) like those found at Rocky Canyon. They are usually found on dry slopes with shallow, rocky soils. These soils lack essential plant nutrients and have varying levels of soil litter. Although chaparral inhabits mostly rocky soils it is also found on a variety of substrates including stabilized dunes, and serpentine (Holland and Keil 1995). Waxes and resins released from decomposing leaf litter can coat soil particles, causing the soil to be hydrophobic (Hanes, 1977). Shallow soils, hydrophobicity, steep slopes and summer drought result in very little available water for chaparral flora. This is offset by the ability of many chaparral species to reach their roots far below the soil layer to depths greater than 8.5 m and form mattes of feeder roots within fine cracks of the bedrock (Jones and Graham 1993).

Chaparral is abundant on the many steep, exposed hillsides that surround the quarry and approximately 54% (140 acres) of the excavation area was originally covered by chaparral (Holland, 1996). While the species composition and structure in the chaparral vary, in general the most common shrub in the chaparral in Rocky Canyon is *Adenostoma fasciculatum*. In many areas, it is virtually the only shrub present. This type of chaparral community is sometimes referred to as chamisal chaparral. Other shrubs scattered within the chaparral include *Ceanothus cuneatus* (buckbrush), *Dendromecon rigida* (bush poppy) and *Arctostaphylos glauca* (big berry manzanita) (Holland 1996). At Rocky Canyon, understory species include exotic grasses such as *Avena* ssp.

(wild oats), *Bromus hordeaceus* (soft chess brome), *Bromus madritensis rubens* (red brome), as well as native grasses such as *Melica imperfecta* (melic grass) and *Nassella* spp. (needlegrass).

Fire and Succession in the Chaparral

Restoration of the California chaparral requires an understanding of the complex and dynamic nature of chaparral succession. Knowledge of the principles of rapid post-fire recovery may help the restoration ecologist speed and enhance chaparral recovery after human disturbance. Complete restoration requires not just a snapshot picture of the dominant species restored on the hillside, but also a restoration of successional plants so that chaparral will proceed in a natural succession in the event of disturbance such as fire. Here, I have included a discussion on chaparral fire succession as background to this study.

Fire is a dominant ecological and evolutionary selective force in the chaparral and has been for the last 2 million years (Axelrod 1958, Hanes 1977). Significant seedling establishment only occurs in the first few years following fire because of the requirement of most chaparral species to have fire related cues for regeneration (Tyler 1995, Hanes 1971, Keeley 1981). Chaparral fires typically occur in late summer and early fall, and are usually stand-replacing crown fires that destroy all above ground biomass (Keeley and Fotheringham 2001). The intervals between chaparral fires vary significantly; therefore, they are not considered cyclic.

The average interval is 40 to 60 years, but unburned stands over 50 years old are not uncommon (Keeley 1987, Hanes 1970).

Fire succession has been studied thoroughly and a well-documented pattern has been described. The vegetation in the first growing season after fire is characterized by a flush of herbaceous growth composed of plant species that were generally not present in the mature chaparral prior to the fire (Hanes, 1977). Keeley et al. (1981) described four major types of herbaceous vegetation that occur in the chaparral immediately after a fire.

1. *Generalized herbaceous perennials* occur as scattered individuals in mature chaparral and rarely flower. When a fire passes through, they are usually spared because the fire does not kill underground bulbs or rhizomes buried deep beneath the soil. After fire, they vigorously sprout and nearly all flower. Examples of this group include monocots such as *Allium*, *Calochortus*, and *Brodiaea* and vines such as *Convolvulus spp.*
2. *Generalized annuals* occur on rock outcrops and openings in mature chaparral and have enhanced seed germination when exposed to increased soil temperature from fire or heating by sun exposure. Examples are *Cryptantha intermedia*, *Gilia sp.*, and *Eschscholzia californica*.
3. *Fire annuals* occur in greatest abundance in the first post-fire year and are usually absent in the following years. The seeds of these

species lie dormant in the soil seed bank and require fire effects (heat, smoke, charate, etc.) to break dormancy and germinate.

Examples of fire annuals are: *Emmenanthe penduliflora*, and *Phaecelia brachyloba*.

4. *Fire perennials*, such as *Lotus scoparius*, *Helianthemum scoparium*, and *Eriophyllum confertiflorum*, are rarely found in the mature chaparral but are common following fire because of enhanced seed germination. They generally reach their maximum population size in the third or fourth year after fire.

Chaparral shrubs are also highly adapted to fire and have evolved many characteristics that ensure post-fire regeneration. Shrubs that are obligate seeders such as some species of *Ceanothus*, are killed by fire and rely on seeds for re-establishment. Often the seeds remain dormant in the seedbank for many years and respond to fire related cues such as heat, smoke, and charate to sprout after fire (Keeley, 1987). 'Resprouters' such as *Heteromoles arbutifolia*, *Prunus ilicifolia* and *Rhamnus californica*, rely on woody structures such as lignotubers and basal burls to resprout after fire. Their seeds are non-refractory (do not require treatment for germination), and are usually destroyed by fire. Many shrubs such as *Adenostoma fasciculatum* and some species of *Arctostaphylos* are considered 'facultative seeders' because they have the ability to resprout

after fire but will also establish numerous post-fire seedlings (Holland and Keil 1995).

In the first post-fire growing season the germination flush of shrubs is offset by high shrub seedling mortality. Kummerow et. al. (1985) reported mortality rates of 90% and 92% respectively for *Adenostoma fasciculatum* and *Ceanothus greggii* seedlings during the first post fire year. Moreno and Oechel (1992) found *Adenostoma fasciculatum* seedling mortality to be 92.7% from initial germination to the following spring. Beyond the first post-fire growing season, there is very little seed recruitment especially among the dominant chaparral shrub species present in the mature chaparral (*Cooper 1922; Hanes 1971; Keeley 1977*). It will be shown that the results of my study are consistent with these findings.

During the first 10 years after fire, the initial flush of herbaceous vegetation is replaced by short-lived shrub and sub-shrub species such as *Salvia mellifera*, *Lotus scoparius*, and *Eriogonum fasciculatum*. These short-lived species slowly die out as a result of competition with the chaparral-dominant shrubs such as *Adenostoma fasciculatum* and *Ceanothus spp.* Other shrubs such as *Trichostemma lanatum* and *Dendromecon rigida* may have a significant presence in the maturing chaparral but are short lived and decrease in numbers as the chaparral matures. Site conditions such as altitude, slope, aspect, and pre-fire shrub composition result in variations in the rate of chaparral recovery and

composition of mature chaparral (Hanes 1971). Under favorable conditions, mature chaparral can recover from fire in as little as 10-15 years (Schlesinger and Gill 1978).

Factors Effecting Post-fire Shrub Establishment

There are several factors that influence the establishment of shrubs in post fire chaparral. Perhaps the most significant are fire intensity, herbivory, water characteristics, and soil nutrient levels. Most of these studies have focused on *Adenostoma fasciculatum* (chamise) and *Ceanothus* spp. because they are often dominant in the California chaparral.

Chaparral vegetation patterns vary in response to fire intensity (Moreno & Oechel, 1991) (Odion, 2000). After a low intensity fire a flush of herbaceous and shrub seedlings germinate and densely cover the ground. In this environment, there is high competition for light, water, and nutrient resources. Chamise seedlings readily become established, whereas *Ceanothus* spp (*Ceanothus*). quickly decline. In a high intensity fire, many seeds including chamise and herbaceous species located near the soil surface are heated past their germination threshold and are unable to sprout. In contrast, *Ceanothus*. seeds have been demonstrated to have a higher threshold for heating and are usually buried deeper in the soil. In this environment, *Ceanothus* seeds germinate readily and because there is less competing vegetation, often become established and form the dominant shrub cover in the mature chaparral (Moreno & Oechel, 1991, 1993).

Herbivory is another variable affecting shrub establishment in chaparral. Immediately following a fire, the number of small herbivorous animals in the area is greatly reduced (Christensen and Muller 1975). However, in the first and second years following fire mammalian herbivores move into the burned chaparral stands and feed on the lush vegetation, including seedlings of chamise and *Ceanothus*. As a result, these shrubs experience significant seedling mortality. Small mammal herbivores such as rabbits and mice, have been shown to have the greatest effect on seedling mortality, preferring *Ceanothus* seedlings to chamise (Mills 1983).

The effects of herbivory by insects are not as clear. Two studies in chaparral near San Diego report conflicting results. Mills (1983) found that insects do not cause significant mortality while Moreno & Oechel (1992) found they do. This is likely a result of differences in the specific habitat and vegetation characteristics such as shrub density, species composition, and physical features such as soil, temperature, and moisture.

Water availability is also an important factor in determining establishment success of chaparral following fire. Kummerow et. al. (1985) found drought to be the main cause of shrub seedling mortality in the first year following fire. Seedlings of chamise are particularly vulnerable to dehydration in the first year because their roots are located in the first 10-15 cm of soil, and they must compete with the dense growth of herbaceous plants. Moreno and Oechel (1992) reported a significant level

of first year seedling mortality related to drought. This is especially true with the shallow-rooted seedlings of chamise, a facultative seeder. Whereas species of *Ceanothus*, which have deeper seedling roots, have a lower drought related mortality rate because their roots reach the deeper soil water. It is interesting to note however, that seedlings of chamise did not show any mortality due to competition from the associated fire-following herbaceous vegetation (Moreno and Oechel 1988).

Effects of fire on soil characteristics also affect seedling establishment and chaparral recovery. It has been shown that chamise produces phytotoxins that inhibit seed germination and seedling growth in competing species. These chemicals are burned and destroyed during fire, setting the stage for enhanced chamise seed germination. (Muller, 1968; Christensen & Muller, 1969). In addition, soil nutrients held in dead wood and leaf litter become mobilized and available for plant uptake after a burn, and soil pH is increased as ash is deposited on the soil surface. These and other effects of fire on soil have been tested and reported by Christensen & Muller (1975).

Restoration Challenges

Although chaparral can recover from fire in 10-15 years, few successful cases of chaparral restoration have been documented in areas of human disturbances such as mining. There are several possible explanations for this lack of success. First, most chaparral species,

particularly the dominant shrubs, have very specific germination requirements triggered by the conditions of fire. The germination requirements of most of these species have been documented, but low field germination persists. Even after germination, climatic factors such as prolonged summer drought, non-native weed competition, and herbivory can drastically reduce shrub survival and chaparral recovery.

At RCQ the use of container stock plants has been successful on relatively flat accessible sites where planting and maintaining the plants is easily accomplished. However, many of these transplants are growing slowly and appear stunted. This has also been reported in other restoration projects using transplants of chaparral species (Young and Evans 2000). In addition, planted container stock plants to date, show few signs of regenerating new plants, possibly because they have not yet produced many seeds. Mid-succession species such as *Eriogonum fasciculatum*, *Lotus scoparius*, and *Salvia mellifera* are successfully establishing themselves from seed, but few seedlings of chaparral dominants such as *Ceanothus cuneatus* and chamise have been observed to date.

Container stock plants may not be a viable option on a large scale where mined slopes are steep (2:1 and steeper). The shallow rocky soils on the slopes make digging and transplanting time-consuming and very difficult. Only small transplant plugs that require immediate and regular irrigation are feasible. Container stock plants are also somewhat expensive to grow and maintain in the nursery and in the field. If not

grown properly and planted in a timely manner, container stock plants can develop deformed roots that permanently reduce the plant's ability to adapt to summer drought conditions (Young and Evans 2000). Another factor to consider is that starts for transplants, if not from the local plants may be genetically different from those on site and may be detrimental to local genetic stock (Montalvo and Ellstrand 2000).

Seeding mined slopes is the best method of revegetation if seed germination and seedling establishment can be successful. Seeding is a natural regeneration method for most dominant chaparral species following fire. It is an easy way to introduce the full diversity of chaparral species and restore a native seed bank that can potentially compete with non-native vegetation. Once established, these plants should be able to produce seeds and naturally regenerate following fire. Another benefit of seeding is that it is easy to collect seed from adjacent undisturbed areas on the site. This maintains the genetic integrity of species that have evolved in that particular location. Lastly, if germination is successful, many seedlings will emerge and undergo natural thinning, leaving the most successful and best-suited plants for that particular location.

Materials and Methods

My experimental design was established to differentiate the factors that influence seed germination and seedling establishment of chamise on mined slopes on RCQ. Quarry. A total of 48 one-square-meter plots were established in the Rocky Canyon Granite Quarry on a 2:1 mined slope with a southwest exposure. This slope was configured in 1999 following the removal of the granite. The experimental plan had a split plot design with irrigation as the whole plot factor and seed and planting treatments as subplot factors (Appendix B). The 48 plots were raked clear of existing surface vegetation and bordered with plastic 8mm-thick garden edging pushed into the soil. The plastic edging was installed to reduce the encroachment of roots from outside the plots.

In December 2004, the plots were planted by gently raking in chamise seeds and the seeds of 9 native herb species used in the study. All 10 species of seeds were covered approximately ¼ inch beneath the soil surface. Prior to planting, the seeds of chamise were treated with smoke for 5 minutes in a turkey smoker using dry chamise wood to simulate smoky post fire conditions. This treatment was used because it was shown to enhance seed germination by Stephanie Scolari (2003) in her work at Rocky Canyon. The chamise seeds were then planted in the experimental plots at a rate of 4.73 grams/plot (approximately 3000 seeds per plot).

Experiments were designed to determine the effects of native fire herbs or invasive weedy plants on the seed germination and seedling

establishment of chamise. Sixteen plots were planted with a native seed mixture containing nine species common to the area and associated locally with early post fire flora. These plots are herein called “herb” plots. Eight of the herb plots received summer irrigation and eight did not (Table 1). The proportion of annuals to perennials in the native seed mixture was typical of that reported after fire in previous studies (Keeley 1981). Each species was treated specifically for fire-stimulated germination requirements (Table 2), and planted in approximately equal densities. The seed amounts in the table below vary as shown, due to differences in individual seed weight (Appendix C). The species used for the seed mixture were selected from those native to Rocky Canyon, or a nearby fire site on Cuesta Grade and described as being common in the immediate post-fire environment (Keeley 1981). Study plots planted with the native-herb treatment were weeded weekly from December 2004 to November 2005 of all seedlings that were not of the ten species. This time frame corresponds with the first growing season from germination to establishment.

Treatment	Number of Plots
Chamise + Herbs	8
Chamise + Herbs +Irrigation	8
Chamise + Volunteer	8
Chamise + Volunteer + Irrigation	8
Chamise only	8
Chamise only + Irrigation	8
Total	48

Table 1. Number of plots per treatment type.

List of Herb Species Planted with Chamise in Post-fire Herb Plots

Species	Life Form	Treatment	Amount Seeded g/M ²
<i>Emmenanthe penduliflora</i>	Annual	Smoke 5 min.	.54
<i>Phacelia brachyloba</i>	Annual	Smoke 5 min.	.54
<i>Phacelia parryi</i>	Annual	Smoke 5 min.	.54
<i>Lupinus hirsutissimus</i>	Annual	No treatment	.81
<i>Lupinus nanus</i>	Annual	No treatment	1.1
<i>Antirrhinum multiflorum</i>	Annual, Perennial	Smoke 5 min.	.54
<i>Lotus scoparius</i>	Perennial, Subshrub	½ smoked 5 min, ½ no treatment	1.6
<i>Helianthemum scoparium</i>	Perennial, Subshrub	Smoke 5 min.	.54
<i>Eriophyllum confertiflorum</i>	Perennial, Subshrub	½ smoked 5 min, ½ no treatment	.54

Table 2. Native herb species planted in herb plots with chamise. All species are commonly associated with native post-fire flora (Jepson 1993), (Keeley 1981) and were identified at Rocky Canyon or a nearby fire site on Cuesta Grade.

Another 16 plots were planted only with chamise seeds and were not weeded. Plants in the existing seed bank or from seeds blown in from surrounding areas were allowed to grow naturally in these plots. The volunteer vegetation that developed in these plots was mostly composed of

the invasive, weedy grasses and forbs that become established on mined slopes in Rocky Canyon following disturbances. These species were allowed to develop on these 16 plots naturally and compete with the chamise seedlings. Eight of these plots were summer irrigated and eight were not (Table 1). These plots simulate the way chamise seedlings would be competing if no native seeding or weed control occurred on the mined slopes. These plots are referred to as the "volunteer" plots.

The final 16 plots were only planted with chamise seeds. These plots were maintained weekly from December 2004 to November 2005 by carefully removing all seedlings except those of chamise with minimal disturbance of the soil surface. There was no interspecific competition with native or introduced grasses and forbs on these plots. They are referred to as the "bare" plots. Eight of these plots were summer irrigated and eight were not.

Drought can be a significant factor in seedling mortality after fire (Kummerow, 1985) and may affect chamise establishment on the barren slopes at Rocky Canyon. To test the effects of summer irrigation on first year establishment, I summer irrigated half the plots in each of the three treatments described above (Table 1). These plots were irrigated with one 320° spray emitter per plot for 30 minutes once a week starting in mid April 2005 and continuing through November 15, 2005. These dates correlate with the time between the first two-week period without rain in the spring, and the first soil-saturating rain in the fall. All irrigated plots

were located down slope from the non-irrigated plots to prevent water from draining down the slope and affecting the non-irrigated plots.

To make sure I could identify the seedlings of chamise and the nine native herb species, I gave them the smoke treatment described previously and planted them in the California Polytechnic Plant Conservatory greenhouse before starting my field studies. They were monitored for germination to guarantee the effectiveness of seed treatments, and photographed so that the seedlings could be readily identified and distinguished from emerging weed seedlings on the study site.

Beginning in January 2005, the plots were sampled weekly to determine seed germination and number of chamise seedlings in the plots. Germination rates were determined by manually counting each seedling and noting any newly emerged or expired individuals. Beginning in May, 2005, survivorship and mortality rates were measured by flagging and labeling each individual seedling with masking tape wrapped around a pin and inserted in the soil near the seedling. When an individual reached a minimum of 2cm, height was measured using a measuring tape extended from the soil surface to the apex of the dominant meristem. Horizontal area was determined by measuring diameters on transverse major and minor axes and computing areas as $[(d1*d2)/4]*\pi$. Each seedling was measured every month until the end of the study except December and January of the 2005/2006 winter due to the inability to access the study

site during these months. Data was collected throughout the first growing season in 2005 and through spring 2006.

Results

Germination

This section covers germination of chamise in spring 2005. Since chamise germination was finished before summer irrigation began, irrigation was not a factor in germination results.

Heavy rain in spring 2005 resulted in excellent seed germination for many species on the study site. Chamise seeds germinated in all 48 plots. Significant differences in chamise seed germination were found among the bare, herb, and volunteer plots ($F_{2,44}=8.494$, overall $P=0.001$) (Figure 3). Germination rates in the bare plots were significantly higher than those in the herb and volunteer plots ($t_{44}=-2.782$, $P=0.008$, and $t_{44}=-3.958$, $P=0.0003$ respectively). Odds of chamise seed germination in the herb plots was only 67% of the germination in the bare plots. In the volunteer plots odds of germination was only 54% of that in the bare plots. The slightly higher germination in herb plots compared to volunteer plots was not statistically significant ($t_{44}=1.25$, $P=0.219$).

Although supplemental irrigation was not started until April 2005, which was after germination was essentially complete, the plots designated to be irrigated, showed 8%, 9%, and 10% higher odds of germination rates in the volunteer, herb, and bare treatments respectively (Figure 4). In order to ascertain whether or not the slightly increased germination in the irrigated plots might have been the result of uncontrolled advantageous environmental conditions, an overdispersed

binomial regression analysis (See Appendix E) was applied comparing germination in all plots. The results of this analysis implied that these differences were not statistically significant ($F_{1,44}=2.278$, $P=0.138$).

Figure 3. Total Chamise germinated in the three seed treatments with irrigation excluded, from 4.73 grams of seed (approximately 3000 seeds).

Figure 4. Total chamise germinated in all treatments, with irrigation included, from 4.73 g of seed (approximately 3000 seeds). Higher germination was observed in plots designated to be irrigated before irrigation had begun. This difference was not significant ($P=0.138$)

The timing of seed germination varied widely for all species. The non-native grasses and forbs germinated quickly (December 2004) and continued to germinate throughout the winter and spring, whereas the native herb species that were seeded in the plots, did not begin to germinate until January 2005, about a month later.

The first chamise seedlings emerged in early February 2005 (Figure 4) after most species in the volunteer and herb plots had germinated and were growing vigorously. By mid March 2005, chamise seeds were still germinating. At this time *Erodium cicutarium* was seeding prolifically and weedy grasses such as *Avena fatua*, and *Bromus* spp. were over 3 feet tall and in full flower. Figure 6 shows a typical herb plot photographed in April 2005 illustrating the rapid growth of the planted herbaceous native vegetation such as *Lupinus hirsutissimus*. Under the lush vegetation in this plot, 23 chamise seedlings have germinated. Other native fire associated species such as *Emmenanthe penduliflora*, *Eriophyllum confertiflorum*, and *Lotus scoparius* also had strong germination in the herb plots. Figure 7 shows a typical volunteer plot photographed at the same time. The annual grasses *Avena fatua* and *Bromus madritensis* dominate. Eight chamise seedlings have germinated in this plot.

Chamise seed germination peaked in late February and early March 2005 and continued through April 2005 (Figure 5). After April 2005, no more chamise seeds germinated. This cessation is consistent with germination data reported by Keeley (1987) who found that chamise seedlings are recruited mainly in the first year following fire.

Figure 5. Mean number of new chamise seedlings germinated in the bare, volunteer, and herb plots over time.

Figure 6. Herb plot "M" in April 2005, showing *Lupinus hirsutissimus* and *Lupinus nanus*, which grew quickly and dominated the plant cover. Twenty three chamise seedlings have germinated and are growing beneath the lush herbaceous foliage in this plot.

Figure 7. Volunteer plot "5" in April. Grasses dominate. Mostly *Avena fatua* and *Bromus madritensis*. Prostrate *Polygonum aviculare* also covered many plots and *Erodium cicutarium* was seeding prolifically. Eight chamise seedlings have germinated and are growing beneath the grasses.

Mortality

This section covers mortality defined as seedling demise after germination. It includes data from chamise germination in spring 2005 through the end of the study in March 2006, during which time water was provided to the irrigated plots in summer 2005. Figure 7 shows the results of mortality over the entire study.

By late April 2005, many chamise seedlings in the volunteer plots were turning purple and drying out. By June the annual species in both the herb and volunteer plots were dry and beginning to decay, and

perennial species emerged beneath the dry annual vegetation and dominated the plot (See photographs, Figures 9 and 10). Chamise seedlings in both the volunteer and herb plots grew very slowly even after the reduced competition from declining annuals and shading from summer heat by newly emerged perennial species and decaying annual vegetation. By August 2005, there was very low survival in any treatment where chamise was competing with other species. In the non-irrigated herb plots there were no survivors, four survived in the irrigated herb plots, one in the non-irrigated volunteer plots, and five in the irrigated volunteer plots. In contrast, 49 chamise seedlings survived in the non-irrigated bare plots and 112 in the irrigated bare plots (Figure 8). A logistic regression analysis showed that the odds of death for chamise seedlings was over 50 times greater likely to die in the herb and volunteer plots than in the bare plots ($X^2_2=269.88$, $P<0.0001$) .

Figure 8. Final Survivorship of chamise in all treatments based on germination totals.

The odds of death were 35% greater for non-irrigated plants over all seed treatments ($X^2=33.13$, $P<0.0001$). Chamise seedlings in the irrigated bare plots had the highest survival rate (74%) and the seedlings in the non irrigated bare plots had the next highest survival rate (39%). The other plots had significantly lower survival rates. Chamise seedlings in the irrigated herb and volunteer plots had a survival rate of 6% while the survival rate in the non irrigated herb and volunteer plots was 0%.

The logistic model showed there to be no interaction ($X^2=4.793$, $P=0.091$) between irrigation and treatment. This suggests that there is little evidence that the affect of irrigation differs among the treatments.

After a few initial increases in seedling mortality in February 2005 to May 2005, chamise in all plots except the irrigated bare plots

experienced a spike in mortality that continued from June through November 2005 (Figure 9). After November, seedling mortality dropped significantly though the late fall and winter months when temperatures cooled and winter precipitation began. However, some seedling mortality did occur in the irrigated herb and volunteer plots, possibly in response to the cessation of summer irrigation.

Figures 10, 11, and 12 show three plots photographed in June 2005. By this time chamise seedlings in the volunteer and herb irrigated plots are declining rapidly. The brown individuals in the bare non-irrigated plot illustrate the typical self-thinning that occurred with this treatment. The chamise that are surviving in this photo continued growing through the rest of the study and experienced no further mortality.

Figure 9. Timing and season of chamise mortality. Most mortality occurred in June while plants were still small seedlings and continued throughout the summer. Beyond spring and summer thinning in the first year, very little mortality was observed for the remainder of the study.

06-05

Figure 10. Volunteer plot 20. All 6 chamise that germinated in this plot were expired by mid September 2005.

06-05

Figure 11. Herb irrigated plot "S". Of the 13 chamise that germinated in this plot, all were expired by the end of the study.

06-05

Figure 12. Bare plot “2”. 15 chamise germinated in this plot and 7 survived. Brown individuals illustrate the typical self thinning experienced in non irrigated bare plots.

Growth

Evaluations of growth described in this section are based upon successive measurements taken after the seedlings reached a minimum of 2 cm height. Chamise seedlings in the herb and volunteer plots both, irrigated and non-irrigated, grew to the 2-3 leaf stage, and then slowly declined. Therefore growth was not evaluated in these plots. Height is herein defined as vertical distance from base to apex. Canopy cover in each plot is described in terms of the summation of areas of all chamise plants within the plot.

A MANOVA analysis was ran on the height, area, and volume data, and showed that irrigated plots had a significantly faster growth rate than non-irrigated with respect to total height ($F_{7,8}=5.749$, $P=0.0125$),

approximate area ($F_{7,8}=11.500$, $P=0.001$), and volume ($F_{7,8}=13.618$, $P=0.001$). During the irrigation period (mid April to mid November, 2005) empirical estimates for the rate of mean height in irrigated plots was 1.6 times the rate in non-irrigated plots (table 3 and accompanying figure 13). During this same period the empirical estimate for the mean horizontal area in irrigated plots was 3.5 times the rate in non-irrigated plots. Confidence intervals for these estimates were not computed.

During the winter period, November 2005 to February 2006, little growth in mean height or area occurred in any of the plots.

Beginning in February 2006, rapid growth occurred in all bare plots. From February to May 2006, empirical estimates for the rate of mean height of chamise in the plots that were irrigated during the previous summer were 1.2 times the rate of those that had not been irrigated. The empirical estimate for mean area in the previously irrigated plots increased at a rate 1.6 times the rate of increase in the non-irrigated plots.

	Jun-05	Jul-05	Aug-05	Sept-05	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06	Apr-06	May-06
Center Height Non Irrigated (cm)	6	8	10	10	14	nd	nd	13	13	23	28	34
Center Height Irrigated (cm)	7	11	14	17	20	24	24	25	26	32	42	52
Area Non Irrigated (cm ²)	8	18	26	31	46	nd	60	64	67	156	274	392
Area Irrigated (cm ²)	18	34	69	104	151	nd	196	204	212	356	551	745
%cover Non Irrigated	1	1	1	2	2	nd	3	3	3	6	12	18
%cover Irrigated	2	4	8	12	13	20	21	22	22	36	40	45

Table 3. Monthly mean values for bare and bare irrigated plots. Irrigated plots were taller, had larger areas/individual and plot coverage than non irrigated. nd=no data. No data was collected for some plots in November and December due to canyon closure after winter storms.

Figure 13. Mean Area and height for all chamise in the bare plots that were irrigated and not irrigated. Similar growth patterns were observed in both treatments with irrigated plots growing much faster in the summer. Both experienced a significant spike in growth the following spring after irrigation had ceased.

The photographs in figure 14 compare the growth from summer 2005 to the following spring 2006 between established chamise in typical bare and bare irrigated plots.

Weeding was performed diligently during spring and summer 2005 and discontinued after irrigation was ended in November 2005 as a matter of practicality for both this study and in possible future reclamation projects. As a consequence of weeding cessation, the photos taken in spring 2006 have an array of volunteer vegetation. Note the dense horizontal growth of the irrigated plot as compared to the more sparse and upright growth in the non-irrigated plot.

A)

B)

C)

D)

Figure 14. Images comparing bare plot "2" (top pictures, A and B) and bare-irrigated plot "T" (bottom pictures, C and D) over the winter growing season after irrigation ceased. Note significant growth with both treatments. Irrigated individuals still show stronger growth.

Discussion and Conclusion

The results of this study indicate that two factors are critical for the establishment and survival of chamise on steep excavated hillsides, interspecific competition and irrigation. Of these, interspecific competition was the most significant. There was no establishment of chamise seedlings where they had to compete with native or introduced grasses and herbs. Survival and growth of chamise was directly dependent on the removal of competing species. Additional summer irrigation increased survival by four times and promoted faster summer growth.

Reasons for inability to compete

Late seed germination and slow initial growth limit the ability of chamise to compete with the herbaceous plants in the plots. This is particularly true in the spring when the grasses and forbs grow rapidly and cover the plots.

Chamise seeds planted in December 2004 did not begin to germinate until February 2005, and germination peaked during the first of March 2005. During this same period of time, annual and perennial herbaceous species germinated prolifically, and the canopy created by competing non-native grasses such as *Avena fatua* and native herbs such as *Lupinus hirsutissimus* quickly shaded small chamise seedlings. The chamise seedlings in the herb and volunteer plots had slow initial growth; but gradually declined, and perished by mid-summer.

In the bare non-irrigated plots, the surviving chamise seedlings grew slowly in the spring and summer of 2005. Chamise in the irrigated plots grew consistently in the summer and slowed after irrigation stopped in the fall 2005. By the 2005/2006 winter, seedlings in both the bare non-irrigated and bare irrigated plots were well established and able to compete successfully with the prolific herbaceous spring growth that came in the 2006 growing season when the bare plots were no longer weeded. Not only were the established shrubs able to compete with the spring vegetation, they grew rapidly and did not experience any mortality beyond fall 2005.

Inter-specific vs. Intra-specific Competition

Chamise in the bare plots prospered in dense intraspecific populations even though they were unable to compete with either native or non-native interspecific vegetation in the herb and volunteer plots. Since competition is generally the result of factors relating to light, nutrients, or water, these results indicate that lack of light was most likely the strongest factor limiting seedling survival. If this were not the case intraspecific competition between chamise growing in dense populations would cause mortality similar to what was seen in plots where it competed with native herbs and weeds. Over the course of the study, Chamise seedlings growing together did not grow large enough to have a significant shading effect on adjacent seedlings. As the shrubs continue to grow at different

rates, the taller faster-growing individuals may eventually shade out the slower growing shrubs in their immediate under-story. (Mcpherson and Muller 1967)

Water was a significant factor in survival rates and growth of chamise seedlings. Bare plots that were irrigated experienced significantly higher survival rates and faster growth than non-irrigated plots. However, irrigation in herb and volunteer plots did not compensate for the devastating effects of light competition.

It is unlikely that competition for nutrients limited the ability of chamise to compete. Chamise is well known to have the ability to survive in nutrient poor soils (Hanes 1977). Chamise growing together in the bare plots would be competing more intensely for the same nutrients and show signs of malnutrition and perish before those in the herb and volunteer plots. During this study, the typical signs of nutrient deficiencies such as leaf discoloration, chlorosis, or distortion of growth were not observed.

The photograph in figure 15 illustrates the dense competition occurring in bare irrigated plots. All 23 seedlings in this plot survived the duration of the study.

Figure 15. Dense intraspecific competition in bare-irrigated plot x. Twenty three chamise seedlings are competing in this small area.

It has been hypothesized that some facilitation may occur between native fire species and *Chamise* in the post-fire environment (Moreno and Oechel 1988). Reasons for this could include such factors as: (1) Shade produced by annual herbs may protect the young seedlings from the intense summer heat. (2) Additional organic matter from decomposing annual species' root matter could retain moisture and provide additional soil nutrients. (3) Herbaceous vegetation may promote mutualistic mycorrhizal relationships among the herbs and chamise seedlings. This study shows that interspecific facilitation between chamise seedlings and native herbs is negligible compared to the negative effects of inter-specific competition.

Effects of Additional Summer Water

Addition of summer water was found to significantly increase survival and growth of chamise seedlings in the weeded, bare plots. Although seedlings in non-irrigated, bare plots were not as vigorous as those in the irrigated, bare plots, many survived and became established during the first growing season without supplemental water. This is impressive considering that there was no rain from June to November 2005. After the second winter (2006), non-irrigated shrubs continued to grow although they were still smaller than the previously irrigated shrubs at the end of the season. Bare irrigated plots suffered little mortality over the course of the study and did not show any mortality after irrigation was ceased in November 2005 and continued to grow throughout winter 2006.

Three Year Follow-up 2008

On March 29, 2008, the study site was surveyed to assess the long-term effects of summer irrigation during my study in 2005. Chamise seedlings in both bare irrigated and bare non-irrigated plots had grown substantially and had several inches new growth during the 2008 growing season. I measured the tallest individual shrub in each bare plot and found no significant difference in the size of the tallest individual in the irrigated compared to the non-irrigated plots. The median height for the tallest chamise plant in the non-irrigated plots was 124 cm compared to 122 cm in the irrigated plots. However, overall the chamise shrubs in the irrigated

plots were taller, larger, and denser than those in the non-irrigated plots. There was also greater variation in the sizes of individual chamise plants in the non-irrigated plots, which had a larger number of small plants than the irrigated plots. In addition, chamise in the non-irrigated plots exhibited a more erect branching pattern than those in the irrigated plots, which had a wider branching pattern sometimes causing the branches to flop over (Figure 16).

During this visit there was no evidence of additional mortality or new chamise plants in any plots since the study was finished in 2006. Since there was no new mortality, irrigation beyond the first summer may not be necessary or beneficial for chamise establishment.

In 2008, volunteer seedlings of ceanothus, manzanita, and toyon that emerged during the study had grown and become established in and around the study site where the ground was initially cleared of competing vegetation. Like chamise, these shrubs have been difficult to establish on Rocky Canyon. It is likely that the requirements for establishment of these shrubs, is similar to those observed in this study in chamise.

Figure 16. Images of a bare-irrigated plot (top) and a bare plot (bottom) in spring 2008. The irrigated plot may be slightly bigger with a looser branching pattern than the non-irrigated which shows a tighter branching pattern. No mortality since the initial spring and summer thinning of 2005 was observed in either treatment.

Herbivory

Herbivory was a common cause of chamise seedling mortality. Gophers, deer, rabbits, and ground squirrels were frequently observed in and near the study site. Immediately after germination any grazing of the tops of the chamise seedlings caused mortality. As the study progressed and the seedlings became established, grazers browsed the terminal shoots

causing a stunted, horizontal growth pattern. Gophers buried several seedlings when they upturned the soil to prepare their burrows (Figure 17).

There was a plethora of insects observed throughout the plots and surrounding area. Caterpillars and beetles were observed grazing on the lush foliage of the herbaceous vegetation. However, no insects were observed feeding directly on chamise.

Figure 17. Image of an herb plot in July 2005, showing the impact of rodent behavior. Digging of holes and tailings can damage and bury emerging seedlings.

Effects of Precipitation During the Study

Rainfall during the winter rainy season of 2004/2005 was 28 inches. This is almost double the mean precipitation of 15 inches in this region. The heavy rainfall contributed to the prolific spring germination

and growth of chamise and competing species in the first year of the study. Since heavy rainfall in the first spring increased the speed of growth of competing species it may be possible that the slow growing chamise would be able to compete more successfully in a lower rainfall first season. Based on the clear results in this study, I doubt moderate variation in precipitation would drastically change the major findings of this study. Further studies could help gain a better understanding on how rainfall affects first season competition dynamics.

Comparison of the Rocky Canyon Quarry Restoration Project to the Post-fire Environment

In the post-fire environment, the majority of seed recruitment for chamise occurs in the first year (Hanes 1971; Keeley 1977). Like the post fire environment, the first growing season is a critical time for seedling establishment on the mined slopes of Rocky Canyon. Results of my study show that chamise seeds germinated prolifically in the first spring, the seedlings thinned throughout the summer, and the survivors became established by the second winter. After this time there was no seedling recruitment for the duration of my study.

The inability of chamise to compete with native post-fire vegetation implies that seed recruitment is best achieved on bare soil. The bare soil required for successful establishment is present for a short time in a post-fire environment and many seedlings start to grow. At Rocky

Canyon bare soil is also present for a short while, after the slope has been re-graded, and before seeds have been introduced from surrounding areas.

A high mortality rate among chamise seedlings has been reported by several investigators in the post-fire environment (Kummerow 1985, Moreno and Oechel 1992). This high rate of mortality can at least partially be credited to high levels of interspecific competition, which is highest where densities of competing species are highest. At Rocky Canyon chamise seedling mortality will be close to 100% where interspecific competition is not controlled. Life history characteristics, such as late spring germination and slow initial growth rate, limit the ability of chamise to compete with other species that are quicker to gain establishment both in the post-fire environment and in the restoration site at Rocky Canyon.

Suggested Restoration Strategies for Rocky Canyon Chaparral

Based on the results of my study and the work of others, I have developed some suggestions that should be helpful in restoration efforts involving the establishment of chamise. These suggestions incorporate what I have learned about fire ecology and life history characteristics of chamise as well as the influence of competition and irrigation on the establishment of chamise on bare, mined sites in RCQ. Based on this information, I am optimistic that thriving chaparral communities can be restored on disturbed, mined slopes.

After a fire, chamise can re-establish itself by resprouting from surviving- underground burls and from seed in the soil exposed to fire conditions. This is not the case in the excavated, mined area where the underground burls are removed. Revegetation on excavated slopes requires seeding and/or planting container stock plants. Therefore, the recommendations listed below are designed to establish the dominant shrubs of the mature chaparral as well as a diverse herbaceous understory that will supply the seed-bank with successional species so the restored community will accommodate future natural disturbances such as fire.

I. First Year Establishment

A. Slopes that are graded and cleared from mining activities should be planted the first year before weed seeds blow in and other species become established.

B. Slopes with existing dry vegetation should be raked and dry matter removed in the fall before it rains to prepare a relatively smooth, level seedbed. I found dry existing grass was easily cleared with a rake.

C. Chamise seeds should be prepared by exposing seeds to chamise smoke for 5 minutes. I used a turkey smoker. This technique has been proven to be effective by Stephanie Scolari (2003) and was also effective in this study.

D. Plots should be laid out with maximum a dimension no greater than 2M and separated by walkways so that weeds can be pulled from outside the plots.

1. This will help focus efforts for irrigation and weeding, permit design of research projects, and discourage soil compaction due to foot traffic where seedlings are becoming established over seedbeds.
2. To reduce erosion, straw mats such as those available at local farm supply retailers should be placed around and between plots. Straw mats would be easier to lay down and more effective than loose straw.

E. A drip irrigation system should be established where system maintenance is economically feasible and water is available.

F. Treat and plant seeds of chamise and other chaparral shrubs such as ceanothus, manzanita, and toyon (see Emery, 1988 for seed treatments) between the months of November and January after winter rains have begun. Rake the seeds lightly into smooth soil surface approximately ¼" deep. Use at least 4.73 g/m² of seeds as this provided sufficient seeds to establish chamise on the bare plots in my study.

H. Plots should be carefully weeded of emerging grasses and non-woody species no less than monthly and preferably bi-weekly through June.

1. Weeding may seem daunting but it was not difficult in this study.

- a. Weeds continued to germinate only as long as it was raining. This required bi-weekly weeding through March then monthly weeding was sufficient.

- b. When weeds were pulled frequently it was easy to remove small individuals.

- c. It is imperative that individuals weeding are able to identify the difference between weed seedlings and shrub seedlings.

I. Once rain ceases in the spring (i.e. a two-week interval with no significant rain), plots should be irrigated weekly until soil is saturated to a depth of 2"-3", until rain returns the following winter.

II. Suggested Follow-up in Succeeding Years

- A. In the second winter existing plots should be planted with a diverse seed mixture composed of "generalized herbaceous perennials', generalized annuals, fire annuals and fire perennials" (see Keeley, 1981). This mixture should include a variety of subshrubs and herbaceous annuals and perennials. These seeds do not need to be treated since the main goal of this treatment is to re-establish a seed-bank.
- B. Weeding and irrigation need not be continued beyond this point.

Success of chaparral restoration relies on a thorough understanding of the complex dynamics of succession after disturbance. Future research that investigates the interactions between different levels of successional species can help us understand proper timing for reintroduction. For example, a study on the interaction between short-lived sub-shrubs and fire annuals and perennials would be beneficial. Perhaps the sub-shrubs should be introduced the second year and then annuals the third year? Other research that would benefit chaparral establishment would be to study the effects of varying densities of herbaceous vegetation on survival

of chamise or to study what conditions favor establishment of one shrub such as ceanothus over another such as chamise or manzanita.

Conclusions

The following list of conclusions highlights the essential findings in this study:

Germination

1. Given smoke treated seed and adequate rainfall chamise will germinate in the depleted soil of the kind found at RCQ.
2. Germination success can be as high as 7 plants/ gram of seed.
3. Post-germination mortality approached 100% when competing weeds were allowed to grow in the spring.
4. Weeding prior to planting and prior to establishment is absolutely necessary for chamise establishment.

Mortality

5. With thorough weeding in the absence of water, survival of seedlings was as high as 73% after germination.
6. With summer irrigation provided, survival was as high as 93% after germination.
7. After reaching establishment (minimum of 2cm height), survival of chamise seedlings in the bare irrigated and non irrigated treatments was 100%.

8. Demise due to competition with native and non-native vegetation was total in both irrigated and non-irrigated plots which indicates that competitors usurping water was not the cause of chamise mortality.
9. Chamise survival was high (>90%) in densely populated irrigated and non-irrigated plots. This indicates that intraspecific competition due to nutrient consumption was not a limiting factor even in densely populated plots.

Growth

10. In the absence of irrigation and first season competition, mean vertical growth was 28 cm. in the first year.
10. In the presence of irrigation mean vertical growth was 45 cm in the first year.
11. Mean horizontal area and canopy cover in the bare-non-irrigated plots increased by 384 cm² (20 cm diameter) in the first year.
12. In the bare-irrigated plots mean horizontal area increased by 727 cm² (27 cm diameter) in the first year.
13. During the first summer, non-irrigated chamise in the bare plots grew an average of 8cm in height. Irrigated chamise grew an average of 13cm in height.
14. Growth in both treatments was negligible from October to February.

15. Rapid spring growth occurred at approximately equal rates for both treatments in the second year. That rate being approximately 8cm/month from February to May.

Follow Up

16. Three years after planting there was no observable mortality of chamise seedlings from the first summer 2005. The tallest individual in both treatments were approximately the same height (122-124cm).

17. After three years, no seedling germination had occurred from the beginning of the study in 2004.

It is the opinion of the author that, with the application of these findings and the recommendations outlined in this paper, restoration of a dynamic chaparral community on steep granite mined slopes can be successfully accomplished.

Bibliography

- Bernstein, S. 1999. Revegetation of Granite Mined Slopes in Rocky Canyon Quarry, San Luis Obispo County, CA. Master's Thesis.
- Cooper, W.S. 1922. The broad-sclerophyll vegetation of California: an ecological study of the chaparral and its related communities. Carnegie Institution of Washington, Washington, D.C. Publication 319.
- Christensen, N.L., and C.H. Muller. 1975. Effects of Fire on Factors Controlling Plant Growth in *Adenostoma* Chaparral. Ecological Monographs **45**: 29-55.
- Emery, D.E. 1988. Seed Propagation of Native California Plants. Santa Barbara Botanic Garden, Santa Barbara, CA.
- Hanes, T.L. 1970. Succession After Fire in the Chaparral of Southern California. Ecological Monographs **41**: 27-52.
- Horton, J.S., and C.J. Kraebel. 1955. Development of Vegetation after Fire in the Chamise Chaparral of Southern California. Ecology **36**: 244-262.
- Holland, V. L. 1996. Botanical report and revegetation plan for expanded Rocky Canyon Quarry. Unpubl. rep. prepared for Willco-Hermreck, Santa Maria, CA.
- Holland, V. L. 1993. Botanical Survey of Rocky Canyon Quarry Site, San Luis Obispo Cty., CA. Oct. 1992 to June 1993. Unpubl. rep. prepared for Willco-Hermreck, Santa Maria, CA.
- Holland, V. L. and Kiel, David J. 1995. California Vegetation. Kendall/Hunt Pub. Dubuque, Iowa.
- Jepson, W. L. 1925. Manual of the Flowering Plants of California. Ass. Students Store, University of California, Berkeley, Calif.
- Jones, D.P., and R.C. Graham. 1993. Water-Holding Characteristics of Weathered Granitic Rock in Chaparral and Forest Ecosystems. Soil Sci. Soc. Am. J. **57**: 256-261.
- Keeley, J.E., 1987. Role of Fire in Seed Germination of Woody Taxa in California Chaparral. Ecology **68**: 434-443.

- Keeley, J.E., and C.J. Fotheringham. 1998. Smoke-Induced Seed Germination in California Chaparral. *Ecology* **79**: 2320-2336
- Keeley, S.C. and M. Pizzorno. 1986. Charred Wood Stimulated Germination of Two Fire-Following Herbs of the California Chaparral and the Role of Hemicellulose. *Amer. J. Bot.* **73**: 1289-1297.
- Keeley, S.C., J.E. Keeley, S.M. Hutchinson. 1981. Post-fire Succession of the Herbaceous Flora In Southern California Chaparral. *Ecology* **62**(6): 1608-1621.
- Kummerow, J., B.A. Ellis, and J.N. Mills. 1985. Post-Fire Seedling Establishment of *Adenostoma Fasciculatum* and *Ceanothus Greggii* in Southern California Chaparral. *Madroño* **32**: 158-157.
- Mcpherson, J. K. and C. H. Muller. 1967. Light competition between *Ceanothus* and *Salvia* shrubs. *Bulletin of the Torrey Botanical Club* 94:41-55.
- Mcpherson, J. K. and C. H. Muller. 1969. Allelopathic effects of *Adenostoma fasciculatum*, "chamise", in the California chaparral. *Ecological Monographs* 39:177-198.
- Mills, J.N. 1983. Herbivory and Seedling Establishment in Post-fire Southern California Chaparral. *Oecologia* **60**: 267-270.
- Montalvo, A.M. and N.C. Ellstrand. 2001. Nonlocal Transplantation and Outbreeding Depression in the Subshrub *Lotus Scoparius* (Fabaceae). *American Journal of Botany* **88**(2): 258-269
- Moreno, J.M. and W.C. Oechel. 1988. Post-fire Establishment of *Adenostoma fasciculatum* and *Ceanothus Greggii* in a Southern California Chaparral: Influence of Herbs and Increased Soil-Nutrients and Water. Time Scales and Water Stress-Proc. from the 5th Conference on Mediterranean Ecosystems. 137-141.
- Moreno, J.M., and W.C. Oechel. 1991. Fire Intensity and Herbivory Effects on Post-fire Resprouting of *Adenostoma fasciculatum* in Southern California Chaparral. *Oecologia* **85**: 429-433.
- Moreno, J.M., and W.C. Oechel. 1991. Fire Intensity Effects on Germination of Shrubs and Herbs in Southern California Chaparral. *Ecology* **72**: 1993-2004.

- Moreno, J.M., and W.C. Oechel. 1992. Factors Controlling Post-fire Seedling Establishment in Southern California Chaparral. *Oecologia* **90**: 50-60.
- Morro Group, Inc. 1995. Final program environmental impact report for the proposed Rocky Canyon Quarry. Prepared for Dep. of Planning and Building, Environmental Division, San Luis Obispo, CA.
- Odion, D.C., and F.W. Davis. 2000. Fire, Soil Heating, and the Formation of Vegetation Patterns in Chaparral. *Ecological Monographs* **70**: 149-169.
- Riggan, P.J., S. Goode, P.M. Jacks, and R.N. Lockwood. 1988. Interaction of Fire and Community Development in Chaparral of Southern California. *Ecological Monographs* **58**(3): 155-176.
- Schlesinger, W. H, D. S. Gill. 1980. Biomass, production, and changes in the availability of light, water, and nutrients during development of pure stands of the chaparral shrubs, *Ceanothus megacarpus*, after fire. *Ecology* **61**:781-789.
- Scolari, S. 2009. Techniques for Triggering Germination of *Adenostoma Fasciculatum* in Revegetation Projects at Rocky Canyon Granit Quarry. Master's Thesis. CPSU. 2009.
- Tyler, C.M. 1995. Factors Contributing to Post-fire Seedling Establishment in Chaparral: Direct and Indirect Effects of Fire. *The Journal of Ecology* **83**: 1009-1020.
- U. S. D. A. Soil Conservation Service. 1983. Soil Survey of San Luis Obispo County, Paso Robles Area. CA.
- Van Dyke, E.; K. D. Holl, K. D.; J. R. Griffin. 2001. Maritime chaparral community transition in the absence of fire. *Madrono*. **48**(4): 221-229.
- Young, T.P. and R.Y. Evans. 2000. Container Stock Versus Direct Seeding For Woody Species in Restoration Sites. Combined Proceedings International Plant Propagators' Society. **50**: 577-582.

Appendix A

Distribution of chaparral in California.

Distribution of chaparral in California (shown in blue). From Keeley, J.E. and F.W. Davis. 2006. Chaparral. In M.G. Barbour (ed), Terrestrial vegetation of California. University of California Press, Los Angeles. In press.

Appendix B

List of Herb Species Planted with Chamise in Post-fire Herb Plots

Species	Life Form	Location	Source	Treatment	Amount Seeded g/M ²
<i>Emmenanthe penduliflora</i>	Annual	Cuesta Grade	(Keeley, Pizzorno 1986)	Smoke 7 min.	.54
<i>Phacelia brachyloba</i>	Annual	Cuesta Grade	(Keeley 1981)	Smoke 7 min.	.54
<i>Phacelia parryi</i>	Annual	Cuesta Grade	Jepson Manual 1993	Smoke 7 min.	.54
<i>Lupinus hirsutissimus</i>	Annual	Rocky Canyon	(Keeley 1981)	No treatment	.81
<i>Lupinus nanus</i>	Annual	Rocky Canyon		No treatment	1.1
<i>Antirrhinum multiflorum</i>	Annual, Perennial	Rocky Canyon	Jepson Manual 1993	Smoke 7 min.	.54
<i>Lotus scoparius</i>	Perennial, Subshrub	Rocky Canyon		½ smoked 7 min, ½ no treatment	1.6
<i>Helianthemum scoparium</i>	Perennial, Subshrub	Cuesta Grade	Jepson Manual 1993	Smoke 7 min.	.54
<i>Eriophyllum confertiflorum</i>	Perennial, Subshrub	Rocky Canyon	(Keeley, Pizzorno 1986)	½ smoked 7 min, ½ no treatment	.54

Appendix C: Study Layout

1 Bare	2 Bare	3 Bare	4 Volunteer	5 Volunteer	6 Volunteer	7 Herbs	8 Volunteer
9 Herbs	10 Herbs	11 Herbs	12 Volunteer	13 Bare	14 Volunteer	15 Herbs	16 Bare
17 Herbs	18 Herbs	19 Bare	20 Volunteer	21 Bare	22 Herbs	23 Bare	24 Volunteer
A <i>Irrigated</i> Herbs C	B <i>Irrigated</i> Bare C	C <i>Irrigated</i> Herbs NC	D <i>Irrigated</i> Bare C	E <i>Irrigated</i> Bare NC	F <i>Irrigated</i> Herbs NC	G <i>Irrigated</i> Volunteer NC	H <i>Irrigated</i> Herbs NC
I <i>Irrigated</i> Herbs C	J <i>Irrigated</i> Volunteer NC	K <i>Irrigated</i> Volunteer C	L <i>Irrigated</i> Volunteer C	M <i>Irrigated</i> Herbs C	N <i>Irrigated</i> Volunteer NC	O <i>Irrigated</i> Herbs NC	P <i>Irrigated</i> Bare NC
Q <i>Irrigated</i> Volunteer C	R <i>Irrigated</i> Bare C	S <i>Irrigated</i> Herbs C	T <i>Irrigated</i> Bare C	U <i>Irrigated</i> Bare NC	V <i>Irrigated</i> Volunteer NC	W <i>Irrigated</i> Volunteer C	X <i>Irrigated</i> Bare NC

Appendix D: Species germinated in Volunteer plots:

Polygonum arenastrum

Anthemis cotula L.

Avena fatua L

Bromus diandrus

Bromus tectorum

Bromus hordeaceus

Centaurea solstitialis

Erodium cicutarium

Hordeum murinum

Lolium multiflorum

Gnaphalium spp.

Amsinckia spp.

Polygonum arenastrum

Lotus scoparius

Appendix E

Germination and Mortality Data for Each Plot

Plot	Treatment	Germinated	# Expired	Survived	% Mortality	% Survived
1	Bare	17	10	7	59 %	41 %
2*	Bare	15	8	7	53 %	47 %
3	Bare	15	4	11	27 %	73 %
13	Bare	7	4	3	57 %	43 %
16	Bare	21	12	9	57 %	43 %
19	Bare	23	21	2	91 %	9 %
21	Bare	7	4	3	57 %	43 %
23	Bare	20	9	11	45 %	55 %
Mean Bare		16	9	7	56 %	44 %
B	Bare/Irr	14	7	7	50 %	50 %
D	Bare/Irr	15	1	14	7 %	93 %
E	Bare/Irr	6	3	3	50 %	50 %
P	Bare/Irr	18	6	12	33 %	67 %
R	Bare/Irr	29	5	24	17 %	83 %
T	Bare/Irr	26	8	18	31 %	69 %
U	Bare/Irr	13	4	9	31 %	69 %
X	Bare/Irr	33	10	23	30 %	70 %
Mean Bare/Irr		19	6	14	29 %	71 %
7	Herbs	14	14	-	100 %	0 %
9	Herbs	8	8	-	100 %	0 %
10	Herbs	13	13	-	100 %	0 %
11	Herbs	10	10	-	100 %	0 %
15	Herbs	8	8	-	100 %	0 %
17	Herbs	14	14	-	100 %	0 %
18	Herbs	9	9	-	100 %	0 %
22	Herbs	9	9	-	100 %	0 %
Mean Herbs		11	11	0	100 %	0 %
A	Herbs/Irr	3	3	-	100 %	0 %
C	Herbs/Irr	10	8	2	80 %	20 %
F	Herbs/Irr	10	10	-	100 %	0 %
H	Herbs/Irr	22	21	1	95 %	5 %
I	Herbs/Irr	11	11	-	100 %	0 %
M	Herbs/Irr	23	21	2	91 %	9 %
O	Herbs/Irr	10	9	1	90 %	10 %
S*	Herbs/Irr	13	13	-	100 %	0 %
Mean Herbs/Irr		13	12	1	94 %	6 %
4	Vol.	12	12	-	100 %	0 %
5	Vol.	8	8	-	100 %	0 %
6	Vol.	7	7	-	100 %	0 %
8	Vol.	6	6	-	100 %	0 %
12	Vol.	5	5	-	100 %	0 %
14	Vol.	11	11	-	100 %	0 %
20*	Vol.	6	6	-	100 %	0 %
24	Vol.	15	15	-	100 %	0 %
Mean Volunteer		9	9	0	100 %	0 %
G	Vol./Irr	5	5	-	100 %	0 %
J	Vol./Irr	10	10	-	100 %	0 %
K	Vol./Irr	5	5	-	100 %	0 %
L	Vol./Irr	18	18	-	100 %	0 %
N	Vol./Irr	6	5	1	83 %	17 %
Q	Vol./Irr	10	7	3	70 %	30 %
V	Vol./Irr	15	15	-	100 %	0 %
W	Vol./Irr	13	12	1	92 %	8 %
Mean Vol./Irr		10	10	1	94 %	6 %

Germination and mortality data for each plot. Bare and bare/irrigated plots had significantly higher germination and lower mortality than other treatments. Plots marked with an asterisk correspond to those pictured in figure 9,10,and 11. (Irr=irrigated)