MIMICKING FIRE FOR POST-MINING RESTORATION SUCCESS

AT ROCKY CANYON QUARRY

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by

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ABSTRACT

Mimicking Fire for Post-Mining Restoration Success at Rocky Canyon Quarry Katherine Marie Wilkin

This study is based at Rocky Canyon Quarry (RCQ), a 200-acre granite aggregate open-pit quarry with chaparral-dominated plant communities located in San Luis Obispo County, CA. At RCQ, the Surface Mining and Reclamation Act (SMARA) of 1975 was interpreted as restoring the landscape to native plant communities. Native plant community restoration projects have occurred there since 1993 through cooperation with California Polytechnic State University Biology Department in San Luis Obispo, CA. I evaluated past restoration at RCQ and researched new techniques to improve chaparral restoration based on the natural processes of fire.

Chaparral is an important fire-dominated plant community within the California Floristic Province, which covers about seven percent of California. Typically during a fire, heat immediately acts on *Adenostoma fasciculatum* (Chamise) seeds/m² in the soil seed bank. Smoke also reaches seeds on and near the soil surface. Chemical effects of fire, such as smoke and charcoal, are deposited on the soil surface and leach into the seed bank after fall rains. In nature, this results in enhanced germination of the seeds and the beginning of chaparral post-fire succession. Fire effects, both heat and chemical, have been supported to increase seed germination in numerous laboratory and field studies. I sought to utilize natural fire cues, such as heat, charate, and liquid smoke, to develop successful and efficient restoration prescriptions. The most successful restoration technique developed utilized Wright's Liquid Smoke and heat to increase seed germination of *Adenostoma fasciculatum* (Chamise), *Ceanothus cuneatus* (California lilac), and *Salvia mellifera* (Black Sage) significantly. A new restoration prescription for RCQ based on literature reviews and the above mentioned research is presented.

Keywords: *Adenostoma fasciculatum*, Black Sage, California lilac, *Ceanothus cuneatus*, Chaparral, Chamise, Charate, Fire effects, Heat, Mine, Restoration, Rocky Canyon Quarry, *Salvia mellifera*, Succession, Surface Mining and Reclamation Act (1975), Wright's Liquid Smoke

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I. Introduction

A. Rocky Canyon Quarry

Rocky Canyon Quarry (RCQ) is a 200-acre granite open-pit quarry located in San Luis Obispo County, California, approximately two miles east of Atascadero and 18 miles northeast of San Luis Obispo (Fig. 1). Rocky Canyon is an east to west trending valley formed with Rocky Canyon Creek, a seasonal creek, flowing through the canyon toward the Salinas River. It is situated in the Santa Lucia Mountains at elevations that range from 305 to 488 meters and has varied terrain. The canyon along Rocky Canyon Creek is relatively flat, but is bordered by steep granite hillsides border the canyon and creek on both its north and south sides. RCQ is located on a large granite outcrop, one of the few granite areas in the South Coast Ranges of California.

Figure 1. Location of RCQ (MapQuest, 2008).

There is a locked gate at the entrance to Rocky Canyon and minimal road access is allowed through the quarry. However, recreational activities such as hiking, horseback riding, and mountain biking are allowed along Rocky Canyon Road, which continues eastward to Creston, CA.

B. Soils

The soils of Rocky Canyon Quarry 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 (Holland, 1992). The details of both surveys are included below.

Generally, the Soil Conservation Service identified coarse sandy loams derived from decomposed granite between 305 and 762 meters 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 five to 15 centimeters of water per hour, and have very low available water capacity. Organic matter is less than 1% for all three. These areas are generally used for rangeland, but Cieneba is poorly suited for this purpose (USDA, 1983).

Vista coarse sandy loam in this region appears on shallow to moderate (9 to 15%) slopes covered with foothill woodland, grassland, and sometimes chaparral. The moderately deep soil, 51 to 101 centimeters deep, is well drained. Erosion occurs on this soil, but it is only a severe problem if vegetation is disturbed (USDA, 1983).

Cieneba coarse sandy loam in this region occurs on hills and mountains with steep to very steep slopes (30 to 75%) and is dominated by chaparral. The shallow soil, 15 to 51 centimeters deep, drains quickly. Plant roots would reach the granite rock between 15 and 30 centimeters down. Any disturbance causes severe erosion (USDA, 1983).

Cieneba-Andregg coarse sandy loam has Cieneba and Andregg soils both occurring intricately within a small area. Therefore, the cover of each individual soil is not described. It is generally composed of 30% Andregg, 35% Cieneba, and a few other closely related soils. Andregg coarse sandy loam has steep to very steep slopes (30 to 75%) covered with chaparral. The moderately deep soil, 51 to 102 centimeters deep, is well drained. Rapid surface runoff contributes to very high levels of erosion. Vegetation cover decreases the erosion potential (USDA, 1983). Cieneba soil was described previously in the paragraph above.

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. The purpose of the soil analysis was to see if soil development had taken place in that two-year period. Results differ somewhat from the 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 Soil Conservation Service did not identify any soils within or near RCQ with pHs less than 5.6. Organic levels were within the range described by Soil

Conservation Service, but they were quite low (0.3%). The Soil and Plant Laboratory recommended organic matter, fertilizer, and calcium carbonate lime amendments to enhance the soils on the oak woodland plots (Morro Group, 1995; USDA, 1983)

C. Climate

RCQ has a semi-arid Mediterranean climate characterized by hot, dry summers and cool, moist winters. RCQ does not have an active weather station; therefore I reviewed data from the nearest stations in Santa Margarita, Atascadero, and Paso Robles. These data may not be completely applicable as local climates are extremely different within 10 miles of RCQ. The Weather Channel estimates that Atascadero and Paso Robles, cities northeast of RCQ, have average annual precipitation between 30 and 36 centimeters per year, while Santa Margarita, which is southwest of RCQ, averages approximately 71 centimeters per year (NOAA WRCC, 2008a; NOAA WRCC, 2008b; The Weather Channel, 2008a; The Weather Channel, 2008b). Based on these data and San Luis Obispo precipitation maps, the estimate for average annual precipitation at RCQ is approximately 46 centimeters (The Morro Group, Inc., 1995). However, precipitation, like temperature, is extremely variable from year to year, and average annual precipitation and temperature data is not useful in ecological studies. Annual precipitation and temperature data from nearby stations are useful in showing local trends of drought, rainfall patterns, and temperature variation. These data can be correlated with RCQ as very similar trends would occur at the quarry.

By correlating RCQ precipitation and temperature patterns with the Paso Robles Station (046730), I could discern some general climatic characteristics for RCQ during the time of this study (Fig. 2, 3). The summer months are characterized by a lack of precipitation, average high temperatures near 33°C, and average low temperatures near 10°C. Fall and winter are typically dramatically cooler with average high temperatures of 18°C and

average low temperatures 2°C. Almost all precipitation occurs during the fall and winter (November to May) and generally peaks near the end of winter. Temperatures warm in the spring to average highs of 23°C and average lows of 5°C (City-Data, 2008).

Figure 2. Monthly average maximum and minimum temperatures with extreme temperatures near RCQ from 1901 to 2007. Measurements were taken at Paso Robles weather station 046730. Daily extreme maximum is the maximum of all daily maximum temperatures recorded for the day of the year. Monthly average maximum is the average of all daily maximum temperatures recorded for the day of the year. Monthly average minimum is the average of all daily minimum temperatures recorded for the day of the year. Daily extreme minimum is the minimum of all daily minimum temperatures recorded for the day of the year (NOAA WRCC, 208b).

Figure 3 shows the average annual precipitation by growing season (July to June) for Paso Robles from 1993 to 2008. The long-term average from 1901 to 2007 is included. 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 (1994 to 2008), annual precipitation was highly variable ($SD=18.6$) and ranged from 15 centimeters in 2006-07 to 79 centimeters in 1994-95. During my study, annual precipitation was well below average— 15 cm 2006-07 and 28 centimeters in 2007-08 (Fig. 3). The majority of data that I used are from the Paso Robles Station (46730) with missing data supplemented from AccuWeather (2008). The data table for the graphic with sources noted for individual months is located in Appendix A (NOAA WRCC, 2008b; AccuWeather, 2008) (Appendix A).

Figure 3. Growing season precipitation totals in centimeters near RCQ during restoration from 1993 to 2008. Long-term precipitation average from 1901 through 2007 is a line on the graphic (NOAA WRCC, 2008b). Growing season, as defined in the figure above, begins in July and concludes in June of the following year.

D. Revegetation and Restoration

Natural area degradation, fragmentation, and destruction are all too common in today's society. Conservation threats are common in California and through chaparral's natural range as a result of urban development, agricultural development, mining, and other human disturbances (Quinn and Keeley, 2006). These threats need to be minimized and restoration efforts are needed to promote the return of native communities after these disturbances.

Historically, few regulations were in place that required revegetation of old mine and quarries. As a result, several areas mined in the 1940s remain mostly barren and unvegetated (Holland, 1993). There is little published information about restoring native Californian plant communities on these areas. All known research has focused on restoration of old roads, abandoned agricultural fields, and burned areas, which were mostly seeded with the introduced, invasive grass *Lolium multiflorum* (Italian Ryegrass) (Barro and Conrad, 1987; Barro and Conrad, 1991; Claassen and Marler, 1998; Claassen and Zasoski, 1998; Curtis and Claassen, 2007; Holl et al., 2000; Janicki, 1989; Serrill, 2006; Stratton, 2003; Zink and Allen, 1998). There is some published research on restoring the South African homolog to chaparral, called fynbos, after both mining and road-cuts (Baxter and Van Staden, 1994; Dixon and Roche, 1995; Dixon et al., 1995; Matesanz and Valladares, 2007; Read et al., 2000).

Even at RCQ, early attempts to revegetate mined sites consisted of planting non-native pines (*Pinus* spp.), on flat terraces between nearly vertical, mined cliffs that were mostly

devoid of vegetation (Fig. 4). However, restoration has changed significantly in the last 20 years.

Figure 4. Restoration at RCQ prior to Dr. Holland joining the project. Revegetation consisted of steep slopes between terraces planted with pine trees.

Based on standards established by the Surface Mining and Reclamation Act (SMARA) of 1975, the RCQ permit require restoration and revegetation of mined areas to a vegetation cover that is structurally and functionally similar their native, pre-disturbance condition (Bernstein, 1999).

During the early 1990s, RCQ received a permit to expand its mining operation from a 12-acre plant with 18 acres of mining to more than 180 acres total. The native vegetation of

RCQ consisted of chaparral dominated by *Adenostoma fasciculatum* (Chamise) 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. The permit allowed mining of an additional 70 acres of chaparral, 31 acres of foothill woodland, and six acres of coastal scrub.

In 1993, V. L. Holland developed a Restoration and Revegetation Plan for RCQ that has been followed for the last 15 years with some modifications. 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 are to redistribute the stockpiled soil and plant materials over the slopes to a depth of at least 10 centimeters. These slopes are then hydroseeded with a mixture of native grasses, forbs, and shrubs during the late fall or early winter prior to the heavy winter rains. Container stock plants are also planted in some locations on the slopes to supplement the seeding.

The design of the quarry after mining results in a series of steep, mined granite slopes separated by flat terraces that extend down slope from the top to the bottom of the hill. After each slope and terrace is mined and shaped, stockpiled topsoil mixed with shredded vegetation is reapplied to the finished slopes. The finished slopes are hydroseeded and planted with native seeds and container stock plants during the fall after completion of mining. The steepness of the slopes varies, but most slopes are approximately 2:1.

Since 1993, V. L. Holland and many Cal Poly students have worked with Union Asphalt to successfully meet the restoration and revegetation requirements at Rocky Canyon Quarry. This work has been sponsored by generous grants provided to Cal Poly by Union Asphalt. As of February 2009, approximately 70 acres had been mined and are in various stages of revegetation.

E. Purpose of Study

During my study of RCQ, I examined the previously restored slopes to evaluate the success of the revegetation efforts. The restored slopes are still in various stages of succession, and none have formed dense chaparral stands. Revegetation has been more successful on some slopes, and even on some sections of slopes, than on others. Some sections of steep slopes are still in ruderal or early successional phases and have low native shrub cover. Others have a significant cover of native shrubs but are not yet similar in composition to surrounding undisturbed natural land. Research for new methods in order to develop the most efficient and successful ways to restore mined areas continue at RCQ. These results will also be useful in other restoration efforts wherever development leaves bare mineral soil in California chaparral.

While there have been many significant research breakthroughs in revegetation at RCQ (Elster, 2007; Holland and Langford, 1995; Holland and Bernstein, 1997; Holland and Bernstein, 1998; Holland and Petroelje, 1999; K. Roy, Personal Communication, 5-21-2008), more research is needed to develop more efficient and successful ways to restore the mined areas. My research seeks to determine new, more efficient ways to improve the restoration of chaparral communities on mined areas or other areas of bare mineral soil. RCQ's long-term restoration goal is to establish native, self-sustaining plant communities similar to pre-existing vegetation. However, because restoration will occur on a series of steep 2:1 slopes between flat benches, the restored communities may never be inherently the same as the undisturbed surrounding communities. Therefore, the restoration goal is

to achieve an environment, which has wildlife habitat, plant communities, and natural processes similar to natural chaparral (Holland, 1993).

My studies sought to determine if greater success can be achieved using new efficient restoration tools to better achieve the general goals of the project which are to (1) replace topsoil; (2) control soil erosion; (3) promote natural succession through recruitment from surrounding areas; (4) enhance recovery by seeding with native grasses, forbs, and shrubs that are genetically and ecologically compatible with surrounding vegetation in composition and structure; and (5) reestablish self-sustaining plant communities that ecologically blend with the surrounding area (Holland, 1993). There are several approaches that need to be researched that would improve native plant establishment and vegetation restoration. These include: (1) increased germination of sown seed, (2) increased survival rates of sown seeds, (3) increased establishment of nursery stock plantings, (4) increased germination of seeds in the seed bank, (5) increased survival rates of seed bank recruits, (6) increased amount of nursery stock planted, and (7) increased amount of seeds in hydroseed mix. My research developed new techniques using a variety of fire effect treatments that could improve germination rates of sown seed and native seed in the soil seed bank. Because these treatments increase germination rates by breaking long-term seed dormancy, there will be a significant improvement in the success of restoration and revegetation efforts on mined slopes.

My research has two distinct parts. The first evaluates past restoration efforts at RCQ and includes a literature review. I reviewed literature that describes evolutionary theories of

seed dormancy; ecology, adaptation and significance of long-term seed dormancy in chaparral; types of seed dormancy and dormancy breakers; and literature on seed response to fire in Central California chaparral. This review helped me determine the best method for successfully restoring native chaparral at RCQ. In the second part of my research I used a series of laboratory, greenhouse and field experiments to seek new, more efficient ways to improve restoration of chaparral communities on mined areas or other areas of bare mineral soil. More specifically, these experiments study all known fire effects which contribute to seed germination and native ecosystem restoration.

Past studies at RCQ have quantitatively sampled plant cover, frequency, density and diversity of restoration where slopes were accessible. In steep terrain not readily accessible and where foot traffic would create erosion problems, the slopes were qualitatively sampled using photo-monitoring and qualitative descriptions.

I applied fire and mimicked various effects of fire, such as heat, charate, smoke, and leachate in my experiments at RCQ during five related experiments. All have been found to break long-term dormancy and enhance seed germination (Fotheringham et al., 1995; Keeley, 1984; Keeley et al., 1985; Keeley, 1987a; Keeley and Fotheringham, 1997; Keeley and Fotheringham, 1998a; Keeley and Fotheringham, 1998b; Keeley and Pizzorno, 1986; Keeley et al., 2005; Jager et al., 1996a; Jager et al., 1996b; Jager et al., 1996c). In an attempt to find the best means to enhance seed germination of planted seeds and of seeds in the seed bank, I built on previous work at RCQ by adding various fire effects in laboratory, greenhouse, and field experiments.

Liquid Smoke (L.S.) mimics smoke from natural fires and causes seeds to break dormancy in the same way natural smoke breaks seed dormancy (Jagger et al., 1996a). One of my experiments evaluated seed germination using L.S. as a soaking agent at different concentrations, time spans, and with the addition of heat to determine how it may be used to increase seed germination. These experiments were conducted in incubators following published protocol and sought to determine the best L.S. and/or heat treatment for seeds prior to being sown.

In a related experiment using preliminary results from the study described above, L.S. was evaluated as a pre-treatment soaking agent before hydroseeding slopes in the field. This experiment sought to determine if pre-treatment soaking of seeds with L.S. increases seed germination and recruitment on restoration sites and/or to determine if the L.S. has any environmental-wide effect on the soil seed bank. On the same site, another experiment was conducted at the same time. Both fire and charate were applied before hydroseeding to determine if they increase hydroseed or soil seed bank germination.

Exploring yet another restoration strategy, natural fire effects were applied to the soil seed bank. The natural fire effects, charcoal and heat, were applied to determine if viable seeds remain in the soil after stockpiling and reapplying soil. The experiments were conducted in a greenhouse and in incubators following published protocol. This experiment sought to determine if naturally occurring viable seeds that remain in the soil may have increased germination rates using fire effect treatments in the field.

I also applied a natural fire effect--charcoal-- on the soil seed bank and hand-cast seed of one restoration site. This experiment sought to determine if charcoal affects the germination, recruitment, and survival of planted seeds and/or the soil seed bank.

I also conducted an experiment in the Oak Woodland Plot to determine if using fire, charcoal (low, medium, and high doses), and fertilizer could increase seed germination in previously seeded plots. I sampled the vegetation after treatment to determine if post-treatment may have affected native plant cover and composition.

These experiments were designed to study some of the known fire effects which contribute to seed germination and may be practical for native ecosystem restoration. It is hoped that findings from the series of fire effect studies described above will contribute to an enhanced prescription for restoration at RCQ.

II. Literature Review

A. Ecology, Adaptation, and Significance of Long-term Seed Dormancy

Chaparral is an important plant community within the California Floristic Province.

Chaparral covers about seven percent of California and dominates as far south as the Baja Peninsula, north to South Central Oregon, west to the Pacific Ocean, and east into the western foothills of the Sierra Nevada Mountains from 300 m to 1,500 m (Keeley and Davis, 2007; Quinn and Keeley, 2006). Chaparral is home to 1,177 (24%) of California's native plant species and 497 California endemic plant species. Most of the plants which occur in chaparral are also found in other plant communities. However, 110 species of shrubs only occur within chaparral. Of these species restricted to chaparral, 62 are considered rare by CalFlora (Keeley and Davis, 2007). Chaparral plant communities have a distinct suite of chaparral-restricted and chaparral-associated species which is related to latitude, elevation, and winter temperatures (Keeley and Davis, 2007; Quinn and Keeley, 2006). *Adenostoma fasciculatum* (Chamise) is the only widespread dominant in chaparral, and it commonly forms pure stands. However, Chamise is more likely to be associated with a locally occurring species of *Ceanothus* or *Arctostaphylos* (Keeley and Davis, 2007; Quinn and Keeley, 2006). These shrubs form a dense shrubland with their sclerophyllous vegetation reaching two to four meters in height. There are few herbs beneath the shrub canopy and variable amounts of litter (Hanes, 1977).

Shrublands like California chaparral are found mostly in Mediterranean climates in habitats that have nutrient limitations and frequent fires. Chaparral's many counterparts around the world have similar climates, slopes, soils, and general habitat conditions. Chaparral-type vegetation is found where cold currents touch the western side of

continents around 30° latitude in central Chile (matorral), around the Mediterranean Sea (e.g., macchia, maquis, and garrique), on the south and west coasts of South Africa (fynbos), and in southern and southwestern Australia (e.g., mallee-heath) (Kelly and Parker, 1989). Each of these ecosystems has unique flora and fauna; however, the flora and fauna, through convergent evolution, have very similar morphological and physiological adaptations, such as long-term seed dormancy, due to evolving with similar environmental stress (Dallman, 1998; Keeley and Bond, 1997). Dominant shrubs in these plant communities worldwide with similar adaptations and physical features are not necessarily related taxonomically (Dallman, 1998).

Chaparral occurs on dry slopes with shallow, rocky nutrient-poor soil. Waxes and resins released from decomposing leaf litter coat soil particles causing the soil to be hydrophobic (Hanes, 1977). Chaparral plants have little available water near the soil surface for most of the year due to shallow soils, hydrophobicity, steep slopes and summer drought. However, chaparral plants have root adaptations that allow them access to water throughout the year. Chaparral plants generally have significant tap roots, more than eight and one-half meter, able to reach year-round moisture and a large network of shallow roots able to take advantage of seasonal rains (Dallman, 1998). Chaparral is replaced by sage scrub in drier areas and by oak woodland in more mesic areas. The plant communities mentioned above and grasslands form mosaics with chaparral due to local environmental conditions (Keeley and Davis, 2007).

Undisturbed chaparral, even under normal conditions, experiences many stresses that reduce seed germination and the establishment of new vegetation. These stresses can

include low light, low nutrients, allelopathy, high herbivory, and seed predation (Christensen and Muller, 1974; Christensen and Muller, 1975). Seedling establishment in the understory of mature chaparral has limited success due to these stresses. However, there are two critical opportunities in these shrublands for seedling establishment. Small, localized opportunities for seed germination and seedling recruitment arise in older stands with small gaps created by old-age mortality. Historically, small-scale vegetation gaps were more frequent. Grizzly bears, now extirpated from chaparral range, probably influenced the structure of chaparral by creating vegetation gaps, eating and distributing seeds and fruits, and uprooting soil to get food. Black bears do not fill the grizzly's ecological void because they do not tunnel through vegetation and create gaps. However, fires create large areas for plants to colonize, and this is when most seedling establishment occurs. Many seeds break long-term dormancy and germinate as a result of the chemicals (e.g., smoke, charate) and heat created by fires. This often results in many seedlings becoming established, including some that are only found after fires (Quinn and Keeley, 2006).

Fire is an important ecological factor for the presence and survival of chaparral. Fires routinely occur every five to 40 years, but sometimes they are absent for up to 100 years. Fires occur independently of the vegetation type and fuel load because they are affected by summer drought and Santa Ana winds (Quinn and Keeley, 2006). Fall fire stimulates dormant seeds in fire-prone communities' soil seed bank to germinate (Odion and Davis, 2000; Sweeney, 1956; Zammit and Zedler, 1988; Zammit and Zedler, 1994; Quinn and Keeley, 2006). Fire has distinct regional patterns throughout the range of chaparral. Therefore, only the fire regime for the region surrounding Rocky Canyon Quarry (RCQ)-

-the inland chaparral occurring along the central coast of California--will be discussed here.

Fire naturally occurs after summer and fall drought. Summer drought occurs every year, but it is unpredictable in severity. After a summer of intense heat and no rain, plant drought stress reaches a point where the chaparral plants become dry above ground (less than 10% water) and roots no longer extract water from the soil. During drought dormancy, plants sequester all water and starch reserves in the root system and burl. Fires often occur during this drought period in the driest months of the year, usually late summer to early fall. Drought dormancy is vital to plant survival. Drought dormancy also fuels fire because most above-ground plant material no longer has water present, and plants ignite easily. Flammable resins sequestered within the leaves of the plant also contribute to the rapid spread of fire. During the fall, there is convergence of drought and Santa Ana winds which both contribute to fire severity (Quinn and Keeley, 2006).

Santa Ana winds cause vegetation to dry out and become more susceptible to fire while also spreading fire further. These winds, locally called sundowners, have high speeds, high air temperatures, and low humidity (Quinn and Keeley, 2006). During extreme events, the winds carry air which can reach more than 38 °C, less than 10% humidity and hurricane force (60-118 mph; Fovell, 2007). When fires occur during these wind events, fires become extreme with surface temperatures of 1649 °C and consume all of the above-ground vegetation (Quinn and Keeley, 2006).

Generally, crown fires occur and consume all above-ground vegetation with temperatures between 350-800 °C. There is rapid decrease in temperature to about 70° C at five centimeters depth; therefore, seeds and other underground structure are protected from high heat intensity (Bradstock and Auld, 1995; Quinn and Keeley, 2006). Zammit and Zedler (1988) reported that heat immediately acts Chamise seeds in the soil seed bank (Zammit and Zedler, 1988). During a fire, smoke reaches seeds on the surface and near the soil surface. The chemical effects of fire, such as smoke and charcoal, are deposited on the soil surface. The chemical effects then leach into the soil seed bank when it rains (Schelsinger and Hasey, 1980; Keeley and Fotheringham, 1998a). Seedlings are present within two weeks after the first rain (Quinn and Keeley, 2006). Seedlings are abundant after fires and apparently do not deplete the stored seed bank even though some of the remaining seed bank is likely to have been consumed or made unviable due to fire (Keeley, 1977). In nature, this results in 2,200,000 to 146,100,000 Chamise seedlings/ha reported depending on the number of years since the last fire (Stone and Juhren, 1953; Zammit and Zedler, 1988).

Many effects of fire have been supported to break seed dormancy in laboratory experiments. Fire effects germination reactions are not the same for all species: some stimulatory effects for one species are inhibitory for another, and stimulatory effects for other species may not be sufficient to trigger germination (Keeley and Fotheringham, 1998a). For species with hard seed coats, such as species in the Fabaceae, Convovulaceae, and Rhamnaceae, heat-shock “weakens the seed coat and/or loosens cells in localized regions, such as the hilum or strophiole which allows imbibition and

germination” (Egley, 1989 as cited in Keeley and Fotheringham, 1997). However, heat-shock is not sufficient to stimulate germination in many plants (Christenson and Muller, 1975; Keeley, 1987a; Keeley, 1991; Keeley et al., 2005; Sweeney, 1956). The chemical effects of fire such as charred wood or ground charred wood (charate) (Wicklow, 1977; Jones and Schelsinger, 1980; Keeley and Pizzorno, 1986; Keeley, 1987a), leachate (Keeley et al., 1985), and smoke (Keeley and Fotheringham, 1998a) all stimulate germination in some chaparral plants. However, ash does not stimulate germination (Christenson and Muller, 1975; Jones and Schlesinger, 1980). The stimulatory ingredients for both charred wood and smoke may be the same. Species which respond to charred wood also respond to smoke (Brown, 1993; Brown et al., 1993). These products increase the permeability of the semi-permeable sub-dermal cuticle to solutes (Kisser-Priesack et al., 1987). Furthermore, the aqueous extracts of plant-derived smoke and charcoal are equally effective to stimulate germination (Baxter and Van Staden, 1994; Baldwin et al., 1994; Brown, 1993; de Lange and Boucher, 1993; Van Staden et al., 1995). Interestingly, aqueous extracts of smoke, commonly called liquid smoke (L.S), are widely available in supermarkets for use in food preparation and have the same effects as smoke (Jager, 1996a; Keeley et al., 2005). Therefore, the term smoke-stimulated refers to both that and charred wood-stimulated germination (Keeley and Bond, 1997).

There is a significant shift in dominant structure in chaparral following fires. The plant community regenerates from the soil seed bank, perennial roots, and burls. For one to two years after fire, annuals and perennial herbs from the seed bank and underground structures dominate. Shrubs’ dominance recovers within the first three to five years due to resprouting and seeds (Quinn and Keeley, 2006; Sweeney, 1956). The resprouting

shrubs, which are between 69 to 96% of pre-fire shrubs depending on fire intensity, rapidly regain their stature within a few years (Moreno and Oechel, 1991). Of the shrub seedlings, generally only 10% survive, and these plants take 10 to 20 years to reach maturity (Kummerow et al., 1985). The high seedling mortality after fires has been correlated with soil drying out and herbivory (Moreno and Oechel, 1991). Some fires are so hot and destructive that resprouting shrubs are killed and the seed bank is the only manner for reestablishment. In these cases, the plant community is dominated by a stand of shrubs of similar age and size dating from the last fire (Quinn and Keeley, 2006). The climax chaparral is reached within 10-20 years of age and is dominated by shrubs (Sweeney, 1956).

Late winter and spring fires lack the regenerative potential of fall fires. Spring fires cause high mortality of seeds in the soil because water in the soil and imbibed seeds is released as steam. Seeds which do germinate have a reduced growth period to reach the summer water table and succumb to summer drought more easily. Spring fires also cause increased mortality of shrubs because plants' carbohydrates and nutrients are distributed throughout the plant, and there is little to no reserves to use in recovery (Quinn and Keeley, 2006).

B. Evolution of Seed Dormancy

Several ecological hypotheses attempt to explain how the seed dormancy evolved. One hypothesis identifies risky environment as a likely factor for the adaptation of seed dormancy in chaparral. Risky environments, which have variable conditions such as precipitation or temperatures so severe that many individuals die, correspond to high levels of seed dormancy. Severe weather causes many individuals, especially annuals, to die before reproduction and also causes perennials to not set seed. Neither contributes to the persistent seed bank. Contribution to the seed bank is especially crucial for annuals which have no individuals that survive to the following year. During the following year, only seeds that lay dormant in the persistent seed bank during the previous year contribute to seedlings. Only species with the ability to survive after these severe weather events with seed dormancy can prosper in these risky environments. In chaparral, rains can vary dramatically year to year. Many seedlings die before setting seed because there are insufficient rains for growth. The risky environments hypothesis also incorporates density-dependent mortality, predation, and seed dispersal. After a bumper year of seed production, there would be high levels of competition between seedlings if they all germinated. However, seed dormancy allows the bumper crop to be dispersed across many different seedling generations. The delayed germination reduces the density-dependent mortality (Bulmer, 1984; as cited by Baskin and Baskin, 1998). These variable environmental conditions are an evolutionary selection pressure which promotes seed dormancy (Cohen, 1966; as cited by Baskin and Baskin, 1998).

C. Seed Dormancy and Release

Understanding the physiology of seed dormancy and the mechanisms that release seed dormancy will aid in restoration. The two main mechanisms that keep seeds in a dormant state are embryo covering and embryo dormancy. These may occur separately or in combination. Embryo coverings are impermeable to gas exchange or water. These coverings restrict embryo growth mechanically. In addition, water-soluble inhibitors are sometimes present. The other mechanism of seed dormancy, embryo dormancy, includes undeveloped or underdeveloped embryos, compounds which inhibit germination, or a failure to utilize food reserves. Many natural processes break both embryo covering and embryo dormancy. Many dormant seeds require more than one stimulus to break dormancy due to the multiple types of dormancy in seeds (Bewley and Black, 1982). This basic seed dormancy and release physiology allows restoration ecologists to utilize natural germination cues to increase seed germination.

Baskin and Baskin (1998) further divide Bewley and Black (1982)'s two dormancy mechanisms into four types of seed dormancy which may be released by distinct mechanisms in restoration. They are: (1) morphological, (2) physiological, (3) morphophysical, and (4) physical dormancy. As restoration ecologists, we must understand the potential for the types of seed dormancy across all plant life forms and how they may affect the outcome of projects. Seed dormancy is present across all life cycles and forms such as herb (annual, biennial, and perennial), shrub, and tree. However, the rates and types differ greatly based on life cycle such as herbs, shrubs, and trees. The general distribution of plants' dormancy may or may not directly apply to

chaparral plants. The majority of shrubs, 88%, have some form of dormancy while the remaining 12% are not dormant. Over 20% of the trees tested were dormant; they were restricted to physiological or physical dormancy. About 31% of the shrubs have physical dormancy, 38% have physiological dormancy, 8% have both physical and physiological dormancy, and 9% have morphophysical dormancy. All of the herbaceous plants tested had some form of dormancy: 78% physiological dormancy, 9% physical dormancy, 9% morphological dormancy, 2% physical and physiological dormancy and 2% morphological dormancy (Baskin and Baskin, 1998). These general findings give a guideline for potential dormancy breaking treatments for use in chaparral restoration.

1. Morphological dormancy as discussed in Baskin and Baskin (1998) is a type of embryo dormancy. The embryo is dormant while it develops or its formation is delayed because fertilization is not immediate. The growth of the embryo is heavily tied to environmental limiting factors such as moisture and temperature. Morphological seed germination is released by time and positive environmental cues.

The ability to break morphological dormancy has great potential to increase seed germination in restoration. We may use many common horticultural techniques to break morphological dormancy in restoration. Irrigation increases moisture and may increase seed germination in restoration. Removing moisture from the environment or regulating temperature is difficult. Temperature may be increased with clear solarizing plastic.

2. Physiological dormancy as discussed in Baskin and Baskin (1998) is another type of embryo dormancy. The embryo is dormant and remains dormant through hospitable environmental signs (Baskin and Baskin, 1998) until a dormancy breaking treatment occurs. Then, after experiencing the appropriate environmental cues, it will germinate. Common dormancy breakers include temperatures such as winter cold stratification, summer heat stratification and fire (Baskin and Baskin, 1998).

The ability to break physiological dormancy has great potential to increase seed germination in restoration. We may use many common horticultural techniques to break morphological dormancy in restoration. Treatments include allowing seeds to age before planting, hot and/or cold stratifying, and/or irrigating seeded areas to increase seed germination (Baskin and Baskin, 1998).

3. Morphophysical dormancy as discussed in Baskin and Baskin (1998) is also a type of embryo dormancy. The embryo is dormant while it develops or it is unable to form because fertilization is delayed. It also remains dormant through hospitable environmental signs. The seed only breaks through dormancy after dormancy breaking treatment and suitable environment is present (Baskin and Baskin, 1998). Morphophysical dormancy may be broken by many plant chemicals such as gibberellins, cytokinins, and ethylene. Gibberellins and other chemicals break seed dormancy and/or accelerate germination in many plants by penetrating small seed coat scars. They generally do not disrupt the seed coat. Sometimes gibberellins are insufficient to induce germination. In these cases,

mild mechanical scarification and gibberellins are both needed to trigger seed germination (Bewley and Black, 1982).

The ability to break morphophysical dormancy has great potential to increase seed germination in restoration. We may use many common horticultural techniques to break morphological dormancy in restoration. Treatments include allowing seeds to age before planting, hot and/or cold stratifying, and/or irrigating seeded areas to increase seed germination. In addition, seed germination can be increased in restoration by using heat to scar the seed coat or fire chemicals to sensitize the seed to hormones and/or scar the sub-dermal cuticle (Baskin and Baskin, 1998; Thomas and Van Staden, 1995).

4. Physical dormancy as discussed in Baskin and Baskin (1998) is a type of embryo covering dormancy. The seed or fruit coats are hard, impermeable to water, and hinder the germination of seeds. The time period of physical dormancy is generally less than physiological dormancy. The embryo coverings do not prevent the imbibition of water indefinitely. Physical dormancy as found in many families such as the Fabaceae, Cannaceae, Malvaceae, and Convolvulaceae requires that the seed coat be scarified. Other plant families also require release from similar dormancy. In nature, seed coats are scarified in the soil and when a seed passes through animal digestive tracts. Seeds are mechanically scarred by soil abrasion, temperature, light, and chemicals leached from the soil by rain. In many cases, seasonal cues allow seeds to break dormancy (Bewley and Black, 1982).

The ability to break physical dormancy has great potential to increase seed germination. We may use many common horticultural techniques to break morphological dormancy and increase seed germination in restoration. Treatments include sulfuric acid, ethanol, mechanical scarification, extreme cold, leachate, charate, extreme heat, radiation, percussion, and pressure release (Baskin and Baskin, 1998; Keeley et al., 1985; Keeley, 1987a; Jagger et al., 1996a).

Physical, physiological and morphophysical dormancy may be broken by light in some seeds. Light can stimulate germination by denaturing the seed coat or providing an environmental cue for season or vegetation gap. Germination may require intermittent light, similar to forest understory. Other plants require specific seasonal photoperiods commonly called day lengths to germinate. The seeds are able to detect the ratio of lightness to darkness or the amount of light. After soil disturbances, a flush of germination occurs when many seeds are exposed to light for the first time. These adaptations to light cue seeds to germinate during favorable environments (Bewley and Black, 1982).

Temperature is one of the most studied natural physical and physiological dormancy breakers. Seasonal high temperatures and temperature fluctuations soften the seed coat. Temperatures cause cracks to form in the impermeable seed coat, allowing water to enter the seed and germination to proceed. Seed coat cracking such as this is common in many species such as *Lupinus* spp. (Lupine). Extreme temperatures, especially while seeds contain water (>8.5% water) may cause catastrophic results (Bewley and Black, 1982). During the summer months or spring fires, water in the soil and within the seed may

reach vaporization point at 100°C (Quinn and Keeley, 2006). The steam produced during high temperatures destroys tissues and leaves seeds unviable. During the winter months, water in the soil and within the seed may reach the freezing point at 0°C and expand during cold temperatures. Such expansions can destroy the tissue and leave seeds unviable (Bewley and Black, 1982).

Fire also causes extreme temperature events, but the effects are less studied than seasonal fluctuations. Dry extreme heat, such as 100°C fire, scarifies the seed coat (Thanos and Rundel, 1995), but temperatures greater than 120°C destroy many chaparral seeds (Sampson 1944; Stone and Juhren, 1952; Quick, 1959; Quick and Quick, 1961; Wright, 1931).

Research has been completed on the active components of L.S. and smoke. The active seed stimulating properties of smoke are produced between 160 and 200°C. Activity is lost at higher temperatures due to volatilization (Jager et al., 1996c). There are many chemicals in L.S. which have been described with chromatography and gas chromatography-mass spectrometry (Table 1, Table 2). Many of these isolated chemicals have not had their germination effect tested. Some of these chemicals stimulate germination. Ethylene and the combination of ethylene with octanoic acid promote germination in lettuce (Jager et al., 1996c). Nitrogen oxide has similar germination results as smoke for *Emmenanthe penduliflora* (Whispering Bells) (Keeley and Fotheringham, 1998b). The pH level does appear to be responsible for stimulating seed germination in lettuce (Brown and Van Staden, 1994). Smoke extracts act similarly to cytokinins in celery; they enhance gibberelin activity (Thomas and Van Staden, 1995).

Germination stimulators were tested on a limited number of species. There in fact may be many different stimulants within smoke which act differentially on species. Few of these compounds have been isolated and tested on the seed germination of common crops let alone chaparral species. We should apply these results cautiously in a restoration setting and therefore only test compounds which have the full spectrum of chemicals present.

Acetic Acid	4-(2-Propio)-vanillone
Formic acid	4-(1-Propio)-vanillone
Maltol	Acetovanillone
Methyl cyclophenenolone	2,4,5-Trimethylbenzaldehyde
Ethylcyclopentenolone	4-Hydroxyacetophenone
Dimethylcyclopentenolones	Eugenol
Furfural	cis & trans-Isoeugenol
5-Hydroxymethylfurfural	2,6-Dimethoxyphenol (Syringol)
From Lignin Pyrolysis:	4-Methylsyringol
Phenol	4-Ethylsyringol
ortho, meta and para Cresols	4-Propylsyringol
Guaiacol	4-Acetosyringol
4-Methylguaiacol	4-(2-Propio)-syringol
4-Ethylguaiacol	4-(1-Propio)-syringol
4-Propylguaiacol	cis & trans-4-(1-Propenyl)-syringol
Pyrocatechol	4-(2-Propenyl)-syringol
Trimethylphenols	Syringaldehyde
Vanillin	

Table 1. Chromatography results of food grade liquid smoke (Leffingham & Associates, 1998).

Methyl acetate	gamma-Octalactone (tentative)
Formic acid	Pyrocatechol
Unknown	5-Hydroxymethylfurfural
Acetic acid	4-Ethylguaiacol
Ethyl formate	Artifact
Acetoin	Syringol
Propanal	Eugenol
Furfural	4-Propylguaiacol
2-Butanone	Vanillin
Acetol acetate	cis-Isoeugenol
2-Acetylfuran	4-Methylsyringol
gamma-Butyrolactone	trans-Isoeugenol
2(5H)-Furanone	Acetovanillone
3-Methylsuccinic anhydride	4-Ethylsyringol
3-Methylenesuccinic anhydride	4-(2-Propio)-vanillone (part peak)
3-Methylcyclopentenone	4-(1-Propio)-vanillone
3-Methyl-2(5H)-furanone	4-(2-Propenyl)-syringol
Phenol	Z-4-(1-Propenyl)-syringol
Methylcyclopentenolone	Syringaldehyde
"3,5-Dimethylcyclopentenolone"	E-4-(1-Propenyl)-syringol
o-Cresol	4-Acetosyringone
Guaiacol	4-(2-Propio)-syringone
Maltol	4-(1-Propio)-syringone
Ethylcyclopentenolone	Palmitic acid
4-Methylguaiacol	Stearic acid

Table 2. Gas chromatography-mass spectrometry results of food grade liquid smoke

(Leffingham & Associates, 1998).

D. Chaparral Seed Dormancy

Many of the plants in chaparral have seed dormancy. These seeds have long-term physiological and short-term environmental or physical dormancy. Fire effects such as heat and chemicals increase seed germination dramatically when secondary dormancy breakers are also applied, such as moisture and light (Christensen and Muller, 1974; Keeley et al., 2005; Stone and Juhren, 1953). For example, the keystone plant in chaparral surrounding RCQ, Chamise, has short-term physical dormancy and/or long-term physiological dormancy. Some Chamise seeds germinate when favorable moisture conditions occur while the remainder requires a heat treatment to break dormancy (Stone and Juhren, 1953). In fact, common shrubs, Chamise and *Ceanothus cuneatus* (Buckbrush), do not respond to common horticultural methods such as concentrated sulfuric acid, 10% hydrogen peroxide, 5.25% sodium hypochlorite (Clorox), and thiourea (Stidham et al., 1980). This bimodal trend contingent on fire suggests that many Chamise seeds used in restoration will not germinate unless they are treated with fire effects or other dormancy breaking treatments. Numerous studies have documented long-term dormancy in many other chaparral plants (Table 3).

							Fire effects		Reference
Life history	Form	Species	Family	Type of dormancy	T (C°)	L:D	Heat	Chemical	
Per.	Shrub	<i>Adenostoma fasciculatum</i>	Rosaceae	NPR	NPR	D	0	+	Keeley (1987a), Keeley et al (2005)
Ann.	Herb	<i>Agoseris heterophylla</i>	Asteraceae	NPR	NPR	NPR	+	+	Keeley (1987a)
Ann.	Herb	<i>Antirrhinum coulterianum</i>	Scrophulariaceae	NPR	NPR	NPR	NPR	+	Keeley (1987a), Keeley and Pizzorno (1986)
Ann.	Herb	<i>Antirrhinum kelloggi</i>	Scrophulariaceae	NPR	NPR	NPR	NPR	+	Keeley (1987a), Keeley and Pizzorno (1986)
Per.	Shrub	<i>Artemisia californica</i>	Asteraceae	Physiological	23	L	0	+	Keeley (1987a)
Ann.	Herb	<i>Cryptantha clevelandii</i>	Boraginaceae	NPR	NPR	NPR	NPR	+	Keeley (1987a), Keeley and Pizzorno (1986)
Ann.	Herb	<i>Camissonia californica</i>	Onagraceae	NPR	NPR	NPR	NPR	+	Keeley (1987a), Keeley and Pizzorno (1986)
Ann.	Herb	<i>Camissonia micrantha</i>	Onagraceae	Physiological	27/18	NPR	NPR	NPR	Sweeney (1956)
Per.	Shrub	<i>Ceanothus cuneatus</i>	Rhamnaceae	Physical and physiological	g.h.	0	+	+	Quick (1959), Keeley (1987a)
Per.	Shrub	<i>Cercocarpus betuloides</i>	Rosaceae	NPR	NPR	0	-	0	Keeley (1987a)
Ann.	Herb	<i>Clarkia epilobioides</i>	Onagraceae	NPR	NPR	NPR	NPR	+	Keeley (1987a)
Ann.	Herb	<i>Clarkia purpurea</i>	Onagraceae	NPR	NPR	NPR	NPR	+	Keeley (1987a)
Per.	Shrub	<i>Clematis lasiantha</i>	Ranunculaceae	NPR	NPR	L	+	+	Keeley (1987a)
Per.	Herb	<i>Delphinium cardinale</i>	Ranunculaceae	NPR	NPR	NPR	NPR	-	Keeley (1987a)
Per.	Herb	<i>Delphinium parryi</i>	Ranunculaceae	NPR	NPR	NPR	NPR	-	Keeley (1987a)
Per.	Shrub	<i>Dendromecon rigida</i>	Papaveraceae	Morphological and physiological	Cool Season	NPR	NPR	NPR	Bullock (1989)
Per.	Herb	<i>Dichelostemma capitatum</i>	Liliaceae	NPR	NPR	NPR	NPR	-	Keeley (1987a)
Ann.	Herb	<i>Emmenanthe penduliflora</i>	Hydrophyllaceae	Physiological	NPR	L	+	+	Sweeney (1956), Fotheringham et al (1995), Wicklow (1977), Jones and Schlesinger (1980), Keeley and Pizzorno (1986)
Per.	Shrub	<i>Eriodictyon crassifolium</i>	Hydrophyllaceae	NPR	NPR	L	+	+	Keeley (1987a), Keeley et al (2005)
Per.	Shrub	<i>Eriogonum fasciculatum</i>	Polygonaceae	NPR	NPR	L	+	-	Keeley (1987a)
Per.	Shrub	<i>Eriophyllum confertiflorum</i>	Asteraceae	NPR	NPR	L	+	+	Keeley and Pizzorno (1986), Christensen and Muller (1975)

Table 3a. RCQ plants with seed dormancy (A through E). Codes are listed on page 39.

Life history	Form	Species	Family	Type of dormancy	T (C°)	L:D	Fire effects		Reference
							Heat	Chemical	
Per.	Shrub	<i>Fremontodendron californicus</i>	Sterculiaceae	Physical	NPR	0	+	+	Keeley (1987a), Keeley et al (2005)
Per.	Shrub	<i>Hazardia squarrosa</i>	Asteraceae	NPR	NPR	0	+	0	Keeley (1987a)
Per.	Sub-shrub	<i>Helianthemum scoparium</i>	Cistaceae	NPR	NPR	NPR	+	0	Kelly et al (1985)
Per.	Shrub	<i>Heteromeles arbutifolia</i>	Rosaceae	NPR	NPR	0	0	-	Keeley (1987a)
Per.	Shrub	<i>Lonicera subspicata</i>	Caprifoliaceae	NPR	NPR	0	+	0	Keeley (1987a)
Per.	Sub-shrub	<i>Lotus scoparius</i>	Fabaceae	Physical	23	L=D	+	+	Keeley (1987a), Christensen and Muller (1975)
Per.	Shrub	<i>Mimulus aurantiacus</i>	Scrophulariaceae	NPR	NPR	L	+	0	Keeley (1987a)
Per.	Herb	<i>Nasella lepida</i>	Poaceae	NPR	NPR	NPR	0	NPR	Keeley (1987a)
Per.	Herb	<i>Penstemon spectabilis</i>	Scrophulariaceae	Physiological	23	NPR	NPR	NPR	Keeley (1987a)
Bienn.	Herb	<i>Phacelia heterophylla</i>	Hydrophyllaceae	Physiological	27/18	NPR	NPR	+	Sweeney (1956)
Per.	Tree	<i>Pinus coulteri</i>	Pinaceae	Physiological	30/20	NPR	NPR	NPR	Krugman and Jenkinson (1974)
Per.	Tree	<i>Pinus sabiniana</i>	Pinaceae	Physiological	22-26	L>D	NPR	NPR	Krugman and Jenkinson (1974)
Per.	Herb	<i>Ranunculus californicus</i>	Ranunculaceae	NPR	NPR	D	0	-	Sweeney (1956)
Per.	Shrub	<i>Rhamnus californica</i>	Rhamnaceae	Physical	NPR	NPR	0	0	Keeley (1987a)
Per.	Shrub	<i>Rhamnus crocea</i>	Rhamnaceae	N	NPR	L	-	0	Keeley (1987a)
Per.	Shrub	<i>Rhus trilobata</i>	Anacardiaceae	NPR	23	L>D	+	+	Keeley (1987a)
Ann.	Herb	<i>Salvia columbariae</i>	Lamiaceae	NPR	NPR	NPR	0	+	Keeley (1984), Keeley and Pizzorno (1986)
Per.	Shrub	<i>Salvia mellifera</i>	Lamiaceae	Physiological	23/13	L>D	+	+	Keeley (1986), Keeley (1987a)
Per.	Sub-shrub	<i>Solanum douglasii</i>	Solanaceae	NPR	NPR	NPR	0	NPR	Keeley (1987a)
Per.	Shrub	<i>Toxicodendron diversilobum</i>	Anacardiaceae	Physical	23	L>D	+	+	Keeley (1987a)

Table 3b. RCQ plants with seed dormancy (F through Z).Codes are listed on page 39.

Table 3 (3a and 3b) includes all plants with seed dormancy for RCQ eco-region from Baskin and Baskin's (1998) summarization and other resources as cited. In addition, literature sources not cited by Baskin and Baskin (1998) were included. NPR is used if no published results were found during the literature search. L:D describes the light or dark requirements for germination where L=D describes seeds which have highest percentage of germination when equal lengths of both light dark occur, where L>D describes seeds which have the highest percentage of germination when there is a greater length of light than darkness and where L<D describes seeds which have the highest germination when there is a greater length of light than darkness (Baskin and Baskin, 1998). L and D describes plant light requirement for germination where L has a 12-hour cycles of both light and dark while D has 24-hours of darkness (Keeley, 1987a).

Keeley's (1987a) results suggest that large improvements in seed germination occur after fire effect treatments for many woody species which are seeded at RCQ. The seed germination response is not equal across all plants tested (Table 4). *Artemisia californica* (California Sagebrush), *Eriogonum fasciculatum* (California Buckwheat), and *Mimulus aurantiacus* (Sticky Monkeyflower) do not benefit from fire effect treatments of heat and charate. Rather, all of these species have comparable germination rates between the control and charate or heat addition. Since the difference between the control and treatment was not statistically significant, the seed should be added directly to the hydroseed mixture without pre-treatment. In contrast, Chamise, Buckbrush, *Lotus scoparius* (Deerweed), and *Salvia mellifera* (Black Sage) all benefit from fire effect treatments. Chamise responded best by the combination of heat and charate and there was a 450% increase in germination from the control when treated with charate and 70°C for

five minutes. Buckbrush had its highest germination rate, 570% greater than the control, when exposed to 100°C for five minutes with charate. Deerweed has its highest germination rates when 120°C is applied for five minutes and there was a 140% increase in the number of seeds which germinated. Black Sage has its highest germination rates when treated with charate and 143% increase in the number of seeds which germinated from the control (Table 5). These results guided my research for the pre-treatment of seeds in restoration. Chamise, Buckbrush, Deerweed, and Black Sage had treatments with significant differences from the control and were tested for potential pre-treatment prescriptions. In contrast, no further testing was completed on California Sagebrush, California Buckwheat, and Sticky Monkeyflower because all their treatments were statistically similar to the control.

Plant Name	Control	70°C 1 hour	100°C 5 min	120°C 5 min	Charate Charate	Charate and 70°C 1 hour	Charate and 100°C 5 min	Charate and 120°C 5 min
<i>Adenostoma fasciculatum</i>	4 ^a	8 ^a	10 ^{a#}	6 ^{a#}	11	18	9 [#]	6 [#]
<i>Artemisia californica</i>	73 ^{a#}	56 ^{a#}	47 ^a	56 ^{a#}	78 ^{a#}	80 ^{a#}	81 ^a	87 ^{a#}
<i>Ceanothus cuneatus</i>	10 [#]	26 ^{b#}	52 ^{a#}	40 ^{ab#}	10 ^{a#}	12 ^{a#}	57 [#]	34 [#]
<i>Eriogonum fasciculatum</i>	83 ^{a#}	72 ^{a#}	67 ^{a#}	27	67 ^{a#}	85 ^{a#}	75 ^{a#}	60 ^a
<i>Lotus scoparius</i>	43 ^{a#}	51 ^{ab}	43 ^{a#}	60 ^b	40 ^{a#}	22 ^a	40 ^{a#}	36 ^a
<i>Mimulus aurantiacus</i>	73 ^{a#}	90 ^{a#}	72 ^{a#}	95 ^{a#}	79 ^{a#}	85 ^{a#}	92 ^{a#}	83 ^{a#}
<i>Salvia mellifera</i>	48 ^a	37 ^{ab}	34 ^b	29 ^b	69 ^a	68 ^a	60 ^a	47

Table 4. Published seed germination treatments and effects. Excerpts from Keeley's (1987a) raw data for plants which are commonly seeded at RCQ are included in the table above. "Temperature treatments cell means with the same superscript letter were not significantly different ($P>0.05$ with Duncan's multiple range test). For given species and temperature, charate, and non-charate treatment cell mean that were not significantly different ($P>0.05$ with two-tailed t-test) are indicated with the superscript symbol # (Keeley, 1987a)."

Plant name	Best treatment		Second best treatment	
<i>Artemisia californica</i>	Charate and 120°C 5 minutes ^a	119%	Charate and 100°C 5 minutes ^a	111%
<i>Lotus scoparius</i>	120°C 5 minutes ^a	140%	70°C 1 hour ^b	119%
<i>Salvia mellifera</i>	Charate ^a	144%	Charate and 70°C 1 hour ^b	142%
<i>Eriogonum fasciculatum</i>	Charate ^a	102%	Charate and 100°C 5 minutes ^a	90%
<i>Ceanothus cuneatus</i>	Charate and 100°C 5 minutes ^a	570%	100°C 5 minutes ^a	520%
<i>Adenostoma fasciculatum</i>	Charate and 70°C 1 hour ^a	450%	Charate ^b	275%
<i>Mimulus aurantiacus</i>	120°C 5 minutes ^a	130%	Charate and 100°C 5 minutes ^a	126%

Table 5. Best seed germination treatments. The best and second best treatments Keeley (1987a) found to increase seed germination in plants commonly seeded at RCQ. The treatment's percent increase in germination from the control is listed in the table above. Statistically similar results are indicated with the same superscript.

Keeley et al. (2005) studied the effects of seed aging, long-term L.S. exposure, and their interaction in both shrubs and herbs. Keeley found that two post-fire annuals, *Mimulus bolanderi* (Bolander's Monkeyflower) and *Mimulus gracilipes* (Slender Stalked Monkeyflower), had significantly enhanced germination rates after being treated with L.S. and smoke. However, the effect was no longer significant after one year of soil storage. The highest germination rate achieved by treatment of the fresh seeds was similar to the germination rates of untreated one-year-old seeds. This trend was only seen in post-fire annuals. Therefore, primary dormancy of seeds in the soil is broken as a result of slow physical and chemical processes such as oxidation and solar radiation. We may be able to age fire-annual seeds in restoration to increase seed germination. I did not pursue research involving aging seeds because of the time constraints of a Master's program. However, research to determine if aging fire-annual seeds is a viable tool in restoration would be well worth pursuing. Some studies have also found primary dormancy of seeds in the soil is broken as a result of slow physical and chemical

processes such as oxidation and solar radiation. These effects increase seed germination after one year of soil stratification (Keeley et al., 2005).

In addition, Chamise, *Eriodictyon crassifolium* (Thick-leaved Yerba Santa), and *Mentzelia dispersa* (Blazing Star) all had significantly higher germination rates in response to L.S. treatments. Keeley et al. (2005) used Wright's Concentrated Hickory Seasoning diluted with distilled water. Generally, L.S. did not inhibit seed germination for any of the species tested for either fresh seeds or seeds greater than one year old. Fresh seeds of both Chamise and Thick-leaved Yerba Santa exhibited the greatest percent germination increases, more than 360%. The one-year-old seeds had higher germination of untreated seeds and conversely a less dramatic increase of around 200% (Keeley et al., 2005). The difference between fresh and one-year-old seeds treated with 1 to 500 L.S. dilution, the most effective treatment, is not significantly different for Chamise. Therefore, aging Chamise is not an effective treatment and research should focus on fire effect treatments. The difference between fresh, one-year-old, and treated seeds for both categories is significantly different for Thick-leaved Yerba Santa and *Mentzelia dispersa*. Both aging and fire effect treatments should be researched for Thick-leaved Yerba Santa and *Mentzelia dispersa*.

There are few experiments which simulate breaking long-term seed dormancy results from the soil seed bank using fire effects in chaparral or homologous communities. Two of the studies collected soil samples, applied fire effect treatments in the laboratory, and placed the soil into a greenhouse (Holl et al., 2000; Read et al., 2000). These studies were able to break long-term dormant seeds from the soil seed bank using fire, heat, and smoke

treatments. Christensen and Muller (1975) collected soil samples, applied heat treatments in the laboratory, and placed the soil back into its original plot where some also had charate added. Only one study completed the entire experiment in the field (Coates, 2003). Coates (2003) applied L.S. directly to the soil, monitored the experiment for one year, and found significant increase in seed germination for herbaceous species.

Christensen and Muller (1975) studied the general trends of germination rates and biomass after fire effect treatments in chaparral. They found no significant differences, neither enhancement nor suppression, in germination rates among soil seed banks treated with ash and commercial fertilizer, and no additional nutrients added in natural areas which had been cleared for this study. They did not report on germination differences by species or other categories, only by total seed germination. The Christensen and Muller (1975) research could be improved by identifying all plants to species which germinate following the treatments and grouping them into meaningful categories. Categories such as native, non-native, annual, perennial, and shrub may be better indicators of plant disturbance response. It is possible that the mean number of plants which germinated remained the same while its composition was significantly different. It may be hypothesized that non-native plants have the highest germination in the control, but that native herb and shrub germination increases with treatments. These hypothesized differences are only one example of how the composition may shift. Ash and commercial fertilizer treatments may be viable treatments in restoration if they affect the composition of plants which germinate. Charcoal additives or fertilizer may be especially desirable in restoration if they increase germination of keystone species such as Chamise or Black Sage.

The treatments with charate will be harder to replicate in the restoration settings. Some of the plants tested, such as Deerweed, had much lower germination when treated with charate. The charate has an unknown effect on many of the herbs and grasses which are seeded. It would be unwise to increase the germination of a few species while compromising the germination of others. Instead, the chemical component of fire should be simulated without exposing all of the species in the seed mixture to the treatment.

III. Evaluation of Restoration at Rocky Canyon Quarry

A. Chaparral Restoration

Introduction

During my study of Rocky Canyon Quarry (RCQ), I examined the previously restored slopes to evaluate the success of the revegetation efforts. As of May 2008, the cover and composition of restored slopes are still in various stages of succession, and none has formed dense chaparral stands yet. Revegetation has been more successful on some slopes, and even on some sections of slopes, than on others. Some sections of steep slopes are still in ruderal or early successional phases and have low native shrub cover. Others have a significant cover of native subshrubs, but the shrub cover and composition is still not the same as that on the surrounding, undisturbed slopes

Beginning in 1998, five sites have been restored. The timeline and treatments to each site are uncertain. References used for the site location have been moved due to the active mining operations. Site 1 is believed to be an unmined natural area that was disturbed during the restoration process of the slopes below. All of the other slopes were mined and restored as described in the introduction. The seed mix and number of plantings are uncertain. In addition, Cat Scolari's experimental slope, Slope 5, had supplemental hand-cast seed. All slopes are believed to have been hydroseeded by 2000 and are between seven and nine years old. Slope age decreases sequentially i.e. Slope 1 is the oldest slope followed by Slope 2, Slope 3, Slope 4, and Slope 5 (Holland and Langford, 1995; Holland and Bernstein, 1997; Holland and Bernstein, 1998; Holland and Petroelje, 1999; K. Roy, Personal Communication, 5-21-2008).

While my research seeks to determine new, more efficient ways to improve restoration of chaparral communities on mined slopes at RCQ, I also evaluated the plant cover and success of restoration on existing slopes.

Method

Quantitative vegetation analysis on the steep slopes was not possible because traversing the slopes was dangerous and destructive to the restoration projects. Therefore, I decided to evaluate the plant cover by taking photographs of the area and evaluating the plant cover as best I could from the photos. Only qualitative vegetation data was taken. A species list was compiled by walking on the terraces above and below each slope.

Reference Site Data Collection

Morro Group, Inc (1995) determined the minimum criteria in a five-year-old chaparral or coastal scrub to have at least 60% shrub cover and “species composition similar to pre-disturbance conditions”. To quantify these goals, Bernstein (1999) sampled mature coastal scrub located on an on-site reference slope and on another site immediately east of the property in 1998 to determine species composition. The vegetation was sampled in three strata based on size of the plants: upper, middle, and lower strata. Bernstein established six randomly placed 10 m transects on the slopes and sampled the vegetation at every meter along the transect for a total of 60 sampling points. The herbaceous vegetation was sampled in four meters by four meters quadrats located in the middle of each transect to determine herbaceous plant density.

Performance Parameters and Standards for Chaparral Native Shrub Cover

Bernstein (1999) created performance standards for the coast shrub vegetation at five, 10, and 15 years after restoration based on sampling results and minimum criteria set forth by the Morro Group, Inc (1995). Results from the sampling were directly used for the year 15 performance parameters. Based on natural succession she noted that the early successional stages were mostly colonizing, herbaceous plants. However, the shrubs would gradually start to replace the herbaceous cover and become the dominant cover on the slopes with time. Her plant cover parameters used both vegetation cover and number of native plants species as shown on the table below (Table 6).

Minimum performance parameters	Year 5	Year 10	Year 15
Absolute vegetation cover (%)	70	80	90
Absolute shrub cover (%)	50	60	70
Absolute vegetation cover – Shrub layer (%)	55	65	75
Absolute vegetation cover – Herb layer (%)	60	50	40
Number of native species	7	8	9

Table 6. Success criteria for restoration at RCQ. Bernstein's (1999) performance standards for vegetation cover on restoration sites.

Results

Few areas of the restored slopes appear to be meeting the performance standards; however. No quantitative data was gathered; so my results are based on visual examination of the slopes in the field, hand-held camera photographs, and aerial photographs. The species list for all chaparral sites is included in Table 7.

Habit	Plant Name	Slope 1	Slope 2	Slope 3	Slope 4	Slope 5
Grass	<i>Avena barbata</i>	LA	LA	LA	LA	LA
	<i>Avena fatua</i>	LA	LA	LA	LA	LA
	<i>Bromus hordeaceus</i>	LA	LA	LA	LA	LA
	<i>Bromus madritensis</i>	LA	LA	LA	LA	LA
	<i>Hordeum brachyantherum</i>	COM	COM	COM	COM	COM
	<i>Lolium multiflorum</i>	LA	LA	LA	LA	LA
	<i>Melica imperfecta</i>	UNK	UNK	UNK	UNK	UNK
	<i>Nassella</i> spp.	UNK	UNK	UNK	UNK	UNK
	<i>Polypogon monspeliensis</i>	UNK	UNK	UNK	UNK	UNK
	<i>Vulpia microstachys</i>	COM	COM	COM	COM	COM
	<i>Vulpia myuros</i>	COM	COM	COM	COM	COM
Herb	<i>Amsinckia</i> sp.	LA	LA	LA	LA	LA
	<i>Artemisia douglasiana</i>	UNK	UNK	LCOM	LCOM	UNK
	<i>Brassica nigra</i>	UNK	UNK	UNK	UNK	UNK
	<i>Castilleja exserta</i>	UNK	UNK	UNK	UNK	UNK
	<i>Centaurea mellitus</i>	COM	COM	COM	COM	COM
	<i>Centaurea solstitialis</i>	COM	COM	COM	COM	COM
	<i>Cichorium intybus</i>	UNK	UNK	UNK	UNK	UNK
	<i>Dicentra chrysantha</i>	UNK	NS	NS	NS	NS
	<i>Dichelostemma</i>	UNK	UNK	UNK	UNK	UNK
	<i>Erodium cicutarium</i>	COM	COM	COM	COM	COM
	<i>Erodium</i> sp.	COM	COM	COM	COM	COM
	<i>Eschscholzia californica</i>	UNK	UNK	UNK	UNK	UNK
	<i>Filago gallica</i>	COM	COM	COM	COM	COM
	<i>Gnaphalium californicum</i> ***	COM	COM	COM	COM	COM
	<i>Gnaphalium canescens</i> ssp. <i>beneolens</i> ***	UNK	UNK	UNK	UNK	UNK
	<i>Gnaphalium luteo-album</i>	UNK	UNK	UNK	UNK	UNK
	<i>Hemizonia</i> sp.	UNK	UNK	UNK	UNK	UNK
	<i>Hirschfeldia incana</i>	LCOM	LCOM	LCOM	LCOM	LCOM
	<i>Hypochaeris glabra</i>	COM	COM	COM	COM	COM
	<i>Juncus patens</i>	NS	NS	LA	NS	NS
	<i>Lotus strigosus</i>	COM	COM	COM	COM	COM
	<i>Lupinus nanus</i>	UNK	UNK	UNK	UNK	UNK
	<i>Melilotus indica</i>	COM	COM	COM	COM	COM
	<i>Salvia columbariae</i>	UNK	UNK	UNK	UNK	UNK
	<i>Solanum xanti</i> ***	UNK	UNK	UNK	UNK	UNK
	<i>Spergula arvensis</i> ssp. <i>arvensis</i>	COM	COM	COM	COM	COM
	<i>Spergularia</i> sp.	UNK	UNK	UNK	UNK	UNK
	<i>Stephanomeria</i> sp.	COM	COM	COM	COM	COM
	<i>Trifolium</i> sp.	UNK	UNK	UNK	UNK	UNK
Subshrub	<i>Helianthemum scoparium</i>	UNK	UNK	UNK	UNK	UNK
	<i>Lotus scoparius</i>	DOM	DOM	DOM	DOM	DOM
Shrub	<i>Adenostoma fasciculatum</i>	UNK	UNK	UNK	UNK	UNK
	<i>Arctostaphylos glaucus</i>	UNK	UNK	UNK	UNK	UNK
	<i>Baccharis pilularis</i> ***	UNK	UNK	UNK	UNK	UNK
	<i>Ceanothus cuneatus</i>	UNK	UNK	UNK	UNK	UNK
	<i>Cercocarpus betuloides</i>	UNK	UNK	UNK	UNK	UNK
	<i>Eriogonum fasciculatum</i>	DOM	DOM	DOM	DOM	DOM
	<i>Eriophyllum confertiflorum</i> ssp. <i>confertiflorum</i> ***	UNK	UNK	UNK	UNK	UNK
	<i>Heteromeles arbutifolia</i>	UNK	NS	NS	NS	NS
	<i>Mimulus aurantiacus</i>	COM	COM	COM	COM	COM
	<i>Salvia mellifera</i>	COM	COM	LA	COM	COM
Tree	<i>Pinus sabiniana</i>	UNK	NS	NS	NS	NS
	<i>Salix lasiolepis</i> ***	NS	NS	UNK	NS	NS

Table 7. Species list for all chaparral restoration sites at RCQ. Description is on page 51.

Table 7 continued. Abbreviations for abundance include uncommon (UNK), common (COM), locally common (LCOM), dominant (DOM), locally abundant (LA), and not seen (NS). Uncommon (UNK) includes plants with few individuals throughout the study site. Common (COM) includes plants which are numerous and widely distributed on the site. Dominant (DOM) includes plants which are numerous, widely distributed on the site, and have significant cover. Locally abundant (LA) includes plants which are abundant to dominant only over a portion of the study site. Locally common (LCOM) includes plants which are common only over a portion of the study site. Not seen (NS) is used as an abbreviation because thorough observations of the slopes were very difficult therefore we are uncertain if the plant is absent or not seen. Plants with three asterisks (***) were not seeded or planted.

The restored areas meet few of the performance parameters for a five-year old or 10-year-old chaparral revegetation site. All of the sites have at least eight native species present and at least 50% herb layer coverage, which meet the set parameters (Table 6, 7). However, much of area is bare mineral soil and lacks vegetation. There are many areas on the slopes where there are lower amounts of vegetation cover, shrub species cover, and shrub layer than the performance parameters, but no quantitative measurements were taken (Fig. 5).

Figure 5. Spring 2008 aerial photograph of the chaparral restoration sites
(GoogleEarth, 2008).

The dominant plants throughout all slopes are subshrubs, such as *Lotus scoparius* (Deerweed) and *Eriogonum fasciculatum* (California Buckwheat), which have a visually estimated cover of less than 50%. *Mimulus aurantiacus* (Sticky Monkeyflower) and *Salvia mellifera* (Black Sage) occur throughout but are not common, and they have a visually estimated cover of less than five percent. *Adenostoma fasciculatum* (Chamise) and *Ceanothus cuneatus* (Buckbrush) occur in isolated areas, generally on the berm above the slopes or on the rock wall beneath the slopes, and they have a visually estimated cover of less than one percent. Large areas on some slopes are dominated by dead annual grasses with a *Hirschfeldia incana* (Perennial mustard) overstory which have a visually estimated cover of five to 10%. These areas dominated by annuals appear grey

in the photograph (Fig. 5, 6). As described above, shrub species cover does meet the minimum criteria (Table 6).

Figure 6. Composite photograph of chaparral restoration sites. The photos were taken during April of 2008 of the east facing slopes from in between the second and the third slope on the southern facing portion.

The shrubs are small and appear stunted in their growth. The majority of subshrubs and shrubs are less than one-half meter tall. Deerweed which is commonly about one-half meter tall in natural areas is less than common stature. The shrub layer has a visually estimated cover of less than 10% and therefore these sites do not meet the set parameter for shrub layer. Since the majority of vegetation remains in the herb layer, all sites meet the minimum criteria for this parameter (Table 6).

Shrubs reached greater heights when growing on berms, around the rock at the base of the slope, and on the terraces. These sites have deeper soil and thus greater water holding capacity. The rocks near the toe of the slope and terraces also received much of the early

soil erosion and continue to receive seed rain from above. The berms did not receive erosion or seed rain. However, the greater plant growth around the berms may also be a result of the structure of berm, up to one meter high and one-half to one-and-one-half meters wide of piled topsoil which acts as a dam and collects moisture. The berms did not receive erosion or seed rain. Generally, the eastern-facing slopes appear to have less native cover than the southern-facing slopes. Slope 2, Slope 3, Slope 4, and Slope 5 all have less than 60% visually estimated total vegetation cover (Fig. 5, 6). Therefore these sites do not meet the set parameter for total vegetation cover (Table 6).

Slope 1 has the highest cover of native shrubs. California Buckwheat and Deerweed dominate. These shrubs have formed an open shrubland with one half to more than one meter in between shrubs. Pine cones and seedlings of *Pinus sabiniana* (Foothill Pine) were observed on the upper berm showing natural recruitment to the site from nearby woodlands. Erosion on this slope is minimal when compared to the other slopes (Fig. 5, 6, 7).

Figure 7. Spring 2008 photograph of the chaparral restoration Slope 1. The photographs were taken during April of 2008 of the first slope from the terrace beneath.

Slope 2, Slope 3, and Slope 4 are similar and characterized by open areas. The majority of the slope is bare mineral soil which occurs in two distinct manners: (1) there are large areas, greater than 10 m x 10 m, which lack vegetation and (2) smaller areas in between shrubs where shrubs are routinely spaced one quarter to one meter apart from one another (Fig. 8, 9). Much of the large expanses of bare mineral soil have ruts caused by erosion, and rocks are exposed due to topsoil erosion during heavy winter rains. Like the vegetation on Slope 1, the dominant shrubs on these slopes are Deerweed and California Buckwheat, but they form a much higher cover on Slope 1. Sticky Monkeyflower and Black Sage are also common on the slopes but have a lower cover. Few of the shrubs are

more than one-half meter tall. Shrubs which are more than one-half meter tall are restricted to the berm or rock face below.

Figure 8. Spring 2008 composite photograph of chaparral restoration sites. The area is labeled with the numbers one through five beginning at the top of the slope. The photographs were taken during April of 2007 of the southern facing slopes from the road.

Figure 9. Large expanses of erosion with rutting and loss of topsoil on chaparral restoration Slope 2. The photograph was taken during April of 2008 of the southern-facing portion of Slope 2 from the terrace beneath.

The slopes do have a few typical chaparral climax species, but they are not common. The eastern facing portion of Slope 5 has the highest cover of keystone chaparral shrubs including *Arctostaphylos glauca* (Bigberry Manzanita), Chamise, and Buckbrush. However, these climax species are uncommon and remain less than one meter tall. Deerweed and California Buckwheat remain dominant. This portion of Slope 5 has minimal erosion (No photograph was taken). This area was near Cat Scolari's experimental site and routinely received hand-cast seed when she visited the site to complete experiments (M. Elster, Personal Communication, 9-26-2007).

Horticultural varieties of some plants were apparently planted in the restoration areas (Fig. 10). Sticky Monkeyflower which occurs throughout the site is a much brighter orange color than occurs in natural populations surrounding RCQ. This color difference indicates that the container stock used on the site was probably a horticultural variety. In the future, close coordination with nurseries and seed companies is recommended to ensure the use of native varieties only.

Figure 10. *Mimulus aurantiacus* (Sticky Monkeyflower) throughout the site is a much brighter orange color than occurs in natural populations surrounding RCQ indicating the container stock used on the site was probably a horticultural variety. The local color of Sticky Monkeyflower, pictured on the left, is a subdued orange. The horticultural variety of Sticky Monkeyflower, pictured on the right, is a very bold orange.

Discussion

The goal of restoration on the steep slopes is to establish a self-sustaining chaparral community which resembles the native chaparral in both composition and cover at RCQ. Currently, the sites meet two of the success criteria: all sites have more native plant species present than the criteria and more than 50% herb layer cover. However, the restoration sites have a vegetation cover that is below the success criteria. In the future, I recommend both supplemental seeding and planting on the slopes to increase plant cover. I also recommend improved erosion control techniques. There are two main techniques which could improve erosion control: (1) use new bonded fiber technology, such as Flex Terra, in the hydroseed mix or (2) irrigate hydroseed before winter rains begin to allow seeds to germinate and allow their roots to hold the soil. I suggest using higher rates of seed application and pre-treating the seeds with liquid smoke (L.S.), heat, or smoke to enhance germination rates. In addition, supplemental plantings will also increase density, especially on the berms and tops of slopes where plants may contribute seed rain to the entire area.

Horticultural varieties, such as Sticky Monkeyflower, do not resemble the native chaparral's composition. In the future, coordination with nurseries and seed companies to ensure the use of native varieties is integral to the success. These horticultural varieties do not support goals four and five of the restoration project #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. Therefore, it is recommended that plants which are obviously horticultural varieties are removed from restoration projects.

The chaparral restoration sites are not similar to the native chaparral in both composition and cover at RCQ. The rangelands above the east and southern facing restoration area have *Quercus douglasii* (Blue Oak) and Foothill Pine woodland with a grass understory (Fig.11). *Quercus agrifolia* (Coast Live Oak) is also present but not common. The steeper slopes of the eastern-facing hillsides have chaparral dominated by Chamise. At this time, there are no Blue Oaks established, and only a few Foothill Pines are present along the restoration site's eastern berm edge. All slopes have Chamise throughout the site, but there are very few plants. The site should continue to have remediation such as supplemental seeding and planting of the species mentioned above until restoration goals are achieved.

Figure 11. East facing portion of Slope 3. The photograph was taken from the road beneath.

As discussed previously, natural succession is an important tool in restoration ecology. When seeding and planting an area, there must be a mixture of pioneer species, ones that are the first to become established on a site after disturbance, and climax species. Many of the pioneer plants, such as Deerweed, also add nitrogen to the soil through the symbiotic relationship with root bacteria. Natural succession following fire in chaparral has been widely studied by many investigators. However, there is a large difference between succession after a fire and succession on the slopes of RCQ where both the vegetation and topsoil have been completely removed and then reapplied after mining. The table below summarizes typical successional events in chaparral following fire and post-mining restoration at RCQ (Table 8). Both post-fire and post-mining successions are dominated by herbaceous plants during the first year after disturbance. However, post-

mining succession has a far greater cover by individual species and grass and less species diversity than post-fire succession. From two to four years after disturbance both sites have increased perennials, especially subshrubs. However, annual grass cover continues to be high for post-mining restoration. There is a clear distinction between post-fire and post-mining restoration from this point forward. The post-mining restoration remains in the two to four years after disturbance stage, where subshrubs dominate, for at least 10 years or more. In comparison, the post-fire succession transitions from subshrub dominance to shrub dominance much more quickly. (Keeley and Keeley, 1981; Keeley and Soderstrom, 1986; Holland and Langford, 1995; Holland and Bernstein, 1997; Holland and Bernstein, 1998; Holland and Petroelje, 1999; Holland, 2002, 2002)

	Fire		Post-mining restoration	
Years after disturbance	Response in vegetation		Response in vegetation	
1	Rapid growth of annual dormant seeds from soil seed bank which become co-dominant.	<i>Papaver californicum</i> <i>Emmenanthe penduliflora</i> <i>Phacelia</i> spp.	Rapid growth from seed mix which composes more than 90% of the relative cover plant cover.	<i>Eschscholzia californica</i> * <i>Vulpia microstachys</i> *
	Rapid growth of dormant bulbs and which become co-dominant.	<i>Calochortus</i> spp. <i>Brodiaea</i> spp. <i>Zigadensus</i> spp.	Few bulbs re-sprout.	<i>Dicentra chrysantha</i> <i>Dichelostemma capitatum</i>
	Perennial herbs sprout from soil seed bank	<i>Delphinium</i> spp. <i>Scrophularia californica</i>	Perennial herbs sprout from seed mix and soil seed bank.	<i>Gnaphalium</i> spp. <i>Solanum xanti</i>
	Slow shrub and subshrub recruitment from both soil seed bank and resprouting.	<i>Adenostoma fasciculatum</i> <i>Arctostaphylos</i> spp. <i>Ceanothus</i> spp. <i>Eriophyllum confertiflorum</i> <i>Helianthemum scoparium</i> <i>Lotus scoparius</i> <i>Salvia mellifera</i>	Very low shrub and subshrub recruitment from seed mix and soil seed bank.	<i>Eriogonum fasciculatum</i> <i>Helianthemum scoparium</i> <i>Lotus scoparius</i> <i>Salvia mellifera</i>
2 to 4	Herbaceous perennials and subshrubs become dominant. Maximum subshrub cover is reached.	<i>Eriophyllum confertiflorum</i> <i>Lotus scoparius</i> <i>Romneya</i> spp. <i>Salvia mellifera</i>	Shrubs, subshrubs, and herbaceous perennials increase in cover.	<i>Eriogonum fasciculatum</i> * <i>Helianthemum scoparium</i> <i>Lotus scoparius</i> *
3 to 9	Shrubs increase in cover to pre-fire levels and crowd out annuals, herbaceous perennials, and subshrubs.	<i>Adenostoma fasciculatum</i> * <i>Arctostaphylos</i> spp.* <i>Ceanothus</i> spp.*	Shrubs, subshrubs, and herbaceous perennials increase in cover.	<i>Eriogonum fasciculatum</i> * <i>Lotus scoparius</i> * <i>Salvia mellifera</i>
			Annuals remain dominant in areas without herbaceous perennials, subshrubs, and shrubs.	<i>Bromus madritensis</i> * <i>Vulpia microstachys</i> *
10 to 50	Shrubs form a dense canopy with little to no understory growth. Significant build-up of senescing plant matter occurs.	<i>Adenostoma.fasciculatum</i> * <i>Arctostaphylos</i> spp. <i>Ceanothus</i> spp.	Shrubs begin to regenerate. Shrubs increase in cover and crowd out herbaceous perennials.	<i>Adenostoma fasciculatum</i> <i>Ceanothus cuneatus</i> <i>Eriogonum fasciculatum</i> * <i>Lotus scoparius</i> * <i>Salvia mellifera</i>
>25 to 50	Shrubs continue to senesce. The plant only has leaves on the margins and the interior are without leaves.	<i>Adenostoma fasciculatum</i> * <i>Arctostaphylos</i> spp. <i>Ceanothus</i> spp.	PROJECTED: Shrubs become dominant.	<i>Adenostoma fasciculatum</i> * <i>Arctostaphylos glauca</i> <i>Ceanothus cuneatus</i> <i>Salvia mellifera</i> *
	Herbs occur in shrub gaps.	<i>Calochortus</i> spp. <i>Nassella</i> spp.		

Table 8. Fire and mining succession compared. Chaparral ecological succession after fire in southern California (Keeley and Keeley, 1981; Keeley and Soderstrom, 1986)

compared to current post-mining restoration at RCQ (Holland and Langford, 1995; Holland and Bernstein, 1997; Holland and Bernstein, 1998; Holland and Petroelje, 1999; Holland, 2002, 2002). The species are listed in alphabetical order. Asterisks (*) indicate plants which are dominate in cover. The restoration vegetation response and dominant species from 10 to 50 years is based on projected results.

The clear distinction between post-fire and post-mining succession are described in more detail to understand potential remediation at RCQ. Christensen and Muller (1975) found Chamise had 80-90% cover in 10 year-old post-fire, however the RCQ restoration sites have 10% to 20% shrub cover and are grass dominated. Some Black Sage and California Buckwheat re-colonized RCQ. On these slopes there has been little natural recruitment of Chamise, *Ceanothus* spp. and Manzanita, chaparral climax species. Deerweed, Black Sage, and California Buckwheat, all early successional species in chaparral, have partially re-colonized these areas.

One difference between the natural areas sampled by Christensen and Muller (1975) and RCQ is the natural areas' resprouting shrubs. These resprouting shrubs account for 69 to 96% of pre-fire shrubs depending on fire intensity and rapidly regain their stature within a few years (Moreno and Oechel, 1991). Due to lack of resprouting shrubs at RCQ, these species must be supplemented with seeding and/or planted container stock.

Past restoration projects have shown that California Buckwheat, Deerweed, and Black Sage were successful secondary colonizing species. While they do not need any heat and or smoke treatment to break dormancy, fire effects do enhance germination (Keeley and Fotheringham, 1998a). This partially explains why these species are also good colonizers

on the restored slopes without fire. Any climax chaparral species such as Chamise, *Arctostaphylos* spp. (Manzanita), and *Ceanothus* spp. which require fire effects to break seed dormancy or resprout vegetatively were rare on restoration sites (Bernstein, 1999). Chamise and some species of *Arctostaphylos* are facultative seeders. Some species of *Ceanothus* are obligate seeders, and their seeds need heat shock or smoke exposure to break dormancy (Quinn and Keeley, 2006). It is important to understand the role of various fire effects on seed dormancy, recruitment, and other ecosystem restoration.

Erosion appears to have a stronger effect on seedling establishment at RCQ by moving seeds from higher on the hill to a lower position. This may be due to the low germination rate of Chamise without fire treatment. The seeds do not germinate during the first year. The hydroseed mix begins to erode during the end of the first year and throughout the second year. Delayed germination occurs after erosion has occurred. Solutions are needed to increase shrubs' establishment throughout the hillsides. Solutions may include increase seedling establishment with seed pre-treatments and irrigation, increasing erosion control properties of the hydroseed mix, roughening the soil surface with rocks and soil contours to capture seeds, and increasing the amount of container stock.

Another difference between mined and natural slopes may be the potential rooting depth of shrubs. Research using ground penetrating radar may determine if newly-exposed bedrock presents a barrier preventing underground root systems from penetrating deeply. Thus, chamise, with roots up to eight and one-half meter deep, may continue to be severely stunted until these cracks develop or are constructed (Dallman, 1998).

Restoration Supplement

During the fall of 2007, supplemental hand seeding occurred. Most of the seeds were purchased from S&S Seeds in 2004 for experiments, but were not used in entirety.

California Buckwheat and Deerweed were cast onto the large barren expanses of the slopes. The species are the first colonizers and have the ability to add nitrogen to the soil.

In addition, approximately 10 pounds of mixed native seeds including Chamise,

Buckbrush, Black Sage, Sticky Monkeyflower, California Buckwheat, *Lupinus nanus*

(Sky Lupine), *Lupinus hirsutissimus* (Stinging Lupine), *Nassella* spp. (Needlegrass), and

Eschscholzia californica (California Poppy) were hand cast onto areas with established

California Buckwheat and Deerweed. We expect both California Buckwheat and

Deerweed will serve as nurse plants and aid in the establishment of keystone chaparral

shrubs. Blue Oak, *Pinus sabiniana*, and Coast Live Oak were collected on-site during the

fall of 2007. These seeds were scratched into the soil on the berms above the slopes.

B. Oak Woodland Restoration

Introduction

The oak woodland restoration site was shaped and planted with natives in 1993. The site is located at the north end of Rocky Canyon Quarry (RCQ) along an AT&T fiber optics line. Topsoil was not available, so decomposed granite was used to fill and shape the site. Approximately 500 large boulders ranging from one-third to one meter in diameter were placed throughout the site. This provides a more natural looking area that blends with the rock outcrops on the surrounding hillsides and also provides microhabitats for plant growth. The areas around the boulders hold water longer and moderate the soil temperature making the microhabitats somewhat more favorable for plant growth.

When established in 1993, the oak woodland restoration site was divided into three treatment zones marked by rebar stakes with a metal tag and PVC sheath: (1) heavily planted with container stock and not hydroseeded (2) moderately planted with container stock and hydroseeded, and (3) only hydroseeded (Table 9). Generally, the one-gallon container stock plantings had two meter diameter circles of shredded redwood bark around them. When established, the oak woodland restoration site had a flat area along Rocky Canyon Road and a steep, 3:1 slope on the side. However, in the last five years, the site has been encroached upon by both a conveyor belt to the north and a stockpile of decomposed granite to the northwest. The conveyor belt supports physically encroached on Plot 3. The stockpile of decomposed granite buried much of the lower reaches of the slope.

Plot	Original area (m ²)	Hydroseed	Container stock density (plant/ m ²)
1	1106.9	No	0.296
2	1523.7	Yes	0.063
3	858.2	Yes	0.023

Table 9. Oak woodland restoration plan. The original size, hydroseed treatment, and density of container stock plantings in the oak woodland experimental plots are included in the table above (Holland and Bernstein, 1997).

Methods

To determine the species composition of the oak woodland restoration site, I conducted multiple surveys of the entire site during the winter, spring, and fall of 2007 (January 17, February 20, April 7, April 14, April 19, April 24, and September 30). During these surveys I recorded all species found in identifiable condition and noted if they were in flower or fruit. Identification and nomenclature followed the Jepson Manual (Hickman, 1993).

To sample the cover and density of vegetation on the site I used both the point intercept and belt-transect methods (Barbour et al., 1999). In 1993, permanent transects were established and marked with rebar stakes for sampling purposes; however, over the years the metal tags and many of the stakes were removed or lost. Therefore, I established new, temporary transects for the 2007 sampling period. I strung a measuring tape along the edge of the oak woodland site next to Rocky Canyon Road and used a random number table to determine the distance along the tape to run perpendicular transects. The starting points to begin vegetation sampling on these transects were determined using a random number table (0-359). Random number tables were constructed using a random number generator (Random.org, 2007), the minimum number was one and the maximum number was determined by either the distance along the edge of the site next to the road or the average width of the site.

Twelve transects were sampled in each of the three plots for a total of 36 transects. All transects were 10 m long; however, if a section of the transect extended outside the site boundaries, only the section within the area was sampled. Therefore, there were a total of

31 complete transects (10 m) and five transects that were less than 10 m long. The shorter transects were 1.0, 3.6, 5.0, 6.8, and 7.8 meters long (Table 10). The 36 transects were used both for point intercept sampling (for cover) and belt transect sampling (for density) as explained below.

Transect name	Transect length (m)		
	Plot 1	Plot 2	Plot 3
1	10	10	3.6
2	10	10	10
3	6.8	10	10
4	10	10	10
5	10	10	7.8
6	10	10	10
7	10	7.4	10
8	10	10	10
9	5	10	10
10	1	10	10
11	10	10	10
12	10	10	10
Length sampled	102.8	117.4	111.4
Points sampled	514	587	557
Area sampled (m ²)	204.6	234.8	222.8

Table 10. Transect length, area and points sampled during spring of 2007.

I used a point intercept sampling method to measure the plant cover along the 36 transects described above (Barbour et al., 1999). A meter stick was lowered perpendicular to the ground at 20 cm intervals along the transect. This resulted in 514 sampling points in Plot 1, 587 in Plot 2, and 557 in Plot 3. For each sampling point, the plant species touched by the meter stick were identified and recorded. Plants which

touched each sampling point were further divided by heights into three layers: (1) less than one-half meter, (2) one-half to one meter, and (3) greater than one meter. All plants touched within each layer were included. Grass litter was only recorded if no plants were present in the less than one-half meter layer. Shrub litter was noted for all layers. These data were used to determine the relative cover of each plant species that occurred along the transect.

Belt transects were utilized to measure density of plant species (Barbour et al., 1999). The belt transect consisted of a two-meter-wide strip centered along each transect. The belt was created by extending meter sticks out from both sides of the line transect and counting all plants that occurred within the belt transect. Only woody species that were rooted within the 36 belt transects were counted. These plant species were also tallied by size classes (<0.5 m, 0.5-1 m, 1-3 m, and >3 m).

I believe that the data might also provide information about natural recruitment. Because I could not determine if the plant species in the plots were from plantings, hydroseeding, or natural recruitment, I used height as an indicator. I assumed that shrubs with a stature less than one-half meter likely represented recruitment after the initial container stock and hydroseeding treatments. All shrubs over one-half meter in height were assumed to have been planted in 1993 and examined to determine if they were marked with a metal tag. These marked shrubs were also used to determine survival rates of the original plantings in 1993.

Results

Species Composition

Young individuals of *Quercus agrifolia* (Coast Live Oak), *Adenostoma fasciculatum* (Chamise), *Eriogonum fasciculatum* (California Buckwheat), and *Mimulus aurantiacus* (Sticky Monkeyflower) were found during my surveys. Young Chamise, California Buckwheat, and Sticky Monkeyflower populations were always near mature parent plants. Coast Live Oak was not near mature parent plants but occurred in the understory of shrubs. Coast Live Oak trees on the site have not produced acorns yet; therefore, recruitment is probably a result of acorns dispersal from the surrounding native oak communities. Young individuals of *Arctostaphylos glauca* (Bigberry Manzanita), *Trichostema lanatum* (Woolly Bluecurls), *Quercus douglasii* (Blue Oak), *Ceanothus cuneatus* (Buckbrush), and *Heteromeles arbutifolia* (Toyon) were not found during these surveys. In addition, previously absent *Pinus sabiniana* (Foothill Pine) is now present on both Plot 2 and Plot 3. One Foothill Pine seedling, which is less than eight centimeters tall, occurs adjacent to a tree with seed cones in Plot 3 (Table 12).

Nat.	Form	Plant name	Plot 1						Plot 2						Plot 3					
			1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.
Yes	Tree/Shrub	<i>Adenostoma fasciculatum</i>	A	P	P	P	COM	FL,FR,SD	A	P	A	P	COM	FL,FR,SD	A	A	A	P	Lcom	FL,FR,SD
NA	Grass/Forb	<i>Amsinckia</i> sp.	A	A	A	A	-	-	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR
Yes	Grass/Forb	<i>Amsinckia spectabilis</i>	A	A	A	A	-	-	A	A	A	A	-	-	P	A	A	P	UNK	FL,FR
No	Grass/Forb	<i>Anthemis cotula</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Tree/Shrub	<i>Arctostaphylos glauca</i>	P	A	A	P	COM	FL,FR*	A	A	A	P	COM	FL,FR*	A	A	A	P	UNK	FL,FR
Yes	Tree/Shrub	<i>Artemisia douglasiana</i>	P	A	A	A	-	-	A	A	A	A	-	-	P	A	A	A	-	-
No	Grass/Forb	<i>Avena barbata</i>	P	P	P	P	LA	FL,FR	P	P	P	P	LA	FL,FR	P	P	P	P	LA	FL,FR
No	Grass/Forb	<i>Avena fatua</i>	A	P	P	P	LA	FL,FR	A	P	P	P	LA	FL,FR	A	P	P	P	LA	FL,FR
Yes	Tree/Shrub	<i>Baccharis pilularis</i> ***	P	P	P	P	UNK	FL,FR	A	P	P	P	UNK	FL,FR	A	P	P	P	UNK	FL,FR
No	Grass/Forb	<i>Brassica nigra</i>	P	A	A	A	-	-	A	A	A	A	-	-	P	A	A	A	-	-
No	Grass/Forb	<i>Bromus hordeaceus</i>	P	P	P	A	-	-	P	P	P	A	-	-	P	P	P	A	-	-
No	Grass/Forb	<i>Bromus madritensis</i>	A	P	P	P	LA	FL,FR	P	P	P	P	LA	FL,FR	P	P	P	P	UNK	FL,FR
No	Grass/Forb	<i>Centaurea melitensis</i>	P	A	A	A	-	-	P	A	A	P	UNK	FL,FR	P	A	A	A	-	-
No	Grass/Forb	<i>Centaurea solstitialis</i>	A	A	A	A	-	-	A	A	P	P	UNK	FL,FR	A	A	A	A	-	-
No	Grass/Forb	<i>Centaurea</i> sp.	A	A	A	A	-	-	A	A	A	A	-	-	A	P	P	A	-	-
Yes	Tree/Shrub	<i>Cercocarpus betuloides</i>	A	A	A	P	UNK	FL,FR	A	A	A	A	-	-	A	A	A	A	-	-
No	Grass/Forb	<i>Cichorium intybus</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Grass/Forb	<i>Clarkia purpurea</i> ssp. <i>quadrivulnera</i> ***	A	A	A	A	-	-	A	A	A	A	-	-	P	P	P	A	-	-
Yes	Tree/Shrub	<i>Dendromecon rigida</i>	A	A	A	P	LCOM	FL,FR	A	A	A	A	-	-	A	A	A	A	-	-

Table 11a. Species list for 1993, 1997, 1998, and 2007 for the oak woodland site (A through D) (USDA, 2008). Codes are listed on page 77.

Nat.	Form	Plant name	Plot 1						Plot 2						Plot 3					
			1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.
Yes	Grass/Forb	<i>Eschscholzia californica</i>	P	A	A	A	-	-	P	P	P	A	-	-	P	P	P	A	-	-
Yes	Tree/Shrub	<i>Eriogonum fasciculatum</i>	A	P	P	P	UNK	FL,FR	A	P	P	P	COM	FL,FR	P	P	P	P	DOM	FL,FR
Yes	Tree/Shrub	<i>Eriophyllum confertiflorum</i> ssp. <i>confertiflorum</i> ***	A	A	A	A	-	-	A	A	A	A	-	-	A	P	P	A	-	-
No	Grass/Forb	<i>Erodium cicutarium</i>	A	A	A	A	-	-	A	A	A	P	Lcom	FL,FR	A	A	P	A	-	-
No	Grass/Forb	<i>Erodium</i> sp.	A	P	A	A	-	-	A	A	A	A	-	-	A	P	A	A	-	-
Yes	Grass/Forb	<i>Epilobium canum</i>				P	UNK	FL,FR				A	-	-				A	-	-
No	Grass/Forb	<i>Filago gallica</i>	P	P	P	A	-	-	P	P	P	P	Lcom	FL,FR	P		P	A	-	-
Yes	Grass/Forb	<i>Gnaphalium californicum</i> ***	A	P	P	A	-	-	A	P	P	P	UNK	FL,FR	A	P	P	A	-	-
Yes	Grass/Forb	<i>Gnaphalium canescens</i> ssp. <i>beneolens</i> ***	A	P	P	A	-	-	A	P	P	P	UNK	FL,FR	A	P	P	A	-	-
No	Grass/Forb	<i>Gnaphalium luteo-album</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Tree/Shrub	<i>Helianthemum scoparium</i>	A	P	P	P	UNK	FL,FR	A	P	P	P	UNK	FL,FR	A	A	A	P	UNK	FL,FR
NA	Forb to Shrub	<i>Hemizonia</i> sp.	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Tree/Shrub	<i>Hesperoyucca whipplei</i>	A	A	A	P	LA	None	A	A	A	A	-	-	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Heteromeles arbutifolia</i>	A	P	P	P	UNK	FL,FR	A	P	A	P	UNK	FL,FR	A	A	A	P	UNK	None
No	Grass/Forb	<i>Hirschfeldia incana</i>	A	A	A	A			A	A	A	P	UNK	FL,FR	A	P	P	A	-	-
Yes	Tree/Shrub	<i>Holodiscus discolor</i> **				A	-	-				A	-	-				A	-	-
Yes	Grass/Forb	<i>Hordeum brachyantherum</i>	A	A	A	A	-	-	A	A	A	A	-	-	P	A	A	A	-	-
NA	Grass/Forb	<i>Hordeum</i> sp.	A	A	A	A	-	-	A	A	P	A	-	-	A	A	A	A	-	-
No	Grass/Forb	<i>Hypochaeris glabra</i>	A	P	P	A	-	-	A	P	P	P	LCOM	FL,FR	A	A	P	A	-	-
Yes	Tree/Shrub	<i>Keckiella cordifolia</i> **				A	-	-				A	-	-				A	-	-

Table 11b. Species list for 1993, 1997, 1998, and 2007 for the oak woodland site (E through K) (USDA, 2008). Codes are listed

on page 77.

Nat.	Form	Plant name	Plot 1						Plot 2						Plot 3					
			1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.
NA	Grass/Forb	<i>Linanthus</i> sp.	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Grass/Forb	<i>Lessingia filaginifolia</i>	A	A	A	P	UNK	FL,FR	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR
No	Grass/Forb	<i>Lolium multiflorum</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
No	Grass/Forb	<i>Lolium perenne</i>	A	P	P	A	-	-	A	P	P	A	-	-	A	P	P	A	-	-
Yes	Grass/Forb	<i>Lotus purshianus</i>	A	P	P	P	LCOM	FL,FR	A	A	A	P	UNK	FL,FR	A	A	A	P	UNK	FL,FR
Yes	Tree/Shrub	<i>Lotus scoparius</i>	P	P	P	P	DOM	FL,FR	P	P	P	P	COM	FL,FR	P	P	P	P	COM	FL,FR
Yes	Grass/Forb	<i>Lotus strigosus</i>	A	P	P	P	LCOM	FL,FR	A	A	A	P	UNK	FL,FR	A	A	A	P	UNK	FL,FR
Yes	Grass/Forb	<i>Lupinus nanus</i>	P	A	A	P	COM	FL,FR	P	A	A	P	COM	FL,FR	P	A	A	A	-	-
Yes	Grass/Forb	<i>Lupinus</i> spp.	A	P	P	A	-	-	A	P	P	A	-	-	A	P	P	A	-	-
Yes	Grass/Forb	<i>Lupinus succulentus</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Grass/Forb	<i>Madia exigua</i> ***	A	A	A	A	-	-	A	P	A	A	-	-	A	P	P	A	-	-
Yes	Grass/Forb	<i>Madia sativa</i>	P	A	A	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
Yes	Grass/Forb	<i>Melica imperfecta</i>	A	P	P	A	-	-	A	P	P	A	-	-	P	P	P	A	-	-
No	Grass/Forb	<i>Melilotus indica</i>	A	A	A	A	-	-	A	A	A	P	Lcom	FL,FR	A	P	P	A	-	-
Yes	Tree/Shrub	<i>Mimulus aurantiacus</i>	P	P	P	P	COM	FL,FR	P	P	P	P	COM	FL,FR	P	P	P	P	DOM	FL,FR
Yes	Grass/Forb	<i>Nassella</i> spp.	P	P	A	P	UNK	FL	P	P	P	P	UNK	FL	P	P	P	P	UNK	FL
Yes	Grass/Forb	<i>Penstemon heterophyllus</i> var. <i>heterophyllus</i> **	A				-	-	A				-	-	A				-	-
Yes	Tree/Shrub	<i>Pinus sabiniana</i>	A	A	A	A	-	-	A	A	A	P	UNK	CN,FR	A	A	A	P	UNK	CN,FR,SD
No	Grass/Forb	<i>Polypogon monspeliensis</i>	P	A	A	A	-	-	P	P	P	A	-	-	P	P	P	A	-	-
Yes	Tree/Shrub	<i>Populus fremontii</i> ***	A	A	A	A	-	-	A	P	P	A	-	-	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Prunus ilicifolia</i> **	A				-	-	P				UNK	None	A				-	-

Table 11c. Species list for 1993, 1997, 1998, and 2007 for the oak woodland site (L through P) (USDA, 2008). Codes are listed on page 77.

Nat.	Form	Plant name	Plot 1						Plot 2						Plot 3					
			1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.	1993	1997	1998	2007	2007 Abun.	2007 Repr.
Yes	Tree/Shrub	<i>Quercus agrifolia</i>	P	P	P	A	-	-	A	A	A	P	UNK	None	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Quercus douglasii</i>	A	A	A	A	-	-	A	A	A	P	UNK	None	A	A	A	P	UNK	0
Yes	Tree/Shrub	<i>Quercus lobata</i>	A	A	A	P	UNK	-	A	A	A	P	UNK	None	A	A	A	P	UNK	0
Yes	Tree/Shrub	<i>Rhamnus californica</i>	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Rhamnus crocea</i> **				A	-	-				A	-	-				A	-	-
Yes	Tree/Shrub	<i>Rhamnus ilicifolia</i>	A	A	A	P	UNK	-	A	A	A	A	-	-	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Rhus trilobata</i>	A	A	A	P	UNK	None	A	A	A	A	-	-	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Ribes</i> sp.	A	A	A	A	-	-	A	A	A	P	UNK	None	A	A	A	A	-	-
No	Grass/Forb	<i>Rumex conglomeratus</i>	A	A	A	A	-	-	A	A	A	A	-	-	A	P	P	A	-	-
No	Grass/Forb	<i>Rumex pulcher</i>	A	A	A	A	-	-	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR
Yes	Tree/Shrub	<i>Salix lasiolepis</i> ***	P	P	P	P	UNK	FL,FR	A	A	A	A	-	-	A	A	A	A	-	-
Yes	Tree/Shrub	<i>Salvia mellifera</i>	A	A	A	P	UNK	FL,FR	P	P	P	P	COM	FL,FR	A	P	P	P	C	FL,FR
Yes	Tree/Shrub	<i>Sambucus mexicana</i>	A	A	A	A	-	-	P	A	A	A	-	-	A	A	A	A	-	-
Yes	Grass/Forb	<i>Solanum xanti</i> ***	A	P	P	A	-	-	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR
No	Grass/Forb	<i>Spergula arvensis</i> ssp. <i>arvensis</i>	A	P	P	P	UNK	FL,FR	A	P	P	P	UNK	FL,FR	A	P	P	A	-	-
NA	Grass/Forb	<i>Spergularia</i> sp.	A	P	P	A	-	-	A	A	P	A	-	-	A	A	P	A	-	-
NA	Grass/Forb	<i>Stephanomeria</i> sp.	A	A	P	P	UNK	FL,FR	A	A	P	A	-	-	A	A	P	A	-	-
Yes	Tree/Shrub	<i>Trichostema lanatum</i>	A	A	A	P	UNK	FL,FR	A	A	A	A	-	-	A	A	A	A	-	-
NA	Grass/Forb	<i>Trifolium</i> sp.	A	A	A	A	-	-	A	A	A	P	UNK	FL,FR	P	A	A	A	-	-
Yes	Grass/Forb	<i>Vulpia microstachys</i>	P	A	P	A	-	-	P	A	A	A	-	-	P	A	A	A	-	-
No	Grass/Forb	<i>Vulpia myuros</i>	P	A	P	A	-	-	P	P	P	P	UNK	FL,FR	P	P	P	A	-	-

Table 11d. Species list for 1993, 1997, 1998, and 2007 for the oak woodland site (Q through Z) (USDA, 2008). Codes are listed

on page 77.

Table 11 (11a, 11b, 11c, and 11d) also contains information about the species such as the plants physiognomy and if it is native to California. The abundance and reproductive state for 2007 are noted as well (Holland and Langford, 1995; Holland and Bernstein, 1997; Holland and Bernstein, 1998). Abbreviations for absence (A) and present (P) are used for each year sampled. Abbreviations for abundance include uncommon (UNK), common (COM), locally common (LCOM), dominant (DOM) and locally abundant (LA). Uncommon (UNK) includes plants with few individuals throughout the study site. Common (COM) includes plants which are numerous and widely distributed on the site. Dominant (DOM) includes plants which are numerous, widely distributed on the site, and have significant cover. Locally abundant (LA) includes plants which are abundant to dominant only over a portion of the study site. Locally common (LCOM) includes plants which are common only over a portion of the study site. * Fruit was present, but in very low densities on some plants and absent from the majority of plants. ** These plants were on the species list for the entire Oakwood plot from 1994 to 1998, but the plot where they were present was not identified. ***Not seeded or planted.

Plant Cover

The trees and shrubs of the overstory (over one meter tall), covered approximately 10% of the oak woodland. The other 90% was composed of understory plants, litter, bare ground, and rocks. Of the trees and shrubs over one meter tall, four species comprised 90% of the total cover in the oak woodland plot: Bigberry Manzanita 38.1%, Foothill Pine 24.5%, Chamise 15.9%, and *Salvia mellifera* (Black Sage) 11.3%. The lower growing trees and shrubs (from one-half to one meter tall) covered about 20% of the oak woodland plot. The same four species comprised 73% of the total plant cover: Bigberry Manzanita 30.4%, Foothill Pine 12.9%, Chamise 16.0%, and Black Sage 13.7%. In this vegetation layer, California Buckwheat was also a dominant comprising 15.2% of the shrub cover (Fig. 12; Table 12, 13, 14).

Figure 12. Photographs of the oak woodland restoration site on April 28, 2008..

Photograph of the oak woodland restoration site on April 28, 2008 from the south (Top left). Plot 1 has high shrub cover to the south (Top left), some large barren expanses, and the stockpile is visible to the northwest (Top right). Plot 2 has barren expanses, recruitment of Foothill Pine, and high weed cover surrounding the utility pole (Bottom left). Plot 3 has high shrub cover to the north near the conveyor belt (Bottom right).

The layer of vegetation that was less than one-half meters tall covered about 20.7% of the oak woodland plot and was composed almost entirely of small shrubs, many of which have recently become established from seed recruitment from the surrounding vegetation. The dominant plants were California Buckwheat (31.4%), Bigberry Manzanita (19.2%), *Lotus scoparius* (Deerweed) (12.2%), and Chamise (10.1%) for a total of 73%. The

herbaceous plants covered less than 2% of the site and over half of this cover was composed of *Nassella spp.* (Needlegrass) (Table 12, 13, 14).

The oak woodland plot was surveyed during a dryer than average year. Much of the common herbaceous plant cover in the area was not have been present. The herbaceous plants may not have germinated during the growing season or they may have died before sampling. The grass litter category combined with all other herbs may serve as an approximate estimate of herbaceous cover during average rain years.

Results are not uniform across the plots. However, no conclusions can be made about the treatments because the original restoration experiment did not have replication. Variable gradients, such as moisture, may exist and confound the treatment response. Therefore, I must cautiously compare the plots.

Plot 1 has the fewest trees and shrubs of all plots, covering only 20% of the area; the other 80% consisted of mostly bare soil and litter. Chamise and Bigberry Manzanita were the co-dominate plants. The majority of Chamise and Bigberry Manzanita were at least one meter tall. Less litter and herbs were present than in any other plot. Plot 1 had the least amount of grass litter, around 1.8% compared to about 12% for all other plots. The litter was dominated by Bigberry Manzanita branches, which were still associated with living plants. About 75% of all plant cover was shrubs, and the remaining 25% was herbs. Sticky Monkeyflower, California Buckwheat, and Black Sage were notably absent from the point intercept data. Plot 1 had the largest number of species present within the point-intercept data with 12 native species of shrubs and trees. (Fig.13; Table 12, 13, 14).

Plot 1 has the highest diversity of native shrubs. It is the only area with *Dendromecon rigida* (Bush Poppy), Woolly Bluecurls, *Epilobium canum ssp. canum* (California Fuchsia), *Hesperoyucca whipplei* (Our Lord's Candle), *Baccharis pilularis* (Coyote Brush), and *Quercus lobata* (Valley Oak) present in the species surveys. Black Sage and California Buckwheat were restricted to the boundary between Plot 1 and Plot 2. These shrubs were not planted as container stock and appear to be progeny of plants from Plot 2 or the surrounding area (Fig.13; Table 12, 13, 14).

Plot 2 is dominated by plant litter and bare mineral soil. Plants covered 25% of the area. California Buckwheat is the dominant shrub. Black Sage, Chamise, Sticky Monkeyflower, and Bigberry Manzanita are not common. Most of the shrubs and trees were over one meter tall, but a large portion were less than one meter. Plot 2 has a utility pole with topsoil around it located within its boundaries. This area, which was recently disturbed, is dominated by herbaceous non-native plants. The majority of non-native plants only occurred in this disturbed area. About 50% of all plant cover in the plot was shrubs, and the remaining 50% was herbs. There were the least number of species present, seven species of shrubs and trees, within the point-intercept data (Fig.13; Table 12, 13, 14).

Plot 3 is also dominated by plant litter and bare mineral soil. Plants covered 31% of the area. California Buckwheat is the dominant plant but Chamise, Bigberry Manzanita, Sticky Monkeyflower, and Black Sage were common. Shrubs in this plot were smaller than those in Plots 1 and 2, and most were between one-half and one meter tall largely. The Plot 3 dominant shrub, California Buckwheat, generally does not grow taller than

one meter and neither does Deerweed, another common plant in the plot. About 50% of all plant cover was shrubs, and the other 50% was herbs. There were nine species of shrubs and trees present within the point-intercept data.

Plot 3 has the fewest number of species and the least native diversity. It lacks some of the dominant shrubs and trees found in the other plots including Chamise and Bigberry Manzanita, and Foothill Pine (Fig.13; Table 12, 13, 14).

Figure 13. Percent of relative plant covers in each plot (1, 2, and 3) for each height classes (less than one-half meter, one-half to one meter, and more than one meter) in 2007.

Plant name

- *Trichostemma lanatum*
- *Spergula arvensis ssp. arvensis*
- *Salvia mellifera*
- *Rumex sp.*
- *Quercus lobata*
- *Pinus sabiniana*
- *Nassella spp.*
- *Moss*
- *Mimulus aurantiacus*
- *Mellica imperfecta*
- *Lotus scoparius*
- *Heteromeles arbutifolia*
- *Hesperoyucca whipplei*
- *Gnaphalium canescens ssp. beneolens*
- *Eriogonum fasciculatum*
- *Epilobium canum ssp. canum*
- *Dendromecon rigida*
- *Centaurea solstitialis*
- *Centaurea mellitus*
- *Bacharis pilularis*
- *Arctostaphylos glaucus*
- *Adenostoma fasciculatum*

Plant name	Plot 1		Plot 2		Plot 3		All	
	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative
<i>Adenostoma fasciculatum</i>	1.70%	17.30%	0.70%	8.00%	2.40%	20.60%	1.60%	15.90%
<i>Arctostaphylos glauca</i>	7.00%	70.70%	3.90%	46.00%	0.50%	4.40%	3.80%	38.10%
<i>Baccharis pilularis</i>	0.00%	0.00%	0.30%	4.00%	0.00%	0.00%	0.10%	1.10%
<i>Eriogonum fasciculatum</i>	0.00%	0.00%	0.50%	6.00%	1.40%	11.80%	0.60%	6.30%
<i>Heteromeles arbutifolia</i>	0.30%	3.40%	0.00%	0.00%	0.00%	0.00%	0.10%	1.10%
<i>Mimulus aurantiacus</i>	0.00%	0.00%	0.20%	2.00%	0.00%	0.00%	0.10%	0.60%
<i>Pinus sabiniana</i>	0.50%	5.20%	2.70%	32.00%	4.20%	35.30%	2.50%	24.50%
<i>Salvia mellifera</i>	0.00%	0.00%	0.20%	2.00%	3.30%	27.90%	1.10%	11.30%
<i>Trichostema lanatum</i>	0.30%	3.40%	0.00%	0.00%	0.00%	0.00%	0.10%	1.10%
Total shrub	9.90%	100.00%	8.50%	100.00%	11.80%	100.00%	10.10%	100.00%
Bare	88.90%		91.50%		88.00%		89.50%	
Shrub litter	1.20%		0.00%		0.20%		0.50%	

Table 12. Absolute and relative cover of all plants greater than one meter tall in all plots and for the entire oak woodland restoration site in 2007.

Plant name	Plot 1		Plot 2		Plot 3		All	
	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative
<i>Adenostoma fasciculatum</i>	3.60%	23.10%	0.70%	5.00%	2.80%	18.80%	2.30%	16.00%
<i>Arctostaphylos glauca</i>	9.40%	60.50%	3.90%	28.70%	0.00%	0.00%	4.50%	30.40%
<i>Baccharis pilularis</i>	0.30%	2.20%	0.30%	2.50%	0.00%	0.00%	0.20%	1.60%
<i>Dendromecon rigida</i>	0.20%	1.10%	0.00%	0.00%	0.00%	0.00%	0.10%	0.40%
<i>Eriogonum fasciculatum</i>	0.00%	0.00%	3.10%	22.50%	3.70%	24.70%	2.20%	15.20%
<i>Heteromeles arbutifolia</i>	0.70%	4.40%	0.00%	0.00%	0.50%	3.50%	0.40%	2.70%
<i>Lotus scoparius</i>	0.30%	2.20%	0.00%	0.00%	0.50%	3.50%	0.30%	2.00%
<i>Mimulus aurantiacus</i>	0.00%	0.00%	1.20%	8.80%	0.40%	2.40%	0.50%	3.50%
<i>Nassella spp.</i>	0.00%	0.00%	0.00%	0.00%	0.20%	1.20%	0.10%	0.40%
<i>Pinus sabiniana</i>	0.50%	3.30%	2.90%	21.20%	2.30%	15.30%	1.90%	12.90%
<i>Quercus lobata</i>	0.30%	2.20%	0.00%	0.00%	0.00%	0.00%	0.10%	0.80%
<i>Salvia mellifera</i>	0.00%	0.00%	1.50%	11.30%	4.50%	30.60%	2.00%	13.70%
<i>Trichostema lanatum</i>	0.20%	1.10%	0.00%	0.00%	0.00%	0.00%	0.10%	0.40%
Total shrub cover	15.50%	100.00%	13.60%	100.00%	14.80%	100.00%	14.60%	100.00%
Bare	82.90%		86.40%		85.10%		84.80%	
Shrub litter	1.50%		0.00%		0.20%		0.60%	

Table 13. Absolute and relative cover of all plants from one-half meter to one meter tall in all plots and for the entire oak woodland restoration site in 2007.

	Plant name	Plot 1		Plot 2		Plot 3		All	
		Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative
Shrubs	<i>Baccharis pilularis</i>	0.90%	4.20%	0.00%	0.00%	0.00%	0.00%	0.30%	1.20%
	<i>Hesperoyucca whipplei</i>	0.30%	1.70%	0.00%	0.00%	0.00%	0.00%	0.10%	0.50%
	<i>Heteromeles arbutifolia</i>	0.90%	4.20%	0.00%	0.00%	0.20%	0.60%	0.30%	1.40%
	<i>Lotus scoparius</i>	2.70%	13.30%	4.40%	19.00%	1.60%	5.60%	2.90%	12.20%
	<i>Mimulus aurantiacus</i>	0.00%	0.00%	3.60%	15.30%	1.40%	5.00%	1.70%	7.00%
	<i>Pinus sabiniana</i>	0.30%	1.70%	2.70%	11.70%	3.10%	11.20%	2.10%	8.70%
	<i>Quercus lobata</i>	0.30%	1.70%	0.00%	0.00%	0.00%	0.00%	0.10%	0.50%
	<i>Salvia mellifera</i>	0.00%	0.00%	2.70%	11.70%	2.60%	9.40%	1.80%	7.40%
	<i>Trichostema lanatum</i>	0.30%	1.70%	0.00%	0.00%	0.00%	0.00%	0.10%	0.50%
	<i>Adenostoma fasciculatum</i>	4.30%	20.90%	0.70%	2.90%	2.30%	8.10%	2.40%	10.10%
	<i>Arctostaphylos glaucus</i>	10.40%	50.90%	2.20%	9.50%	1.20%	4.40%	4.60%	19.40%
	<i>Eriogonum fasciculatum</i>	0.00%	0.00%	7.00%	29.90%	15.50%	55.60%	7.40%	31.20%
	All shrubs	20.50%	100.00%	23.20%	100.00%	27.80%	100.00%	23.80%	100.00%
Herbs	Moss	0.00%	0.00%	0.20%	12.50%	0.00%	0.00%	0.10%	3.60%
	<i>Centaurea mellitus</i>	0.00%	0.00%	0.20%	12.50%	0.20%	4.90%	0.10%	6.60%
	<i>Centaurea solstitialis</i>	0.00%	0.00%	0.00%	0.00%	0.50%	15.00%	0.20%	10.20%
	<i>Epilobium canum ssp. canum</i>	0.20%	100.00%	0.00%	0.00%	0.00%	0.00%	0.10%	3.60%
	<i>Gnaphalium canescens ssp. beneolens</i>	0.00%	0.00%	0.30%	25.00%	0.00%	0.00%	0.10%	6.60%
	<i>Mellica imperfecta</i>	0.00%	0.00%	0.00%	0.00%	0.20%	4.90%	0.10%	3.60%
	<i>Nassella spp.</i>	0.00%	0.00%	0.20%	12.50%	2.40%	70.20%	0.90%	51.80%
	<i>Rumex sp.</i>	0.00%	0.00%	0.00%	0.00%	0.20%	4.90%	0.10%	3.60%
	<i>Spergula arvensis ssp. arvensis</i>	0.00%	0.00%	0.50%	37.50%	0.00%	0.00%	0.20%	10.20%
	All herbs	0.20%	100.00%	1.40%	100.00%	3.50%	100.00%	1.70%	100.00%
Litter	All litter	22.40%		42.40%		35.70%		33.50%	
	Shrub litter	15.90%		12.90%		14.30%		14.30%	
	Herb litter	6.50%		29.50%		21.40%		19.10%	
Plants	All non-native plants	0.30%		3.20%		2.60%		2.10%	
	All native plants	16.00%		20.70%		26.40%		21.00%	
	All plants	20.70%		24.70%		31.30%		25.50%	
Other	Bare soil	52.20%		31.50%		29.90%		37.90%	
	Rock	4.80%		1.50%		3.10%		3.10%	

Table 14. Absolute and relative cover of all plants less than one-half meter tall in all plots and for the entire oak woodland restoration site in 2007.

Shrub and Tree Density

The overall density of shrubs on the oak woodland site is 0.8 shrubs/m². Deerweed was by far the most numerous of the shrubs and comprised over 60% of the total shrubs encountered during our belt transect sampling. Sticky Monkeyflower and California Buckwheat were also more numerous than the other shrubs and comprised 11% and 9% of the total shrubs on the site respectively. Thus, these three shrubs accounted for 80% of the shrubs found in our most successful restoration area sampled on the site

Shrub density was similar in all of the oak woodland plots but did vary as did the species composition in the plots. Plot 2 had the greatest density of shrubs ($0.98/\text{m}^2$) followed by Plot 1 ($0.76/\text{m}^2$) and Plot 2 ($0.72/\text{m}^2$). It appeared that shrub density was highly dominated by the high densities of Deerweed. Disregarding Deerweed, all of the other shrubs in Plot1 and Plot 2 have equivalent densities, but Plot 3 would still have higher shrub density due to California Buckwheat. Plot 1 has higher densities of later successional shrubs, such as Chamise and Bigberry Manzanita, probably because they were planted on the plot as container stock plants. Plot 2 and Plot 3 have far more early successional or pioneer species. Many of these, such as Black Sage and California Buckwheat, were in the hydroseed mix (Table 15).

Plant name	Plot 1		Plot 2		Plot 3		All	
	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative
<i>Adenostoma fasciculatum</i>	0.054	7.10%	0.004	0.40%	0.058	8.10%	0.038	4.60%
<i>Arctostaphylos glauca</i>	0.054	7.10%	0.009	0.90%	0.005	0.60%	0.021	2.60%
<i>Baccharis pilularis</i>	0.039	5.20%	0.009	0.90%	0.014	1.90%	0.02	2.40%
<i>Ceanothus cuneatus</i>	0	0.00%	0	0.00%	0	0.00%	0	0.00%
<i>Cerocarpus betuloides</i>	0	0.00%	0.004	0.40%	0	0.00%	0.002	0.20%
<i>Epilobium canum</i>	0.005	0.60%	0	0.00%	0	0.00%	0.002	0.20%
<i>Eriogonum fasciculatum</i>	0	0.00%	0.043	4.40%	0.18	24.80%	0.076	9.20%
<i>Helianthemum scoparium</i>	0	0.00%	0	0.00%	0.005	0.60%	0.002	0.20%
<i>Hesperoyucca whipplei</i>	0.024	3.20%	0	0.00%	0	0.00%	0.008	0.90%
<i>Heteromeles arbutifolia</i>	0.01	1.30%	0	0.00%	0.009	1.20%	0.006	0.70%
<i>Lotus scoparius</i>	0.499	65.80%	0.698	71.30%	0.305	42.20%	0.504	61.20%
<i>Mimulus aurantiacus</i>	0.059	7.70%	0.128	13.00%	0.085	11.80%	0.092	11.20%
<i>Pinus sabiniana</i>	0.005	0.60%	0.009	0.90%	0.009	1.20%	0.008	0.90%
<i>Quercus berberidifolia</i>	0	0.00%	0.004	0.40%	0	0.00%	0.002	0.20%
<i>Salvia mellifera</i>	0	0.00%	0.072	7.40%	0.054	7.50%	0.044	5.30%
<i>Trichostema lanatum</i>	0.01	1.30%	0	0.00%	0	0.00%	0.003	0.40%
Total	0.758	100%	0.979	100%	0.723	100%	0.824	1

Table 15. Absolute (plants/m²) and relative density of the shrubs on the oak woodland site with total shrub density for 2007.

The heights of the shrubs on the plots were similar. Overall, the shrubs that are less than one-half one meter tall had the greatest density, more than twice the density of the shrubs in the other height classes. Shrubs over one meter tall, while larger in cover, were lower in density. Plot 2 had the most dramatic decreases in plant density as height class increased from 0.71 (less than one-half meter), 0.22 (one-half to one meter), to 0.06 plants/m² (over one meter tall). Plot 1 and Plot 3 had a similar decrease in shrub density with height.

Plot 2 had the highest density of shrubs, with nearly one shrub/m². The higher density is based solely on the density of Deerweed in the less than one-half meter layer, 0.62 plants/m², which is nearly double the density of Deerweed in Plots 1 and Plot 2. The plots all had similar densities for all other height classes (Fig.14).

Figure 14. Density (plants/m²) of shrubs for each height class and the sum of all height classes for each plot is included in the graphic.

The plant composition of the less than one-half meter height class is similar for all plots. Deerweed clearly dominates from 67 to 89%. Sticky Monkeyflower is also common but only accounts for about 10% of the shrubs, and the other species were lower and more variable. Plot 2 had the fewest species present, four, followed by Plot 1 with five species and Plot 3 with six species.

The plant composition of one-half to one meter height class is distinct for all plots. Plot 1 continued to be heavily dominated by Deerweed, 67% of the shrubs, and the remaining species had 10% or less relative density. Plot 2 continued to have a large Deerweed presence, 33% relative density, but it was no longer dominant. In addition, Deerweed,

Sticky Monkeyflower (31%), Black Sage (15%), and California Buckwheat (12%) were also abundant. *Quercus berberidifolia* (Scrub Oak) was present in one belt but was stunted in growth and remained less than 0.6 m in height 14 years after being planted. Plot 3 was dominated by California Buckwheat (54% relative density). Sticky Monkeyflower (20%), Black Sage (12%), and Deerweed (12%) were the other common plants.

All plots have different plant compositions for the greater than one meter height class. Interestingly, there are no plant species with more than 50% relative density. Plot 2 and 3 both have large numbers of both Black Sage and California Buckwheat, but neither is present in Plot 1.

Discussion

The studies and observations of the oak woodland plots during the 2006-2007 growing season indicate mixed success on the restoration of native plant communities at RCQ.

However, there are positive signs that indicate the site may ultimately meet the goals of our project and will (1) re-establish ecosystems that are near pre-disturbance conditions; (2) blend in with the surrounding undisturbed communities; (3) be self-sustaining.

Though reaching project goals is taking longer than expected, the natural process of succession is evident on all sites, and native shrub and tree recruitment and reproduction is occurring. In addition, the sites are no longer dominated by grasses and herbs as they were the first few years, but rather by subshrubs and shrubs evidence that natural succession is occurring successfully. Plant cover did decrease in 2007, which was likely a result of two years of drought. Supplemental seeding occurred on all sites during 2007 in an attempt to increase plant cover.

The comparison of shrub species on the oak woodland plots gives some indication as to the degree of success which has occurred on each plot. Plot 1 is dominated by later successional shrubs such as Chamise and Bigberry Manzanita, whereas Plot 3 is dominated by early successional shrubs such as California Buckwheat. Many container stock plants planted on the site proved not to be well suited for the harsh conditions created by the decomposed granite soil and have died over the years. Others are doing very well and reproducing themselves naturally.

The overall shrub density of the oak woodland plot was less than in previous years sampled (Table 16). It is likely that the mortality of container stock has continued.

However, the decrease of shrub density is partially due to the decline of Deerweed. The density of Deerweed in 2002 was 0.764 shrubs per m² whereas in 2007 it was only 0.5 shrubs per m² (Holland, 2002) (Table 17).

	2000	2001	2002	2007
Plot 1				0.76
Plot 2				0.98
Plot 3				0.72
Average	1.11	1.06	0.87	0.82

Table 16. Average shrub density of all plots for 2000 through 2002 and shrub densities of all plots for 2007 (Holland, 2002).

Plant name	2002	2007	Density change from 2002 to 2007
<i>Adenostoma fasciculatum</i>	0.021	0.038	0.017
<i>Arctostaphylos glauca</i>	0.021	0.021	0.0001
<i>Baccharis pilularis</i>	0.036	0.02	-0.016
<i>Ceanothus cuneatus</i>	0	0	0
<i>Cercarpus betuloides</i>	0	0.002	0.002
<i>Epilobium canum</i>	0	0.002	0.002
<i>Eriogonum fasciculatum</i>	0.054	0.076	0.022
<i>Helianthemum scoparium</i>	0	0.002	0.002
<i>Hesperoyucca whipplei</i>	0.014	0.024	-0.007
<i>Heteromeles arbutifolia</i>	0.007	0.006	-0.001
<i>Lotus scoparius</i>	0.764	0.504	-0.26
<i>Mimulus aurantiacus</i>	0.132	0.092	-0.04
<i>Pinus sabiniana</i>	0.011	0.008	-0.004
<i>Quercus berberidifolia</i>	0	0.002	0.002
<i>Salvia mellifera</i>	0.043	0.044	0.001
<i>Trichostema lanatum</i>	0	0.003	0.003

Table 17. Shrub densities averages across all plots for both 2002 and 2007 including the density change between from 2002 to 2007 (Holland, 2002).

Some *Lupinus* spp. (Lupines) continue to be present throughout the plots and contribute to nitrogen fixation and soil development. However, Deerweed outnumbers Lupines greatly and is the primary nitrogen fixer. It is very numerous and contributes to a large portion of the absolute cover as well as density in all three plots. Deerweed was not seeded on oak woodland Plot 1 but was a natural recruit that has contributed greatly to the plant cover.

The plant cover of the oak woodland plots decreased in 2007 from the previous years sampled. Intermittent sampling of the site has occurred since 1999; however, comparison between years of different rainfall and sampling time result in some sampling errors making comparisons difficult. Herbaceous plant cover, especially annual forbs and

grasses, can be significantly different from year to year due to variations in weather; however, the cover data from 2002 and 2007 are provided in Figure 15 for comparison (Holland, 2002).

Figure 15. Absolute plant cover for all plots for 2007 and 2002 (Holland, 2002).

The recent droughts may also affect the continued success of the revegetation efforts. For example, when Bigberry Manzanita shrubs are under severe stress, they are subject to pests and pathogens (Fig. 16). Over 80% of these shrubs on the oak woodland plots have significant soft scale populations. *Arctostaphylos* ssp. are commonly inflicted with *Coccus hesperidum* (brown soft scale) and *Hemiberlesia rapax* (greedy scale), though these scales usually do not damage the host. Throughout the oak woodland restoration site, Bigberry Manzanita generally has wilted leaves which drop prematurely. Some plants have signs of quick infestations such as brown leaves remaining on branches and/or large portions of the trunk breaking off. Scale populations are known to increase dramatically in dusty conditions such as those at RCQ. Scale is spread by honey-dew seeking ants, and dusty conditions decrease their natural predators. The oak woodland

plot is located next to a crushed granite conveyor belt, an active supply yard, and a dirt road where more than 20 cars pass per day. Plants afflicted with scales also have sooty mold which feeds on the honey dew produced by plant-sucking insects. Sooty mold generally does not affect the health of the plants, but it does alter the cosmetic appearance. In severe cases, sooty mold may reduce the amount of light for photosynthesis and under drought conditions, plants may wilt more readily. Afflicted plants do not appear to produce flowers or fruit while plants without aphids have mature fruits (UC Davis Integrated Pest Management Program, 2003). UC Davis Integrated Pest Management Program recommends treating the insect pest. Bigberry Manzanita in surrounding natural areas do not appear to be afflicted with severe aphid infestations and had fruit present.

Figure 16. Pest infestation on *Arctostaphylos glauca* (Bigberry Manzanita). Many Bigberry Manzanita have scales on the oak woodland plot. The leaves are black with sooty mold and wilting (Left). The afflicted plant has dead branches to the upper and lower left portions of the plant. The ground underneath the plant is stained with both sooty mold and honey dew (Right).

VI. Experiments

A. Breaking Seed Dormancy with Short-term Treatments

Introduction

Fire is a dominant force in California chaparral. Typically during a fire, heat immediately acts on the 2,000 to 146,200 *Adenostoma fasciculatum* (Chamise) seeds/m² in the soil seed bank (Zammit and Zedler, 1988). Smoke also reaches seeds on and near the soil surface. Chemical effects of fire, such as smoke and charcoal, are deposited on the soil surface and leach into the seed bank after fall rains (Schelsinger and Hasey, 1980; Keeley and Fotheringham, 1998a). In nature, this results in enhanced germination of the seeds and the beginning of chaparral post-fire succession. Long-term seed dormancy is broken, which characteristically results in 220 to 14,610 Chamise seedlings/m² emerging from the soil (Stone and Juhren, 1953; Zammit and Zedler, 1988). This natural response to fire--the increase of germination from the soil seed bank--may be utilized to improve chaparral restoration in mined and disturbed areas. Successful increase of seed germination by pre-treating seeds with fire effects for dominant shrubs, Chamise, *Ceanothus cuneatus* (Buckbrush), *Salvia mellifera* (Black Sage), and *Lotus scoparius* (Deerweed) are reported.

In most restoration projects, seeds have not been treated to break seed dormancy (Belyea, Personal Communication, 9-27-2008; Berlin, Personal Communication, 9-26-2007; James, Personal Communication, 9-27-2008; Miller, Personal Communication, 9-26-2007; Richardson, Personal Communication, 9-27-2008). However, breaking long-term seed dormancy to increase germination in a cost and time-efficient manner is important to improve revegetation and restoration. Fire effects, such as heat, charate, leachate, smoke

and/or Liquid Smoke (L.S.), have all been shown to be effective in breaking long-term dormancy in many chaparral plants. Several investigators have found that treating seeds with smoke for 10 weeks increased percent germination significantly (Fotheringham et al., 1995; Keeley, 1984; Keeley et al., 1985; Keeley, 1987a; Keeley and Fotheringham, 1997; Keeley and Fotheringham, 1998a; Keeley and Fotheringham, 1998b; Keeley and Pizzorno, 1986; Keeley et al., 2005; Jager et al., 1996a; Jager et al., 1996b; Jager et al., 1996c). Based on Keeley (1987a) I have identified species commonly used in restoration at Rocky Canyon Quarry (RCQ) which have the potential for an increase in seed germination with pre-treatments. No one has published results showing that short-term exposure affects seed germination in Chamise, Buckbrush, Black Sage, and California Broom.

My experiments are designed to determine if short-term exposure to fire effects significantly affects germination. The original intent of the experiments was to determine if pre-treatment with L.S. significantly affects seed germination of common chaparral plants. This short-term exposure is applied to seeds before they are added into a hydroseed mix. Such on-site treatments do not require additional laboratory equipment that would otherwise be needed for mechanical abrasion, heat application, and chemical scarification. In addition, this type of treatment can save time as it requires only a team of one or two people. Studies by other investigators have demonstrated a combination of these treatments increased germination rates as did the addition of a heat treatment (Keeley, 1987a). Therefore, I also conducted experiments that included both heat treatments and L.S. treatments.

Methods

Seeds were donated from S&S Seeds of Carpinteria, California. Chamise, Buckbrush and Black Sage were collected during the fall of 2006 by S&S Seeds and tested during the winter of 2006-2007 and fall of 2007 for Trial 1, Trial 2, and Trial 3. Trial 4 used Chamise, Buckbrush, California Broom, and Black Sage from S&S Seeds fall 2007 collection. Seeds were stored at room temperature in plastic mesh bags with variable light conditions.

In all experiments, the seeds were divided into observational units which contained 30 seeds. Several replicates were included in each trial for statistical analysis though the numbers of replicates per treatment and per trial were not necessarily similar. The total number of seeds used in each experiment varied from 90 to 540 (Table 18, Table 19, Table 20, Table 21).

Treatment	Trial 1	Trial 2	Trial 3	Trial 4	Grand total per treatment
1 hr. Pure L.S.	-	-	180	-	180
1 to 10 L.S.	-	-	-	150	150
1 to 10 L.S. Heat	-	-	-	150	150
1 to 100 L.S.	90	90	120	120	420
1 to 100 L.S. Heat				180	180
1 to 1000 L.S.	90	120	180	-	390
1 to 2000 L.S.	90	120	150	-	360
18 hr. Pure L.S.	-	-	210	-	210
27 hr. Pure L.S.	-	-	180	-	180
30 hr. Pure L.S.	-	-	180	-	180
4 hr. Pure L.S.	-	-	180	-	180
Control	90	150	150	150	540
Heat	-	-	-	90	90
Pure L.S.	-	-	180	180	360
Pure L.S. Heat	-	-	-	270	270
Grand total per trial	360	480	1710	1290	3840

Table 18. Number of seeds tested per treatment per trial and total per treatment for *Adenostoma fasciculatum* (Chamise).

Treatment	Trial 1	Trial 2	Trial 4	Grand total per treatment
1 to 10 L.S. with Heat	-	-	180	180
1 to 100 L.S.	90	210	-	300
1 to 100 L.S. with Heat	-	-	150	150
1 to 1000 L.S.	90	150	-	240
1 to 2000 L.S.	90	180	-	270
Control	90	150	150	390
Heat	-	-	180	180
Pure L.S. with Heat	-	-	300	300
Grand total per trial	360	690	960	2010

Table 19. Number of seeds tested per treatment per trial and total per treatment for *Ceanothus cuneatus* (Buckbrush).

Treatment	Seeds tested
1 to 10 L.S.	300
1 to 100 L.S.	300
Control	300 (180)
Heat	300 (120)
Pure L.S. with Heat	300
Grand total tested	1200

Table 20. Number of seeds tested per treatment for *Lotus scoparius* (Deerweed) for

Trial 1. Many samples for both the control and Heat treatments had severe fungal infections during cold stratification before germination. Therefore, these samples were dropped from statistical analysis. The number used for statistical analysis is in parenthesis.

Treatment	Trial 1	Trial 2	Trial 3	Trial 4	Grand total per treatment
1 to 10 L.S.	-	-	-	150	150
1 to 10 L.S. Heat	-	-	-	120	120
1 to 100 L.S.	90	90	150	150	480
1 to 100 L.S. Heat	-	-	-	150	150
1 to 1000 L.S.	90	150	150	-	390
1 to 2000 L.S.	90	90	150	-	330
Control	90	60	120	150	420
Heat	-	-	-	150	150
Pure L.S.	-	-	-	150	150
Pure L.S. Heat	-	-	-	300	300
Grand total per trial	360	390	570	1320	2490

Table 21. Number of seeds tested per treatment per trial and total per treatment for *Salvia mellifera* (Black Sage).

Individual observational units, 30 seeds, were placed onto non-bleached coffee filters and tied with natural twine. Samples were soaked and submerged in Wright's L.S. dilutions for 10 minutes to simulate the soak and mix period during hydroseeding. In addition, the soaking period of Chamise was extended to one hour, four hours, 18 hours, 27 hours, and 30 hours during Trial 3. Temperatures and length of heat treatments were determined from Keeley's (1987a) work (Table 22.). One replicate was treated in each beaker at a time. The treated samples were untied and gently placed onto Whatman # 1 filter paper with a metal spatula. All samples were then placed into a forced air convection oven at 30°C for one hour to dry, unless a heat treatment was specifically being tested, to simulate the drying process after hydroseeding. If a heat treatment was being tested it was applied directly after soaking instead of drying. Only one treatment type was dried at a

time in the oven to eliminate air contamination with L.S. Seeds were transferred to a "60x15 mm sterilized Petri dish with two layers of Whatman # 1 filter" (Keeley, 1987a; Baskin and Baskin, 1998; Keeley et al., 2005; J. Keeley, Personal Communication, 2-01-2-2008) (Fig. 17).

Plant name	Heat treatment
<i>Adenostoma fasciculatum</i>	70°C for 1 hour
<i>Ceanothus cuneatus</i>	100°C for 5 minutes
<i>Lotus scoparius</i>	120°C for 5 minutes
<i>Salvia mellifera</i>	70°C for 1 hour

Table 22. Heat treatments as described in Keeley's (1987a) which were used for each species.

Figure 17. Schematic of methods for Breaking Seed Dormancy with Short-term Treatments.

Two days later, germination was initiated with one and one-half to two millimeters of water. Petri dishes were placed in a single layer on metal trays in Ziploc sandwich bags to "reduce evaporation and gas transfer between treatments" (Keeley, 1987a). Each tray had one species with treatments randomly placed. Placement changed every week. Ziploc bags had most of their air removed and were closed. Overlapping Ziploc bags were placed underneath the neighboring Petri dishes. The samples were cold stratified in "trays stored for one month (4-14-2007 to 5-14-2007) under variable light conditions at ~4°C" (Keeley, 1987a). Incubation with a diurnal light schedule followed (18°-12°C) for eight

weeks (Baskin and Baskin, 1998; Keeley et al., 2005; J. Keeley, Personal Communication, 2-01-2-2008).

After cold stratification, seeds were examined weekly for germination for at least six weeks. Germination was determined by epicotyl emergence. Germinated seeds were recorded and then removed. (Baskin and Baskin, 1998; Keeley et al., 2005; J. Keeley, Personal Communication, 2-01-2-2008) (Fig. 17).

The data were analyzed with Minitab Statistical Software 15 English. A logistic regression model blocked by trial was used to compare the germination rates of different treatments. Model fit was assessed by Pearson, Deviance, and Hosmer-Lemeshow “goodness of fit” tests. There was no evidence that models were not a good fit for all species tested except California Broom. Because of the large number of treatments compared, I assessed statistical significance using both Fisher and Bonferroni adjusted α -values based on the number of comparisons and $\alpha=0.05$.

Results

Percent germination of the seeds changed dramatically when treated with fire effects (Table 23). For all plants tested, at least one treatment was greater than the control and one treatment was less than the control. Chamise only had 4% germination when no treatment was applied, but it increased to 30% when treated with 1 to 10 L.S. Heat. Chamise had no germination when treated with 1 to 2000 L.S. or when soaked in Pure L.S. for 30 hours. Buckbrush only had 1.03% germination when no treatment was applied, but it increased to 17% when treated with Pure L.S. Buckbrush had no germination when treated with 1 to 2000 L.S. California Broom only had 9% germination when no treatment was applied, but it increased to 14% when treated with 1 to 100 L.S. California Broom had the lowest germination, 1.67%, when treated with Pure L.S. and Heat. Black Sage only had 8% germination when no treatment was applied, but it increased to 42% when Heat was applied. Black Sage had the lowest germination, 7%, when treated with 1 to 1000 L.S. As demonstrated in both the Bonferroni and Fisher significance in Table 23, the percent seed germination discussed above does not directly correspond to the best treatment. Because this analysis is not sufficient to determine which treatment is best for restoration, a thorough statistical analysis for each species individually follows.

Treatment	<i>Adenostoma fasciculatum</i>	<i>Ceanothus cuneatus</i>	<i>Lotus scoparius</i>	<i>Salvia mellifera</i>
Control	4% ^{c 1}	1.03% ^{a 1}	8.89%	8% ^{a 1}
Heat	12% ^{abc 3}	6.67% ^{a 2}	10.00%	42% ^{c 2}
1 to 2000 L.S.	0% ^{bc 1}	0% ^{ab}	-	12% ^{bc 34}
1 to 1000 L.S.	2% ^{abc 1}	0.83% ^{a 123}	-	7% ^{abc 34}
1 to 100 L.S.	8% ^{abc 234}	1.67% ^{ab}	13.67%	15% ^{bc 34}
1 to 100 L.S. Heat	17% ^{abc 234}	1.33% ^{ac 1}	-	32% ^{bc 234}
1 to 10 L.S.	17% ^{abc 234}	-	11.67%	22% ^{ab 3}
1 to 10 L.S. Heat	30% ^{ab 6}	6.67% ^{ac 2}	-	30% ^{bc 34}
Pure L.S.	16% ^{a 2456}	-	-	26% ^{abc 34}
Pure L.S. Heat	20% ^{abc 245}	17% ^{bc 3}	1.67%	34% ^{c 24}
1 hr. Pure L.S.	9% ^{ab 56}	-	-	-
4 hr. Pure L.S.	7% ^{abc 2}	-	-	-
18 hr. Pure L.S.	0% ^{abc 1}	-	-	-
27 hr. Pure L.S.	1% ^{abc 1}	-	-	-
30 hr. Pure L.S.	0% ^{abc 1}	-	-	-

Table 23. Percent germination for all species tested and each treatment. All

treatments which are not significantly different are indicated with the same superscripts.

The Bonferroni similarities, indicated with letters, are based on Bonferroni-adjusted value for individual comparisons which have group values of $\alpha=0.05$: the value for *Adenostoma fasciculatum* (Chamise) is $\alpha=0.00048$, *Ceanothus cuneatus* (Buckbrush) is $\alpha=0.0018$, and *Salvia mellifera* (Black Sage) is $\alpha=0.0011$. The Fisher similarities, indicated with numbers, are based on $\alpha=0.05$. The data for *Lotus scoparius* (Deerweed) did not fit the logistical regression model and no statistical similarities are presented.

Adenostoma fasciculatum (Chamise)

There was evidence for different germination rates based on treatments for Chamise when the control and all treatments are compared (p-value=0.000). No statistical computations were completed for 30 hr. Pure L.S. because no seeds germinated in this treatment. The control has lower estimates of germination than all other treatments although there is no statistical evidence for a difference from some of the other treatments. I used two criteria to declare significant differences for treatments: (1) Bonferroni-adjusted for multiple comparisons is conservative (group $\alpha=0.05$ and individual comparisons $\alpha=0.00048$) and (2) Fisher test with no adjustment for multiple comparisons is liberal ($\alpha=0.05$).

There is strong evidence, where both Bonferroni and Fisher tests concur, for differences in germination rates present between the control and the following treatments: 1 hr. Pure L.S. (p-value=0.000), Pure L.S. (p-value=0.000), 1 to 10 dilution of L.S. with Heat (p-value=0.000). 1 hr. Pure L.S. is estimated to increase germination by 394% (95% CI: 122%, 999%). Pure L.S. is estimated to increase germination by 243% (95% CI: 96%, 501%). 1 to 10 dilution of L.S. with Heat is estimated to increase germination by 347% (95% CI: 145%, 717%) (Table 24, Fig. 18).

There is marginal evidence, significance at Fisher $\alpha=0.00048$, but not at the Bonferroni $\alpha=0.05$: 1 to 100 dilution of L.S. (p-value=0.008), 1 to 100 dilution of L.S. with Heat (p-value=0.022), 1 to 10 dilution of L.S. (p-value= 0.027), Pure L.S. with Heat (p-value=0.001), and 4 hr. Pure L.S. (p-value= 0.001). Further focused research is needed to

confirm these differences. Although 1 to 100 dilution of L.S. is estimated to increase germination by 125% (95% CI: 24%, 309%), there is only modest evidence suggesting it is different from the control. Although 1 to 100 dilution of L.S. with Heat is estimated to increase germination by 109% (95% CI: 11%, 291%), there is only modest evidence suggesting it is different from the control. Although 1 to 10 dilution of L.S. is estimated to increase germination by 109% (95% CI: 9%, 300%), there is only modest evidence suggesting it is different from the control. Although Pure L.S. with Heat is estimated to increase germination by 161% (95% CI: 47%, 363%), there is only modest evidence suggesting it is different from the control. Although 4 hr. Pure L.S. is estimated to increase germination by 294% (95% CI: 71%, 807%), there is only modest evidence suggesting it is different from the control (Table 24, Fig. 18).

There was a lack of evidence, where neither Bonferroni nor Fisher tests had supporting evidence for differences in germination rates between the control and the following treatments: Heat (p-value=0.36), 1 to 2000 dilution of L.S. (p-value=0.094), 1 to 1000 dilution of L.S. (p-value=0.397), 18 hr. Pure L.S. (p-value=0.177), and 27 hr. Pure L.S. (p-value=0.229) No statistical computations were completed for 30 hr. Pure L.S. because no seeds germinated in this treatment. While I estimate Heat increases germination by 45%, our 95% CI indicates that this concentration may in fact increase germination by up to 223% or decrease germination by up to 35%. While I estimate 1 to 2000 L.S. dilution decreases germination by 83%, our 95% CI indicates that this concentration may in fact increase germination by up to 34% or decrease germination by up to 98%. While I estimate 1 to 1000 L.S. dilution increases germination by 45%, our 95% CI indicates that

this concentration may in fact increase germination by up to 246% or decrease germination by up to 98%. While I estimate 18 hr. Pure L.S. dilution decreases germination by 76%, our 95% CI indicates that this concentration may in fact increase germination by up to 90% or decrease germination by up to 97%. While I estimate 27 hr. Pure L.S. dilution decreases germination by 72%, our 95% CI indicates that this concentration may in fact increase germination by up to 122% or decrease germination by up to 96% (Table 24, Fig. 18).

Treatment	Bonferroni	Fisher	Percent germination	Percent change compared to control
Control	c	A	4%	-
Heat	abc	C	12%	45 (-35, 223)
1 to 2000 L.S.	bc	A	0%	-83 (-98, 34)
1 to 1000 L.S.	abc	A	2%	45 (-39, 246)
1 to 100 L.S.	abc	BCD	8%	125 (24, 309)
1 to 100 L.S. Heat	abc	BCD	17%	109 (11, 291)
1 to 10 L.S.	abc	BCD	17%	109 (9, 300)
1 to 10 L.S. Heat	ab	F	30%	347 (145, 717)
Pure L.S.	a	BDEF	16%	243 (96, 501)
Pure L.S. Heat	abc	BDE	20%	161 (47, 363)
1 hr. Pure L.S.	ab	EF	9%	394 (122, 999)
4 hr. Pure L.S.	abc	B	7%	294 (71, 807)
18 hr. Pure L.S.	abc	A	0%	-76 (-97, 90)
27 hr. Pure L.S.	abc	A	1%	-72 (-96, 122)
30 hr. Pure L.S.	abc	A	0%	-

Table 24. Results for *Adenostoma fasciculatum* (Chamise). The tabulated values include the percent germination, the percent change in seed germination for the odds ratio, and 95% Confidence Interval for the germination of Chamise seeds with all treatments compared to the control. All treatments which are not significantly different are indicated with the same superscript letter. The Bonferroni value for individual comparisons is $\alpha=0.00048$ with a group value of $\alpha=0.05$. The Fisher similarities are based on $\alpha=0.05$.

Figure 18. Percent germination of *Adenostoma fasciculatum* (Chamise) seeds for all treatments and the control from all trials without blocking by trial. Fisher similarities are indicated with the same superscript letter. Bonferroni similarities are not included on the graphic but are available (Table 24).

The three treatments with strong evidence suggesting they are distinct from the control include (1) 1 to 10 L.S. with Heat (p-value=0.000), (2) Pure L.S. (p-value=0.000), and (3) 1 hr. Pure L.S. (p-value=0.000). No evidence was present between the following treatments: 1 to 10 L.S. Heat and Pure L.S. (p-value=0.2730), 1 to 10 L.S. Heat and 1 hr. Pure L.S. (p-value=0.807), Pure L.S. and 1 hr. Pure L.S. (p-value=0.311). The 1 to 10 dilution of L.S. with Heat, 30% seed germination, is empirically interesting because it has the highest percent germination, at least 10% more than any other treatment. However, it is only statistically different from the control (Table 24, Fig. 18).

The power, or probable ability of the procedure to find a difference as subtle as the differences I saw, is only 52%. With our minimum number of seeds per treatment (experimental units=5 with 30 seeds each, seeds=150), in the worst case scenario, I can

only detect differences in germination rates as large as 18 to 20% with 90 to 95% probability, respectively. To determine if Heat is statistically different from all other treatments 14 and 17 replications would need to be complete for 90 and 95% confidence, respectively.

Ceanothus cuneatus (Buckbrush)

There was evidence for different germination rates based on treatments for Buckbrush when the control and all treatments are compared (p-value=0.000). No statistical computations were completed for 1 to 2000 dilution of L.S. because no seeds germinated in this treatment. The control has lower estimates of germination than all other treatments although there is not evidence for a difference from some of the other treatments. I used two criteria to declare significant differences for treatments: (1) Bonferroni-adjusted for multiple comparisons is conservative (group $\alpha=0.05$ and individual comparisons $\alpha=0.0018$) and (2) Fisher test with no adjustment for multiple comparisons is liberal($\alpha=0.05$).

There is strong evidence, where both Bonferroni and Fisher tests concur, for differences in germination rates present between the control and only Pure L.S. with Heat (p-value=0.000). Pure L.S. with Heat is estimated to increase germination by 953% (95% CI: 228%, 3281%) (Table 25, Fig. 19).

There is marginal evidence, where the Fisher test supports differences while the Bonferroni tests lacks evidence, for differences between the control and the following treatments: Heat (p-value=0.045) and 1 to 10 dilution of L.S. with Heat (p-value= 0.045). Although Heat is estimated to increase germination by 267% (95% CI: 3%, 1208%), there is only modest evidence suggesting it is different from the control. Although 1 to 10 L.S. dilution with Heat is estimated to increase germination by 267% (95% CI: 3%,

1208%), there is only modest evidence suggesting it is different from the control (Table 25, Fig. 19).

There was a lack of evidence, where neither Bonferroni nor Fisher tests had supporting evidence for differences in germination rates between the control and the following treatments: 1 to 1000 dilution of L.S (p-value=0.609), 1 to 100 dilution of L.S (p-value=0.195), and 1 to 100 dilution of L.S. with Heat (p-value=0.69). While I estimate 1 to 1000 L.S. dilution increases germination by 77%, our 95% CI indicates that this concentration may in fact increase germination by up to 1455% or decrease germination by up to 80%. While I estimate 1 to 100 L.S. dilution increases germination by 242%, our 95% CI indicates that this concentration may in fact increase germination by up to 2094% or decrease germination by up to 47%. While I estimate 1 to 100 L.S. dilution with Heat decreases germination by 31%, our 95% CI indicates that this concentration may in fact increase germination by up to 318% or decrease germination by up to 88% (Table 25, Fig. 19).

Treatment	Bonferroni	Fisher	Percent germination	Percent change compared to control	Percent change compared to pure L.S. with heat
Control	a	A	1.03%	-	-91 (-97, -69)
Heat	a	B	6.67%	267 (3, 1208)	-65 (-82, -33)
1 to 2000 L.S.	ab	-	0.00%	-	-
1 to 1000 L.S.	a	ABC	0.83%	77 (-80, 1455)	-83 (-98, 79)
1 to 100 L.S.	ab	ABC	1.67%	242 (-47, 2094)	-68 (-96, 157)
1 to 100 L.S. Heat	ac	A	1.33%	-31 (-88, 318)	-93 (-98, -73)
1 to 10 L.S. Heat	ac	B	6.67%	267 (3, 1208)	-65 (-82, -33)
Pure L.S. Heat	bc	C	17.00%	953 (228, 3281)	-

Table 25. Results for *Ceanothus cuneatus* (Buckbrush). The tabulated values include the percent germination, the percent change in seed germination for the odds ratio, and 95% Confidence Interval for the germination of Buckbrush seeds with all treatments compared to the control and compared to Pure L.S. with Heat after adjusting for different trials. All treatments which are not significantly different are indicated with the same superscript letter. Bonferroni value for individual comparisons are $\alpha=0.0018$ with a group value of $\alpha=0.05$. The Fisher similarities are based on $\alpha=0.05$.

Figure 19. Percent germination of *Ceanothus cuneatus* (Buckbrush) seeds for all

treatments and the control from all trials without blocking by trial. Fisher

similarities are indicated with the same superscript letter. Bonferroni similarities are not included on the graphic but are available (Table 25).

Of the three treatments which had strong or marginal evidence for significant differences from the control (1) 1 to 10 L.S. with Heat, (2) Heat, and (3) Pure L.S. with Heat, there was evidence for statistical difference from one another. There is strong evidence, where both Bonferroni and Fisher tests concur, for differences in germination rates present between the following treatments: Heat and Pure L.S. with Heat (p-value=0). There is marginal evidence, where the Fisher test supports differences while the Bonferroni tests lacks evidence, for differences between the following treatments: Pure L.S. with Heat and

1 to 10 L.S. with Heat (p-value=0.002). Therefore, Pure L.S. appears to increase germination from the control more than any other treatment.

Lotus scoparius (Deerweed)

The data for California Broom did not fit the logistical regression model and no statistical analysis is presented.

The control and some of the treatments had similar germination rates. The control and Heat had germination rates within 1% of one another, 9% and 10% germination respectively. Both 1 to 100 L.S. and 1 to 10 L.S., 14% and 12% respectively, are slightly greater than the control. The Pure L.S. with Heat had the lowest germination of all treatments, with only 2% germination (Fig. 20).

Figure 20. Percent germination of *Lotus scoparius* (Deerweed) for all treatments.

Salvia mellifera (Black Sage)

There was evidence for different germination rates based on treatments for Black Sage when the control and all treatments are compared (p-value=0.000). The control has lower estimates of germination than all other treatments although there is not evidence for a difference from some of the other treatments. I used two criteria to declare significant differences for treatments: (1) Bonferroni-adjusted for multiple comparisons is conservative (group $\alpha=0.05$ and individual comparisons $\alpha=0.0011$) and (2) Fisher test with no adjustment for multiple comparisons is liberal ($\alpha=0.05$).

There is strong evidence, where both Bonferroni and Fisher tests concur, for differences in germination rates present between the control and the following treatments: Heat (p-value=0.000), 1 to 2000 dilution of L.S (p-value=0.000), 1 to 100 dilution of L.S (p-value=0.000), 1 to 100 dilution of L.S with Heat (p-value=0.000), 1 to 10 dilution of L.S. with Heat (p-value=0.000), and Pure L.S. with Heat (p-value=0.000). Heat is estimated to increase germination by 354% (95% CI: 172%, 657%). 1 to 2000 L.S. dilution is estimated to increase germination by 185% (95% CI: 63%, 397%). 1 to 100 L.S. dilution is estimated to increase germination by 138% (95% CI: 53%, 271%). 1 to 100 dilution of L.S. with Heat is estimated to increase germination by 195% (95% CI: 75%, 398%). 1 to 10 L.S. dilution and Heat is estimated to increase germination by 168% (95% CI: 54%, 368%). Pure L.S. with Heat is estimated to increase germination by 228% (95% CI: 106%, 420%) (Table 26, Fig. 21).

There is marginal evidence, where the Fisher test supports differences while the Bonferroni tests lacks evidence, for differences between the control and the following treatments: 1 to 1000 dilution of L.S (p-value=0.036), 1 to 10 dilution of L.S (p-value=0.044), and Pure L.S (p-value=0.004). Although 1 to 1000 dilution of L.S. is estimated to increase germination by 87% (95% CI: 4%, 234, %), there is only modest evidence suggesting it is different from the control. Although 1 to 10 L.S. dilution is estimated to increase germination by 77% (95% CI: 2%, 207%), there is only modest evidence suggesting it is different from the control. Although Pure L.S. is estimated to increase germination by 120% (95% CI: 28%, 277%), there is only modest evidence suggesting it is different from the control (Table 26, Fig. 21).

Treatment	Bonferroni	Fisher	Percent germination	Percent change compared to	Percent change compared to
Control	a	A	8%	-	-78 (-87, -63)
Heat	c	B	42%	354 (172, 657)	-
1 to 2000 L.S.	bc	CD	12%	185 (63, 397)	-37 (-67, -18)
1 to 1000 L.S.	abc	CD	7%	87 (4, 234)	-59 (-79, -21)
1 to 100 L.S.	bc	CD	15%	138 (53, 271)	-47 (-67, -17)
1 to 100 L.S. Heat	bc	BCD	32%	195 (75, 398)	-35 (-59, 4)
1 to 10 L.S.	ab	C	22%	77 (2, 207)	-61 (-76, -36)
1 to 10 L.S. Heat	bc	CD	30%	168 (54, 368)	-41 (-64, -2)
Pure L.S.	abc	CD	26%	120 (28, 277)	-51 (-70, -21)
Pure L.S. Heat	c	BD	34%	228 (106, 420)	-28 (-52, 8)

Table 26. Results for *Salvia mellifera* (Black Sage). The tabulated values include the percent germination, the percent change in seed germination for the odds ratio, and 95% Confidence Interval for the germination of Black Sage seeds with all treatments compared to the control and compared to Heat after adjusting for different trials. All treatments which are not significantly different are indicated with the same superscript letter. Bonferroni value for individual comparisons are $\alpha=0.0011$ with a group value of $\alpha=0.05$. The liberal similarities are based on Fisher at $\alpha=0.05$.

Of the six treatments which had strong evidence for significant difference from the control, there was evidence for statistical differences from one another. There is no strong evidence, where both Bonferroni and Fisher tests concur, for differences in germination rates present between the treatments. There is marginal evidence, where the Fisher test supports differences while the Bonferroni tests lacks evidence, for differences between the following treatments: Heat and 1 to 100 L.S. ($p\text{-value}=0.006$) and Heat and 1 to 10 L.S. with Heat ($p\text{-value}=0.043$). No evidence is present for the majority of comparisons between treatments where strong evidence was present for a significant difference from the control. Therefore, no one treatment necessarily stood out above the other treatments based on statistics. The treatment Heat had marginal evidence for differences from six treatment comparisons. Heat was the only treatment with marginal evidence for differences for more than two other treatments. For Heat, there was no evidence of differences for the following treatments: 1 to 2000 L.S. ($p\text{-value}=0.15$), 1 to 100 L.S. with Heat ($p\text{-value}=0.074$), and Pure L.S. with Heat ($p\text{-value}=0.113$) (Table 26, Fig. 21).

Heat is empirically interesting because it has the highest percent germination, at least 8% more than any other treatment. The power, or probable ability of the procedure to find a difference as subtle as the differences I saw, is only 30%. With our minimum number of seeds per treatment (experimental units=5 with 30 seeds each, seeds=150), in the worst case scenario, I can only detect differences in germination rates as large as 18 to 20% with 90 to 95% probability, respectively. To determine if Heat is statistically different from all other treatments 26 and 32 replications would need to be complete for 90 and 95% confidence, respectively (Fig. 21).

Figure 21. Percent germination of *Salvia mellifera* (Black Sage) seeds for all treatments and the control from all trials without blocking by trial. Fisher similarities are indicated with the same superscript letter. Bonferroni similarities are not included on the graphic but are available (Table 26).

Discussion

Short periods of exposure (10 minutes to four hours) of L.S. and/or Heat significantly enhance seed germination of Chamise, Buckbrush, California Broom, and Black Sage.

The active components of smoke are contained within commercially available Wright's Liquid Smoke which stimulates seed germination (Jager, 1996a; Keeley et al., 2005). The stimulatory effect of L.S. and/or Heat was retained when seeds were re-dried and stored for two days. L.S. and/or Heat are effective tools in restoration to treat long-term dormant seeds to increase germination. Recommendations for seed treatment for restoration are based on the statistical significance where the recommended treatment has the highest increase in seed germination for the CI. In the case of statistically similar treatments, cost, empirical percent seed germination, and practicality were taken into consideration.

The recommended treatment for Chamise is 1 to 10 dilution of L.S. for 10 minutes with Heat. Our empirical findings are similar to Keeley's (1987a) results. Keeley found the highest percent germination when both heat and charate were applied. I do not recommend soaking the seeds in Pure L.S. for one hour due to the possibility of schedule problems associated with hydroseeding.

The recommended treatment for Buckbrush is Pure L.S. with Heat. Our statistical findings were not similar to Keeley's (1987a). Keeley's (1987a) did not support that charate addition is statistically different from the control. However, empirically Keeley's (1987a) data for charate addition and 100°C for 5 minutes is five times greater than the control. Statistically differences were probably found in my experiment due to much larger sample sizes.

There is no recommended treatment for California Broom at this time due to problems associated with fungus and statistical analysis.

The recommended treatment for Black Sage is Heat. Our empirical findings are similar to Keeley's (1987a) results. Our empirical data demonstrate Heat was the highest percent germination followed by the combination of Heat and L.S.

Difficulties were encountered in handling some seeds. Black Sage seeds were hard to guide and may have suffered mechanical abrasion. They may also have suffered mechanical abrasion when some seed coats adhered to drying filter (4-11-2007). Also, many of the Black Sage seeds and some of the Chamise seeds stuck to the Petri dish top due to static cling. While the seeds were not laying on filter paper, they were still in contact with a water source which was condensation on the Petri dish lid.

Fungus was common among all treatments. It generally began to occur during week four of the study for most of the species. However, severe fungal infections occurred much earlier for California Broom in the control and Heat samples, on week two of cold stratification, and these samples were not included in the statistical analysis. Fungus continued to grow on all California Broom treatments throughout the experiment. At the conclusion of the California Broom, all samples were severely infected. Fungus is associated with weak or underdeveloped seeds (Baskin and Baskin, 1998). The fungus generally began on seeds and remained associated with seeds for the majority of the experiment. Baskin and Baskin (1998) do not recommend using disinfectants during germination studies. In a separate non-reported experiment I soaked the seeds in a 10%

bleach solution for one hour before (Unpublished data). Fungus remained prevalent even in the bleach treated seeds.

Future research should include dormancy-breaking treatments described in Emery (1988). Seed Propagation of Native California Plants (Emery, 1988) was published before much of the published data for breaking chaparral species' seed dormancy was published.

These common horticultural treatments were not included in the original study.

Treatments for Chamise include burning pine needles over the soil or soaking in H_2SO_4 for 15 minutes. Treatments for Buckbrush include soaking in hot water and cold stratification for three-months. Treatments for Black Sage include soaking in 400 ppm GA_3 for one-hour or cold stratification for undetermined period of time.

Seed pre-treatment is most economically beneficial when the seeds have very low germination rates without treatment and large germination rates after treatment. I must compare the cost of pre-treatments, both for material and human resources, to the money saved from increased germination. The pre-treatments would only be economically viable if the increase in seed germination decreased the cost of seed while the pre-treatments cost less than the seed cost avoided. The pre-treatments would be most cost effective on plants such as Chamise and Buckbrush whose germination rates increase dramatically from four to 18% and 10 to 57% germination. For these examples, one pound of seed would have the effect of more than four or five pounds of seeds. The cost of one pound of native seeds from S&S Seeds was \$37 in the fall of 2007. Therefore, one pound of treated seed costs \$37 for seed, \$14 for one hour of labor, cost for L.S. varies based on concentration (\$2.00 for Pure L.S. to \$0.14 for 1:2000 L.S.) and therefore the savings

may be from \$38 (lowest 95% confidence interval estimate for Chamise treated with 1:10 dilution of L.S. with Heat) to \$1,198 (highest 95% confidence interval estimate for Buckbrush treated with Pure L.S. with Heat) (Table 27).

Plant name	Recommended pre-treatment		Financial benefit	Recommended pre-treatment without heat		Financial benefit
<i>Adenostoma fasciculatum</i>	1 to 10 dilution of L.S. with Heat	347 (145, 717)	112 (38, 249)	Pure L.S.	243 (96, 501)	74 (20, 169)
<i>Ceanothus cuneatus</i>	Pure L.S. with Heat	953 (228, 3281)	337 (68, 1198)	1 to 100 L.S.	242 (-47, 2094)*	74 (-33, 759)
<i>Salvia mellifera</i>	Heat	354 (172, 657)	115 (48, 227)	1 to 2000 L.S.	185 (63, 397)	52 (7, 131)

Table 27. Seed pre-treatment recommendations and financial benefit. The recommended pre-treatment for *Adenostoma fasciculatum* (Chamise), *Ceanothus cuneatus* (Buckbrush), and *Salvia mellifera* (Black Sage) and an alternative pre-treatment without the use of heat are indicated in the table above. The tabulated values include the percent change in seed germination for the odds ratio and 95% Confidence Interval for the germination of each species where the treatments are compared to the control. The tabulated values include potential dollar savings based on the odds ratio and cost of L.S. and 95% Confidence Interval where the treatments are compared to the control. *Indicates the treatment is not significantly different from the control and therefore not recommended for restoration.

B. Seed Bank of Rocky Canyon Quarry (RCQ): Potential for Vegetation Recovery

Introduction

Chaparral is a resilient plant community which rebounds quickly from natural disturbances such as fire. Chaparral plants deposit seeds with long-term dormancy into the soil. These seeds accumulate in the soil seed bank in between fire events, thus creating soil seed banks with an extraordinarily large numbers seeds. For example, it has been documented that *Adenostoma fasciculatum* (Chamise) have between 20,000,000 and 3,200,000,000 seeds/ha in the soil seed bank. Many seeds require fire to break their long-term dormancy as shown by the huge flush of seedlings after a fire. Some have estimated there are between 2,200,000 to 146,100,000 of Chamise seedlings/ha following a fire, and this represents only a small portion of the seeds in the seed bank (Stone and Juhren, 1953; Zammit and Zedler, 1988). Much of the remaining seed bank is likely to have been consumed or made unviable due to fire (Keeley, 1977). Of these seedlings, it is estimated that only 92% survive (Kummerow et al., 1985). In addition to keystone shrub species, many fire-following annuals, and perennials are also abundant in the soil seed bank and are stimulated by fire effects (Keeley et al., 1985). These data led us to an investigation of the size and composition of the soil seed bank on one restoration site at Rocky Canyon Quarry (RCQ). As more sites are mined, similar experimentation should be completed to increase the replication of this study.

This project seeks to utilize the natural fire recovery mechanisms of chaparral plant communities to improve post-mining plant restoration from bare mineral soil. Heat, charate, leachate, smoke, and/or liquid smoke (L.S.) have all been supported as effective

triggers in chaparral plant germination (Keeley et al., 1985; Keeley, 1987a; Keeley et al., 2005; Jagger et al., 1996a; Jagger et al., 1996b). These treatments may provide an alternative to using fires to stimulate chaparral seeds in the seed bank to germinate. Many restoration horticulturalists do not use fire effect treatments (Belyea, 9-27-2008; Berlin, 9-26-2007; James, 9-27-2008; Miller, 9-26-2007; Mathew, 9-27-2007; Richardson, 9-27-2008). Some, such as Melanie Baer-Keeley at Sequoia and Kings Canyon National Parks, add one to two pounds of charate/acre to hydroseed mixes, but the effects are not quantified or described in published literature (Pers. Comm. Baer-Keeley, 2008). Therefore, I examined ways to improve seed germination and restoration by applying fire effects such as heat and/or charate. It may be possible to stimulate seeds in the soil seed bank to germinate, establish plant cover, and reproduce, thereby preserving the local genetic integrity and composition of the pre-disturbance plant community. Utilizing these seeds from the soil seed bank would maintain the local gene pool while not diluting the gene pool with plants introduced from nursery or seed distributor populations. Furthermore, the costs associated with collection, processing, storage or purchase of seeds would be reduced or transferred if fire effects could be utilized to stimulate the native seed bank.

While extensive research has supported that native chaparral species generally increase their germination rates with fire-effect treatments (Keeley et al., 1985; Keeley et al., 1987a; Keeley, 1977; Stone and Juhren, 1953; Zammit and Zedler, 1988), I am uncertain of fire effects on non-native plants in the soil seed bank. The RCQ soil seed bank has not been evaluated to determine if it is a viable resource. However, it is important to develop

techniques to exploit the soil seed bank fully and “maximize the germination of seeds which it contains” (Read et al., 2000).

In addition, exploiting the fire annuals’ seed bank may function as an ecological insurance program against any damaging fire effects in the future. Annuals that germinate following fire assist with erosion control and serve as nurse plants for many perennial and shrub seedlings. These annuals have documented soil seed resident times between 20 and 75 years with maximum documented time about 100 years (Quinn and Keeley, 2006). The RCQ natural areas have not burned since the late 1960s or early 1970s (Bob Kober, Personal Communication, 5-1-2008). Many of the restored areas will not be able to carry fire for several years due to low accumulation of senesced wood and large gaps in vegetation. This lengthy period of time may result in some loss of the native fire annuals because some seeds may perish with increased residence time in the soil seed bank. In addition, few fire following annuals are incorporated into seed mixes because they are not routinely available on-site or from commercial seed distributors. As a result, the restoration sites at RCQ risk failure if they cannot recover from natural fire events due to the lack of accumulated fire annual seed.

The goals of this study were: (1) “to quantify the size and composition of the soil seed bank” after stockpiling and reapplication at one RCQ restoration site and (2) to determine if fire effects are necessary and/or to break long-term dormancy and stimulate germination of species from the soil seed bank in restoration (Holl et al., 2000).

Methods

Experimental Design

This experiment evaluated the soil seed bank and determined if fire effects were necessary or/ useful in restoration. To accomplish these goals the experiment had both in situ and ex situ portions. Melinda Elster and I collected soil samples from the site, subjected them to fire-effect treatments (Heat and/or Charate) or a control (no treatment). We grew them in controlled settings to determine the usefulness of these treatments in restoration. We studied the collection site intensively to describe the cover and composition of the plants. The ex situ portion is referred to as the Seed Bank Study and the in situ portion is referred to as the Field Study. Then, the composition of the plants identified in the two studies was compared.

Soil Seed Bank Study

This investigation was a two-factor design using heat and charate. The four treatments are (1) heated soil with no charate, (2) unheated soil with charate, (3) heated soil with charate, and (4) a control of untreated soil. There were a total of eight replications of each treatment during two trials. Our blocking consisted of trial number. We designed this experiment to find out if four alternative responses exist to fire-effect treatments. The possible responses and corresponding consequences are: (1) high seed germination irrespective of treatment suggesting that no effect exists, (2) no germination suggesting that the soil seed bank remained dormant or unviable, (3) varying germination rates suggesting that the treatments do not have a dominant effect on germination, and (4) statistically significant differences between treatments suggesting that the treatments have an effect.

Soil samples were collected from the upper test site at RCQ on October 10, 2006 (Fig. 22). A 7.5 cm x 7.5 cm Dutch auger was used to collect about one kilogram of soil from each of the 16 randomly chosen one meter-squared plots. A grid system of one meter-squared plots, which was on the site from another experiment, was used. Sixteen (16) plots were randomly selected and used to collect soil samples. Soil cores were collected from eight spots in each of the one meter-squared plots, one sub-sample from each corner and four from random locations. The sub-samples from a plot were mixed together in a plastic bag resulting in one composite sample from each one square meter plot following a method used by Odion and Davis (2000).

Figure 22. Photographs of Seed bank of RCQ: Potential for vegetation recovery study site. The photograph was taken by Melinda Elster in 2007.

The 16 soil samples were screened using a one sixth centimeter (one-quarter inch) mesh to remove rocks and gravel. Soil sub-samples of 700 g were randomly taken from the one

kilogram sample. Soils were stored in plastic bags in the dark at room temperature during the interim. Soil samples were randomly assigned to treatment groups. The individual samples were mixed three times within the original collection bag. Four samples were randomly selected and randomly assigned to a treatment. The process was repeated for all treatments.

Charcoal was prepared from chaparral twigs collected at RCQ. The twigs ranged from five to 15 mm in diameter. The twigs were partially fired in a Smokey Joe Charcoal Grill, allowed to cool over night, then ground, and sieved to make charate. These methods were adapted from a website on home charcoal preparation (Lea, 2006). Other researchers, such as Keeley and Pizzorno (1986), describe methods to make small quantities of charcoal with Bunsen burners, but no descriptions of making large quantities of charcoal were included in the fire-effects research papers. We placed the chaparral twigs on a barbeque grill in crisscross layers until full. Fire was initiated with paper, cardboard, and small twigs. After fire was established, the dampers on the lid were gradually closed so that the wood would smolder overnight. The resulting charcoal was ground in a blender and sieved using a two millimeter screen mesh to create charate following a method used by Keeley and Pizzorno (1986).

Literature was reviewed to determine amounts of charate which have a positive effect on germination. Investigators have used varying rates and settings in their experiments as shown in Table 28 below. Natural settings and plant containers, both open systems, have much larger amounts of charate applied than the closed system Petri dishes. More charate may have been applied to these experimental units which have rain and wind exposure. We used Odion and Davis's (2000) second trial application rate of 12 g of charate for

each 20 cm diameter foil pan for this experiment (Christensen and Muller, 1975; Keeley et al., 1985; Keeley, 1986; Keeley, 1987a; Odion and Davis, 2000).

	Original experimental		Description of
	Rate (g/1 m ²)	unit size	original experimental unit
Odion (2000) Trial 1	669	20 cm diameter	plant container
Odion (2000) Trial 2	366	20 cm diameter	plant container
Keeley (1985)	318	10 cm diameter	plant container
Keeley (1986)	127	100 mm diameter	Petri dish
Keeley (1987a)	177	60 mm diameter	Petri dish
Christensen and Muller (1975)	280	1 acre	natural area

Table 28. Published rates of charate. Rates of charate application from the literature review with the original experimental unit size and description. These rates were used to determine treatment application rates.

Soil sub-samples assigned to the heat treatment were prepared in aluminum baking pans with a maximum soil depth of three millimeters and placed into a forced-air convection oven, which was preheated for 15 minutes at 100°C. The order of treatment was randomly assigned to soil sub-samples. Each sub-sample was heated in the oven for seven minutes (Odion and Davis, 2000). After the heat treatment, all sub-samples were spread evenly on 19 cm x 19 cm foil pans filled with two centimeters deep-washed, dried, and sterilized sand (Odion and Davis, 2000; Zammit and Zedler, 1988). For the two treatments with charate, 12 g of charate was sprinkled on top of soil pans (Odion and Davis, 2000).

Samples were placed into a germination chamber or greenhouse and surveyed every seventh day for the duration of the trial. The number of monocots and dicots was recorded after germination and before plants could be identified to a more specific level. These numbers were recorded to determine the maximum number of individuals for use

in statistical analysis. Once plants reached identifiable stages they were identified to the most precise level. The number of plants for each species was recorded. Plants were placed into categories based on life history traits (Hickman, 1993; USDA, 2008). Categories included plant clades (monocot or dicot), place of origin (native or non-native to California), life form (grass, herb, shrub), and total number of plants. Plants were identified using *Weeds of the West* (Whitson, 2002), *The Jepson Manual* (Hickman, 1993), and *Roadside Plants of Southern California* (Belzer, 1984). In addition, Oliver Hernandez and Dr. David Keil assisted in the identification of some plants (O. Hernandez, Personal Communication, 2-16-2008; D. Keil, Personal Communication, 3-16-2008). Data from week four, before dramatic decline in the overall plant number occurred, were used for quantitative analysis. Data beyond week four were used to identify plants to the species level.

The first trial occurred from November 1 to February 17, 2006 in a germination chamber. Each sample was watered with 400 ml of water before placement into a germination chamber. Samples were loaded randomly onto three shelves in a germination chamber set at 20°C with 12 hours of light/dark cycles (Keeley, 1986). To ensure no blocking effects, samples were randomly repositioned once per week. Samples were removed from the chamber and watered as needed through the duration of the experiment.

The second trial occurred April 3 through October 1, 2007 in the Cal Poly Plant Conservatory greenhouse. All samples were irrigated twice per week with the greenhouse watering system. To ensure no blocking effects occurred samples were randomly repositioned once per week.

The data were analyzed with Minitab. I used logistic regression blocking by trial to estimate the germination rate of different treatments. The model was assessed by Pearson, Deviance, and Hosmer-Lemeshow “goodness of fit” tests. For some of the models, both non-native dicots and monocots did not fit the model. Others, like total non-native plants, were a marginal fit. The native plants were a good fit to the logistic regression model (Appendix D). The outcomes of the logistic regression was based on the null hypothesis which states that all treatment and control groups have equal germination rates and the alternative hypothesis states that at least one mean is significantly different. Due to the large number of treatments, I assess statistical significance using both Bonferroni adjusted based on the number of comparisons and $\alpha=0.05$.

Field Study

To determine what plant species occur naturally in the areas where the soil samples were collected, Melinda Elster observed and sampled the vegetation in these areas on December 27, 2006, May 26, 2007, and June 9, 2007. I assisted designing and completing the surveys on June 9, 2007. We recorded species richness, vegetation cover, and vegetation density of perennials using the point intercept, belt transect sampling methods, and counting all plants present. Species richness was determined by multiple walk-throughs of the site. Plant density was determined twice by counting all plants in the plot using a grid system. The third and last plant density sampling used the belt-transect method. On June 9, 2007, the majority of annuals appeared to be dead. Therefore, they were not included in the point-intercept or belt-transect sampling.

On June 9, 2007 four 10 m transects with two meter belt transects were sampled using the point-intercept and belt-transect, respectively. The transects were located “along a base line on the top of the study plot four random numbers were chosen, with four randomly chosen points measured into the plot” (Elster, 2007). A 10 m transect was laid out on a east-west 45° declination, five meters each way from the point. A meter stick was lowered perpendicular to the ground at 20 cm intervals along the transect for point-intercept. The belt consisted of a two-meter wide strip centered along each transect. The belt was created by extending meter sticks out from the center of the line transect while sampling on each side. Only woody species which were rooted within the 10 m by two meter belt were counted. Plants were identified to species, and their diameter was measured. Adequate sampling occurred because a “tally of the number of new species in each transect was kept, giving a cumulative number of species sampled, indicating that the most numerous species were sufficiently sampled” (Brower et al., 1998 as cited in Elster, 2007).

Results

Soil Seed Bank Study

As indicated earlier, four alternative responses exist to fire-effect treatments. High germination irrespective of treatment suggests that no effect exists. No germination suggests that the soil seed bank remained dormant or unviable. Varying germination suggests that the treatment is not the dominant effect on germination. Statistically significant differences between treatments results suggest that the treatment has an effect.

The data for non-native dicots and monocots do not fit the logistical regression model (Hosmer-Lemeshow: $\chi^2(4) = 20.4$, $p = 0.000$). The total number of monocots is synonymous with the total number of non-native monocots because all monocots were non-native. No formal statistical analysis will be completed for non-native dicots or monocots.

There was evidence of statistically different germination rates based on treatments for native plants ($p\text{-value} = 0.008$, $p\text{-value} = 0.016$, $p\text{-value} = 0.036$). There was no evidence of statistically significant difference in germination rates between the control and heat treatment ($p\text{-value} = 0.101$). There was no evidence of statistically significant differences present between the treatments: heat and charate ($p\text{-value} = 0.254$). There was no evidence statistically significant differences present between the treatments: heat/charate and charate ($p\text{-value} = 0.887$). There was a statistically significant difference in germination between the control and the treatments charate ($p\text{-value} = 0.008$) and heat/charate ($p\text{-value} = 0.016$). Heat and heat/charate have significantly different germination rates as well ($p\text{-value} = 0.036$). I estimate that heat/charate reduces germination by 94% (95% CI: 50%,

99%). I estimate that charate reduces germination by 66% (95% CI: 18%, 85%). While I estimate heat reduces germination by 43%, our 95% CI indicates that heat may in fact increase germination by up to 12% or decrease germination by up to 71% (Table 29).

Treatment	Total native plants	Total non-native plants
Control	- ^a	- ^a
Heat	0.57 (0.29, 1.12) ^{ab}	2.12 (1.05, 4.28) ^{*b}
Heat/Charate	0.06 (0.01, 0.50) ^{*c}	15.11 (1.97, 115.57) ^{*b}
Charate	0.34 (0.15, 0.82) ^{*bc}	2.25 (1.01, 5.04) ^{*b}

All groups denoted with a similar superscript, such as ^a, ^b, or ^c, are statistically similar.

*Significant confidence interval.

Table 29. Results for Soil Seed Study The tabulated values include the odds ratio and 95% Confidence Interval for both native and non-native plants when the treatments are compared to the control. All significant results are indicated with an asterisk. All treatments which are similar are indicated with the same superscript letter.

There were statistically different results based on treatments for non-native plants. There was no significant difference between all treatments: heat, charate and heat/charate.

There was a significant difference between the control and all treatments: heat, heat/charate, and charate (P-value=0.036, 0.009, and 0.048). I estimate that heat increases germination by 112% (95% CI: 5%, 328%). I estimate that heat/charate increase germination by 1,411% (95% CI: 97%, 11,457%). I estimate charate increases germination by 125% (95% CI: 1%, 404%) (Table 29).

Field Study

Perennial Density

On December 27, 2006 there were 10 species of perennials which had an absolute density of 1.18 plants/m². The most abundant species was *Lotus scoparius* (Deerweed) followed by *Salvia mellifera* (Black Sage). On May 26, 2007, the number of species had increased to 14 species of perennials which had an absolute density of 1.36 plants/m². There was an observable shift in species composition in this second survey with an increase in the relative density of Chamise from 8.36% to 23.62%, a decrease of Deerweed from 40.65% to 27.31%, and Black Sage from 30.99% to 24.48%. The density of perennials continued to increase throughout the spring. On June 9th, 2007 the density was estimated at 2.5 plants/m². Chamise with 35.3% relative density was the most abundant species. Black Sage, with a relative density of 30.3%, co-dominates. Deerweed continued to decrease from a relative density of 40.7% in May 2006 to 12.4% relative density on June 9, 2007. *Helianthemum scoparium* (Peak Rush-rose) increased from 0% in December 2006 to a 15.4% relative density in June 2007. Other perennials occur but remain uncommon and in low densities (Elster, 2007) (Fig. 23, Table 30).

According to Elster (2007) several species that are considered fire-followers and are common in disturbed areas were observed in the plot: *Dendromecon rigida* (Bush Poppy), *Dicentra chrysantha* (Golden Ear-drops), and Peak Rush-rose. *Eriogonum fasciculatum* (California Buckwheat), Bush Poppy, Golden Ear-drops, *Ribes malvaceum* (Chaparral Currant), and *Solanum xanti* had fewer than five individuals each.

Plant name	Relative 12/27/2006	Relative 5/26/07	Relative 6/09/07	Absolute (plants/m²) 6/09/2007
<i>Adenostoma fasciculatum</i>	8.36%	23.62%	35.3%	0.8875
<i>Ceanothus cuneatus</i>	0.99%	1.85%	3.0%	0.075
<i>Dendromecon rigida</i>	0.28%	0.37%	1.0%	0.025
<i>Dicentra chrysantha</i>	0.57%	0.37%	0%	0
<i>Eriogonum fasciculatum</i>	0.00%	0.49%	0%	0
<i>Helianthemum scoparium</i>	0.00%	7.75%	15.4%	0.3875
<i>Lotus scoparius</i>	40.65%	27.31%	12.4%	0.3125
<i>Mimulus aurantiacus</i>	1.42%	1.11%	2.0%	0.05
<i>Pseudognaphalium californicum</i>	10.62%	6.15%	0%	0
<i>Pseudognaphalium sp.</i>	1.98%	4.80%	0%	0
<i>Ribes malvaceum</i>	0.00%	0.12%	0%	0
<i>Salvia mellifera</i>	34.99%	24.48%	30.3%	0.7625
<i>Solanum xanti</i>	0.00%	0.37%	0%	0
<i>Trichostema lanatum</i>	0.14%	1.23%	0.5%	0.0125
Absolute perennial (plants/m ²)	1.18	1.36	2.5125	2.5125

Table 30. Species list, relative density of perennials, and absolute density

(perennials/m²) based on multiple site censuses. The censuses occurred on December 27, 2006 and May 26, 2007 and had all perennials counted and identified within the plot. Estimations on June 9, 2008 of perennial relative density, plants/m², and total perennials/m² were based on belt transects (Elster, 2007).

Figure 23. Relative perennial density of Seed bank of RCQ: Potential for vegetation recovery site. Relative density of perennials based on site censuses on December 27, 2006 and May 26, 2007 and estimations on June 9, 2008 of perennial relative density based on belt transects (Elster, 2007).

Perennial Cover

Shrub cover was approximately 4% using the point-intercept method. The majority of the area was bare mineral soil. Deerweed was the dominant shrub with approximately 52% relative cover. “Chamise, Peak Rush-rose, and Black Sage were the next dominant species with relative coverage of 15%, 14%, and 10% respectively” (Elster, 2007) (Table 31).

Plant name	Relative	Absolute
<i>Adenostoma fasciculatum</i>	15.08%	0.59%
<i>Ceanothus cuneatus</i>	0.65%	0.03%
<i>Lotus scoparium</i>	51.70%	2.04%
<i>Helianthemum scoparium</i>	13.56%	0.53%
<i>Pseudognaphalium canescens</i>	2.72%	0.11%
<i>Pseudognaphalium californicum</i>	4.05%	0.16%
<i>Salvia mellifera</i>	10.46%	0.41%
<i>Trichostema lanatum</i>	0.02%	0.00%
<i>Mimulus aurantiacus</i>	0.90%	0.04%
<i>Solanum xanti</i>	0.02%	0.00%
<i>Dendromecon rigida</i>	0.27%	0.01%
<i>Dicentra chrysantha</i>	0.56%	0.02%
Total plants	100%	3.94%

Table 31. Estimations of perennial cover for the field study on June 9, 2008.

Comparison of Seed Bank and Field Study

The total number of non-native species in the seed bank (14) based on greenhouse studies and field species was similar (14). The total number of native species was much greater in the field (14) and field point-intercept survey (8) compared to the seed bank (4) (Table 32).

Plant name	Field species survey	Field cover survey	Seed bank	Native
<i>Adenostoma fasciculatum</i>	Present	Present		Yes
<i>Bromus arenarius</i>	Present		Present	No
<i>Bromus madritensis ssp. madritensis</i>	Present		Present	No
<i>Ceanothus cuneatus</i>	Present	Present		Yes
<i>Centaurea melitensis</i>	Present		Present	No
<i>Centaurea solstitialis</i>	Present		Present	No
<i>Conium maculatum</i>	Present		Present	No
<i>Cryptantha sp.</i>	Present		Present	Yes
<i>Dendromecon rigida</i>	Present	Present		Yes
<i>Dicentra chrysantha</i>	Present			Yes
<i>Eriogonum fasciculatum</i>	Present			Yes
<i>Erodium sp.</i>	Present		Present	No
<i>Helianthemum scoparium</i>	Present	Present		Yes
<i>Hirschfeldia incana</i>	Present		Present	No
<i>Lotus scoparius</i>	Present	Present	Present	Yes
<i>Mimulus aurantiacus</i>	Present	Present	Present	Yes
<i>Oxalis corniculata</i>	Present		Present	No
<i>Picris echioides</i>	Present		Present	No
<i>Polypogon interruptus</i>	Present		Present	No
<i>Pseudognaphalium californicum</i>	Present			Yes
<i>Pseudognaphalium sp.</i>	Present			Yes
<i>Ribes malvaceum</i>	Present			Yes
<i>Salvia mellifera</i>	Present	Present		Yes
<i>Senecio vulgaris</i>	Present		Present	No
<i>Solanum xanti</i>	Present			Yes
<i>Spergula arvensis</i>	Present		Present	No
<i>Stellaria pallida</i>	Present		Present	No
<i>Trichostema lanatum</i>	Present	Present		Yes
<i>Vulpia myuros</i>	Present		Present	No

Table 32. Species list for both the field survey and soil seed bank studies (USDA, 2008).

The number of species in the seed bank study plateau. The composition of plants, which emerged and lived until identification, varied among blocks, but their composition was very similar within a block. Species in each individual block species accumulation curve begins to level off after three samples. However, when blocks were combined, the species

accumulation curve begins to level off after five samples. The number of species did not level off for the field cover survey (Fig. 24). These results suggest adequate sampling occurred for the ex situ seed bank analysis but not for the field cover survey. Therefore, the results of the two studies are not necessarily comparable. The field study results underestimate the number of species present while the seed bank study adequately samples it.

Figure 24. Species accumulation curve for soil seed bank study and field survey.

Seed bank samples with black dots were in block one and those with grey were in block two.

All of the non-native and native species in the seed bank were also in the field species richness survey. These species were common throughout the site. Only 25% of the native shrub species in the field-cover survey were also in the seed bank study. Deerweed and *Mimulus aurantiacus* (Sticky Monkeyflower) were the only shrubs found in the seed

bank study, and there were very few seedlings present. Common shrub seedlings in the field survey, Chamise, Peak Rush-rose, and Black Sage, were not present in the seed bank study. None of the uncommon seedlings in the field-cover survey were present in the seed bank study.

Discussion

The primary goal of this research was to examine the size and composition of the seed bank at one restoration site at RCQ to determine the potential for plant regeneration from the soil seed bank. Few native species were present in the ex situ seed bank study, but the density and species richness of the in situ survey was greater. These results indicate that supplementing the natural regeneration with seeds and container stock would accelerate revegetation and recovery of chaparral.

Native plant germination does not appear to be enhanced by the treatments as hypothesized. In fact, the charate and heat/charate treatments diminished the number of native plants that germinated while heat had no effect. The effects of the treatments on native plants were indecisive. I found that germination of non-native plants was enhanced by the treatments: germination rates increased from 112% to 1,411% compared to the control. The treatments do not accomplish the goals of our restoration project, which are to increase native plant cover while keeping non-native plants to a minimum. Based on the results of this experiment, charate and heat treatments are not recommended for use in restoration. However, further experimentation should be completed since these results do not coincide with previously published literature completed in the laboratory and intact chaparral (Christensen and Muller, 1975; Keeley et al., 1985; Keeley, 1986, Keeley, 1987a; Odion and Davis, 2000).

Even though many studies have demonstrated charate breaks long-term chaparral seed dormancy (Wicklow, 1977; Jones and Schelsinger, 1980; Keeley and Pizzorno, 1986; Keeley, 1987a), the treatment design may have been inherently flawed. Christenson and

Muller (1975) did not find significant differences in germination rates based on the total number of plants emerging. I initially hypothesized that Christenson and Muller's results were diluted due to compositional shifts in species which germinated. However, our results do not support the stated hypothesis. Future soil seed bank studies at RCQ should utilize treatments which have been demonstrated to significantly affect total number of seed which germinated and categorical data as well, such as Read et al. (2000) or Holl et al. (2000). Holl et al. (2000) utilized one factor, fire, to stimulate germination of seeds in the seed bank. However, fire effects are composed of both heat and chemicals and can be separated with other treatment designs. Read et al. (2000) utilized the individual components of fire, heat and smoke. As completed in this study, heat was applied with an oven. I found no significant difference in seed germination with heat treatments, whereas Read et al. (2000) found differences. As previously stated, because seed germination is not enhanced by heat for many, the chemical fire effect must also be evaluated (Christenson and Muller, 1975; Keeley, 1987a; Keeley, 1991; Keeley et al., 2005; Sweeney, 1956). Read et al. (2000) also applied plant-derived smoke in fumigation tents to significantly stimulate germination in the seed bank. It is possible that the soil seed bank at RCQ is not viable. However, I recommend completing the experiment with the smoke treatments as described in Read et al. (2000) before ruling out the soil seed bank as a tool at RCQ. Furthermore, I recommend replicating this experiment on multiple areas at RCQ before and after mining and soil redistribution.

The growth chambers were not ideal to complete the study. During the first trial in the growth chambers the plants suffered. There was insufficient light which made the plants etiolate or grow long and straggly. Moisture within the chamber was hard to regulate

because no humidity regulators were present. Plants suffered from dehydration even though they were watered one to two times per week. The second trial was conducted at California Polytechnic State University's Plant Conservatory Greenhouse due to these problems.

The sample size may be too small to gather information on native regeneration after stockpiling soil. There were very low germination rates of native plants which suggest that the soil seed bank remained dormant or unviable. There were only 49 total native plants which germinated. Of these natives, only four were shrubs or subshrubs and all the others were native herbs (Appendix D). The soil was collected from a site which had regeneration at a density of 1.36 native shrubs and perennial plants/m² during the spring after soil collection (Elster, 2008). The recruitment density is dramatically less than in natural settings after fires, experiments with artificial clearings, or after old-road succession (Holl, 2000; Keeley, 1987a; Keeley, 1987b; Keeley, 1995; Stone and Juhren, 1953; Zammit and Zedler, 1988). It is possible seeds were mechanically or chemically scoured during movement to and from the stockpile or during stockpiling. The conditions within the stockpile may have rendered them not viable. These seeds may have germinated before redistribution on the restoration site or may have scarred so severely they were no longer viable. More repetitions should be completed due to the low number of native plants which germinated.

C. In Situ Effects of Seeding and Charate

Introduction

This experiment has the same premise as the one previously described in Experiment B: Seed Bank of Rocky Canyon Quarry: Potential for Vegetation Recovery. However, this experiment was conducted in the field and is compared to results found in the ex situ charate experiment. Initially, heat treatments were not applied in the field because of concerns about using fire at the Rocky Canyon Quarry (RCQ) site. Subsequently, I was able to devise a fire treatment for experiments that alleviated such concerns. In addition, a native seed mix supplement was included in the experiment because of the insufficient number of native perennials from the RCQ soil seed bank in the previous experiment. I accept that seeding may be necessary and wish to determine the effect of charate on seeding. This experiment evaluates the effects of charate on the soil seed bank and sown seeds in the field to determine if charate is a possible additive during restoration.

Our study quantifies the effects of charate and/or seeding on the rates of seed germination from the soil seed bank after stockpiling and reapplication at RCQ. I hypothesized fire effects would have a positive effect on native plant seed germination from both the seed mix and soil seed bank. I am uncertain of the effects on non-native plants in the soil seed bank.

Method

The experiment is a two-factor design using charate and a native seed mix. The four treatments are: (1) native seed mix without charate; (2) native seed mix with charate; (3) no seed mix with charate; and (4) a control without either treatment. There were a total of four replications of each treatment in a Latin Square. The blocking consists of row and column within the Latin Square.

The experiment was initiated on December 17, 2006, on a mined slope that had been prepared for restoration during February 2005 as described previously. The seed mix included annual and perennial herbs and shrubs purchased from S&S Seeds in 2005, stored in mesh bags under variable light conditions at room temperature, with minimal amounts of inert material present. Charate was prepared as described in Experiment B: Seed Bank of Rocky Canyon Quarry: Potential for Vegetation Recovery (Lea, 2006). The same rate of charate, 366 g/m^2 , was also used (Odion and Davis, 2000).

The outline of all one meter-squared plots was determined using survey tape. I placed rebar as guidelines at the outer margins of all rows and columns. Then, the plots boundaries were dug by hand with a drain spade. The walk-ways, one-half meter wide and slightly raised, were placed in between columns to minimize foot traffic within plots and reduce run-off between columns. The soil removed to place edging 13 cm high, and black polyethylene, was used to secure edging on the exterior of the plot. Edging was place around the margins of each plot. The plots within a column shared interior boundaries marked with one and one-quarter meter long pieces of edging to divert run-off

away from the adjacent plot. All rocks greater than 38 cm² were removed from the plot surface.

All treatments were initially assigned to all columns and rows. Then, the columns and rows were randomly re-ordered to create a randomized Latin square. The seed mix and charate were sprinkled near the center of the plot (Table 33). The surface of all plots was scoured with a metal leaf rake to disperse treatments and act as a control. The order of scouring was not random between treatments. All plots without charate, which included the control and seeds, were completed first. All plots with charate, both with and without seeds, were scoured last to avoid contamination. Within the two blocks of scouring, the order was random.

Plant name	Seeds per plot (g)	Seeds per plot
<i>Adenostoma fasciculatum</i>	1.5	3,638
<i>Eriogonum fasciculatum</i>	2.5 +/- 0.1	2,480+/- 99
<i>Helianthemum scoparium</i>	0.25	661
<i>Lupinus hirsutissimus</i>	2	132
<i>Lupinus nanus</i>	2.0 +/- 0.1	198 +/- 20
<i>Mimulus aurantiacus</i>	0.1	2646
<i>Nassella lepida</i>	1.0 +/- 0.1	914+/- 91
<i>Phacelia brachyloba</i>	0.5	Not available
<i>Phacelia parryi</i>	0.5	2,646

Table 33. Seed mix for in situ effects of seeding and charate. The weights of some species' seeds were precise and varied up to 0.1 grams between plots. In these instances, the seeds per plot (g) is denoted with variability recorded (EX: +/- 0.1). The seeds per plot variability is also shown (EX: +/- 99).

Plant cover was monitored using Braun-Blanquet cover classes on one-half meter-squared subplots placed 25 cm away from all plot boundaries (Table 34). The number of plants in both the monocot and dicot clades were identified and recorded before plants could be identified to a more specific level. Once plants reached identifiable stages they were identified to the most precise level. The number of plants for each species was identified and recorded.

Class	Range of Cover (%)
5	75-100
4	50-75
3	25-50
2	5-25
1	1-5
Cross	<1
R	<<1

“*Individuals occurring seldom or only once therefore cover ignored and assumed to be insignificant.”

Table 34. Braun-Blanquet cover classes (Mueller-Dombois and Ellenberg, 1974).

Results for all plots were divided into native, non-native, and total plant cover using an ANOVA. The data were analyzed with Minitab. I used ANOVA to examine the relationship between mean plant cover and the different treatments. Each ANOVA model was screened to determine if the technical requirements for the model were met using Anderson-Darling Test for Normality and Levene’s Test for Homogeneity of Variances. In each variable, native, non-native, and total plant cover, technical requirements were met (Appendix E). Post-hoc multiple comparisons were completed using the liberal

Fisher's LSD 95%, and Tukey's and Bonferroni's 95% which are more conservative tests.

Results

Two growing seasons after treatment, significant interactions for total plant cover and main effects for native plant cover existed (p-value=0.023). There was no evidence that Charate had significant effects on native, non-native, and total plant cover (p-value=0.168, p-value=0.809, p-value=0.420). Non-native plant cover remained constant across all treatments (p-value=0.620, p-value=0.168, p-value=0.620) (Table 35).

Treatment	Non-native	Native	Total
Seed	0.620	0.023*	0.134
Charate	0.168	0.809	0.420
Seed*Charate	0.620	0.115	0.041*

Table 35. Results for In Situ Effects of Seeding and Charate on plants.

* Indicates significant results

There is evidence of an interaction between seeding and charate treatments (p-value=0.041) in terms of total plant cover. The reaction to charate or seeding is dependent on the presence or absence of the other factor. There is no evidence of significant main effects for each factor by itself, seeds or charate additions (p-value=0.134, p-value=0.420) (Fig. 25, Table 35).

Figure 25. The response of the seed treatment is dependent on the charate treatment applied.

There was no evidence any of the treatments significantly affected non-native plant cover. No statistically significant differences were present for the interaction (p-value=0.620) or between the treatments native seed and charate addition for non-native plant cover (p-value=0.620, p-value=0.168).

Only one of the treatments significantly affected native plant cover. There was no evidence of a statistically significant interaction between the addition of native seed and charate addition (p-value=0.115). There was no evidence of a statistically significant effect of the charate on plant cover (p-value=0.809). The seed treatment significantly

increased the native plant cover (p-value=0.023). Fisher, Tukey, and Bonferroni 95% confidence intervals confirm that native plant cover increases with the seed treatment. Fisher's 95% Confidence Interval found the plant cover increased by 0.3 to 2.5 cover classes when seeds are added.

Charate addition and seeding achieve similar plant cover, but the composition is quite different. Sky Lupine was the dominant native plant in the seeded plots but was not found in any other plots. *Lotus scoparius* (Deerweed) was the dominant native plant in all other plots. No native herbs were present on plots that were not seeded. Only one *Adenostoma fasciculatum* (Chamise) plant occurred throughout all experimental plots, and it was present on a plot treated with charate.

Discussion

Based on this experiment, seeding is an integral part of native plant restoration. We must continue seeding because it enhances the native plant cover and composition. Adding charate does not significantly affect seed germination of seeds in the soil seed bank as hypothesized. Furthermore, the combination of seeding and adding charate actually depressed total plant cover.

The implementation of the charate rate used in the experiment, 1,481 kg of charate per acre, was not supported to be an effective restoration tool. In addition, it would require extra labor and supply costs. Horticultural charcoal costs about \$2.50/kg or \$3,702/acre. The application of charate on a large scale may also be troublesome. Charate cannot be included in the hydroseed tank due to tank-size limitations. An alternate application method for charate could be lawn fertilizer spreader such as a rotary or cyclone type. Additional research associated with charate application methods is needed to determine if charate is a potential restoration tool.

The charate treatment may have been an ineffective seed germination trigger for native plants due to factors such as the amount of charate or particle size. This experiment used a particle size which could be used in a hydroseeder. However, this particle size could be swept away by winds, especially if not integrated into hydroseed blankets. In my study, it is possible that the charate treatment did not remain on the plots long enough to influence the seeds. When the charate treatments were applied, the charate was visible on the soil surface. However, one month later after no rain occurred, there was no visible charate.

Future experiments should test different amounts of charate and larger sizes of charate which are commercially available and cannot be blown away.

The experimental unit size of the experiment was designed to be one meter-squared to adequately sample native plants which at the time of installation had a density of 1.18m^2 . The emergence of native plants continued throughout the growing season and reached 1.36 m^2 in May of 2007 (Elster, 2007). However, after installation of one meter-squared plots, an edge effect was noticed to be irregular and dependent on the angle of edging. Grass proliferated when the edging was less than 90° . Research has noted an interaction between grass and chaparral plants where non-native grass cover reduced native plant cover (Taskey et al, 1989). Therefore, the plot size was reduced to one-half meter-squared due to edge effect, which is well below the frequency of native perennials quantified by Elster (2007). The one-half meter-squared plot may be insufficient to characterize the soil seed bank response to native seed and charate addition.

During the course of the experiment one plot was heavily disturbed by dirt side-cast by a bull dozer. Soil and rocks covered about one-third of the plot. It appears the side-cast debris remained on Plot 1A for less than one week. Fortunately, the majority of debris which was removed by hand did not contaminate the subplot where vegetation was monitored. Fortunately, it occurred during early June when there were very few plants living above ground. I am uncertain about this problem's effect on the plot. The disturbance probably did not harm any seeds in the soil seed bank of the plot, but it is possible that seeds from the debris were deposited in the plot (Fig. 26).

Figure 26. Plot disturbance of In Situ Effects of Seeding and Charate. The side-cast debris was only in Plot 1A. Fortunately, as seen in the photograph above, the majority of debris did not contaminate the monitored subplot.

Due to the many problems associated with this experiment (such as sample size, experimental unit size, charate size and resident time on plot, and disturbance), the results of this experiment are not discussed further.

D. Fire Effects on Restored Area a Decade after Seeding

Introduction

The objective of this experiment is to test fire and fire-effect treatments on germination of the soil seed bank as remediation on restored areas that do not meet the desired cover.

Method

The treatments are: (1) charate at three different rates (low, moderate, and high); (2) fertilizer at recommended rate; (3) fire; and (4) a control. A total of 36 one-half meter-squared quadrats (plots) were placed throughout the Oak Woodland Restoration Site after all appropriate sites were located. All plots were placed in bare areas at least one-half meter from any vegetation to reduce the risk of the fire escaping. The plots were numbered from north to south and east to west using a random numbers table (Random.org, 2007). Each plot was marked on the northern and southern corners with 38 cm rebar so they could be relocated. The southern stake has a metal tag with the treatment labeled (Table 36).

Treatment	Field label
Control	Cont
Low Charate	Low
Moderate Charate	Mod
High Charate	High
Fertilizer	Fert
Fire	Fire

Table 36. Key for short-hand field labels. The southern rebar of all plots had a metal tag indicating the treatment or control applied. The short-hand used on these metal tags is included in the table above.

The plots were numbered from north to south and east to west using a random number table (Random.org, 2007). The 36 plots were assigned treatments based on numerical order. Numbers 1-6 served as the controls, 7-12 were treated with a low amount of charate, 13-18 with a moderate amount of charate, 19-24 with a high amount of charate, 25-30 with fertilizer and no charate, and 31-36 were burned with a small fire. Examples of plot treatments are included in the figure below (Fig. 27.)

Figure 27. Photograph of charate treatments for Fire Effects on Restored Area a Decade after Seeding. The photographs show the low charate, medium charate, high charate, and fertilizer treatments when applied (Clockwise). The number in the left hand corner indicates the plot number.

The fires were completed before the first significant rain of the season. After the first rain, water enters into the seed as germination begins, and fires superheat the water within the seed and soil beyond temperatures conducive to life (Quinn and Keeley, 2006). The fire treatment was confined in a California State Park campground fire ring, which is a one meter diameter metal ring with 30 cm tall sides. Similar amounts of dry branches and leaves from *Baccharis pilularis* (Coyote Brush), *Adenostoma fasciculatum* (Chamise), *Arctostaphylos glauca* (Bigberry Manzanita), *Eriogonum fasciculatum* (California Buckwheat), *Salvia mellifera* (Black Sage), and *Lotus scoparius* (Deerweed)

without flowers or seeds provided the fuel for the fire. This plant material was placed in the campfire ring on top of four sheets of crinkled up black and white newsprint. Two layers of one-sixth centimeter ($\frac{1}{4}$ -inch) wire mesh, which served as a spark arrestor, was placed on top of the fire ring and secured by placing about five pounds of rocks on top of it. The fire ring was removed after the charcoal and ashes were cool to the touch. The fires were ignited in the early morning, beginning at 6 a.m., when relative humidity was high and wind was low to nonexistent. Backpack pumps with water were at hand in case of any problems, and Rocky Canyon Quarry's (RCQ) water truck was on stand-by at the site (Fig. 28, 29).

Figure 28. Photograph of fire treatment for Fire Effects on Restored Area a Decade after Seeding. Similar amounts of shrubs were placed on top of four sheets of crinkled up black and white newsprint on Friday October 5th 2007 (Top Left). The spark arrestor was placed on top of the fire pit before ignition and secured with rocks (Top Right). The fire was ignited with a lighter, and oxygen was added to the fire at 7:44:39 am (Bottom Left). The wood caught fire at 7:44:44 am (Bottom Right).

Figure 29. Photograph of fire treatments continued for Fire Effects on Restored Area a Decade after Seeding. Long flame lengths were suppressed with a charcoal grill lid to keep them away from nearby vegetation on Plot 19 on Friday October 5th 2007 at 7:45:09 am (Top Left). Long flame lengths continued for approximately less than one minute Friday October 5th 2007 at 7:45:37 am (Top Right). The fire had diminished intensity at 7:46:46 am (Bottom Left). All fires were completed from ignition to no flames and/or red coals in less than 10 minutes. The ground remained warm up to 20 minutes after flames were no longer present (Bottom Right).

The fertilizer and charate treatment was sprinkled evenly over the one-half meter-squared plots the day of the fire treatments. The low, medium, and high levels of charate were determined by literature review (Table 27) (Keeley, 1986; Odion, 2000). Black Gold horticultural charcoal produced by Sun Gro Horticulture Distribution Inc. cost four dollars per two quart and weighs 785 g. Ultra Vigoro All Purpose Plant Food 12-5-1

produced by Vigoro costs five dollars per five pound bags and was applied at the recommended rate for perennial plants, 3.36g/0.5 m².

Sampling of the one-half meter-squared treated plot and the one meter-squared plot which included the treatment occurred on April 15, 2008 (Fig. 30). Plants were identified and their density measured. The cover of each plant species was identified and placed into Daubenmeyer cover classes. A non-parametric test, Kruskal-Wallis, was used to analyze the data because it lacked a normal distribution even after transformation. The analysis determined which treatments are significantly different and p-values adjusted for ties were reported. The number of preferred shrub seedlings was counted in both the one-half meter-squared plot and the one meter-squared plots.

Figure 30. Graphical depiction of plots sampled for Fire Effects on Restored Area a Decade after Seeding. Diagram of plots treated, one-half meter-squared, and sampled both one-half meter-squared and the one meter-squared plots.

The preferred shrub species, which are shrubs commonly associated with mature plant communities at RCQ, are listed below (Table 37). Preferred shrubs were identified because they are commonly associated with mature plant communities at RCQ.

Therefore, the success of these preferred shrubs fulfills the goals of restoration where the plant community is accelerated through ruderal stages and mature plant community arises more quickly.

Plant name
<i>Adenostoma fasciculatum</i>
<i>Arctostaphylos glauca</i>
<i>Ceanothus cuneatus</i>
<i>Cercocarpus betuloides</i>
<i>Dendromecon rigida</i>
<i>Eriogonum fasciculatum</i>
<i>Mimulus aurantiacus</i>
<i>Pinus sabiniana</i>
<i>Prunus ilicifolia</i> **
<i>Quercus agrifolia</i>
<i>Quercus douglasii</i>
<i>Quercus lobata</i>
<i>Rhamnus californica</i>
<i>Rhamnus crocea</i> **
<i>Rhamnus ilicifolia</i>
<i>Rhus trilobata</i>
<i>Ribes sp.</i>
<i>Salvia mellifera</i>
<i>Trichostema lanatum</i>

Table 37. Preferred shrubs at RCQ. Preferred shrubs at RCQ include those commonly associated with mature plant communities.

Results

Charate and fertilizer treatments were still visible on many plots when I conducted our vegetation sampling. However, eight plots were highly impacted by drainage on the site from these treatments: low amount of charate, moderate amount of charate, high amount of charate, and the control. Two (2) of the affected plots had three to five centimeters of soil deposition which buried the metal tags affixed to rebar. These plots had no trace of the treatments. The impacted plots were not included in the statistical analysis.

A few plant species were found only within plots for a particular treatment. *Calandrinia breweri* (Brewer's Red-maids), a native fire-disturbance-following species, was only found on one plot treated with fertilizer. *Gnaphalium* spp. were only present on two plots with fire treatments.

There was no evidence of a significant effect of treatment on plant density for both the one-half meter-squared treatment area and the one meter-squared expanded plot (p-value=0.237, p-value=0.830). There was no evidence of a significant effect of treatment on plant cover for both the one-half meter-squared treatment area and the one meter-squared expanded plot (p-value=0.208, p-value=0.142).

The number of preferred shrubs could not be statistically analyzed due to the low frequency of shrub recruitment. Average number of preferred shrubs was correlated with fire and fertilizer treatments (Fig. 31). No distinction between fertilizer and fire was made due to overlapping standard errors. No distinction between the control, low charate, moderate charate, and high charate were made due to overlapping standard errors. The

plots with fertilizer and fire treatments had a greater number of preferred shrubs than all of the other treatments. One plot within the fertilizer treatment had 15 Chamise seedlings which were more than triple seen in any other plot.

Figure 31. Results for density of preferred shrubs for Fire Effects on Restored Area a Decade after Seeding. The fertilizer and fire treatments had higher average number of preferred shrubs than all other treatments in both the one-half meter-squared and one meter-squared plots. Error bars represent the standard error of the mean.

Con. is an abbreviation for control, Fer. is an abbreviation for fertilizer, Mod. is an abbreviation for moderate.

Discussion

None of the treatments had an effect on plant density or cover class. The empirical outcome for the number of preferred shrubs for both fire and fertilizer is of interest.

Future experiments should focus on increasing the number of replication for all treatments to allow for the low frequency of preferred shrubs.

No management prescription will be made until further experimentation is complete.

E. Chaparral Test Slope

Introduction

The premise of this experiment is similar, utilizing fire effects, to all previous work. The objective of this experiment is to test the liquid smoke (L.S.) dilution determined to be ideal in both preliminary (including Trial 1, 2, and 3) results from Experiment A:

Breaking Seed Dormancy with Short-term Treatments and the review of published literature..

In addition to treating seeds, the L.S. may also have an affect on the soil seed bank.

Previous studies did not find any significant difference in soil seed bank response between the control and when 10 ml/m², 20 ml/m², and 50 ml/m² of L.S. were sprayed directly onto soils from disturbed natural areas which were former mine sites in chaparral's Australian counterpart, mallee-heath (Coates, 2003). However experiment is distinct from the previous work in part because the dosage of L.S. was only 3.8 ml/m²; and, the residence time of L.S. on the soil may be greater due to hydroseeding.

Hydroseed fiber and binders were saturated with the L.S. and may have leached into the soil during following rains in a similar manner as fertilizer during hydroseeding or leachate after fires (J. Gorter, Personal Communication, 4/5/2007). The total area treated with L.S., one-quarter acre, was far greater than the two meter-square plots treated.

Therefore, the potential for environmental-wide results exists and will also be discussed.

Method

The experiment had three factors of treatments, L.S., fire, and charate. The area was divided into three separate plots of equal area for the L.S. hydroseed treatment, hydroseed without L.S., and control. No replication of hydroseed treatments was planned due to limitations of space at Rocky Canyon Quarry (RCQ) and hydroseed equipment. Fire and charate were only applied to areas treated with hydroseeded mixture (Fig. 32). The control was slated to have infrequent traffic from mining equipment; however no traffic occurred before the first year biological surveys. The nested treatments, fire and charate, were each applied to three one-half meter-squared plots each on hydroseed plots (one week before hydroseed). The plots were located five meters above the base of the slope, with at least one meter of space between plots left to right. The location of the plot was determined with a random number table where the maximum number was the width of plots. Fire was applied as previously described. A moderate level of charate, 300 g/m^2 , was applied as described in Experiment C: In Situ Effects of Charate and Seed.

Figure 32. Fire treatment application on Test Slope. Mike Tom applies the fire treatments on the 1.5:1 slope.

KCI Environmental, a hydroseed company, arrived on site with a hydroseed tank and trailer with dry ingredients. The hydroseed plot without L.S. was sprayed first to avoid L.S. contamination of the hydroseed machine. Crew members began filling a 3,000-gallon tank near the seeding location. They then added BFM Flexterra, and paddles continuously agitated the mixture. Once the tank was two-thirds full, seed mix, and binder were added. The mixture was blended for five to 10 minutes until there were no seeds floating or large chunks of material. The mixer was shut off, and the team drove to the hydroseed location. Once at the location, they restarted the mixer engine and attached hoses to begin hydroseeding. It took 30 to 40 minutes to spray the entire 3,000-gallon tank over one acre. The hydroseed mix generally included fiber (1,500-2,000 lb/acre),

seed variable (30-200/acre), Mycorrhizal Inoculum at the rate of 3.5 million propagules/acre, and water (2,000-2,250 gallons/acre dependent on amount of fiber). We used native seed mix (56lb/acre) (Table 38), HydroPost Compost (2,000lb/acre), BFM Flexterra (3,500lb/acre), and Biosol 7-2-3 organic fertilizer (1,000 lb/acre) (Table 37). However, AM-120 Mycorrhizal Inoculum (60lb/acre at 3.5 million propagules/acre) was not included in the hydroseeding due to an ordering error. Generally, the mixture of binder, fiber, seeds, and water are about 3/10-centimeters thick on top of the soil surface. The mixture stays moist for one hour after application due to evaporation water loss to the soil substrate (J. Gorter, Personal Communication, 4/5/2007).

Plant name	Native	Life cycle	Form	Rational for planting	Seeds (lb/acre)	Seeds/Lb	Pure live seed /Lb
<i>Adenostoma fasciculatum</i>	Yes	Per.	Shrub	Keystone species	1	11,600,000	580,000
<i>Artemisia californica</i>	Yes	Per.	Shrub	Colonizer	2	55,000,000	5,500,000
<i>Ceanothus cuneatus</i>	Yes	Per.	Shrub	species	1	3,375,000	45,000
<i>Dendromecon rigida</i>	Yes	Per.	Shrub	Colonizer	0.5	1,590,000	53,000
<i>Eriogonum fasciculatum</i>	Yes	Per.	Shrub	Colonizer	12	4,500,000	450,000
<i>Eschscholzia californica</i>	Yes	Ann.	Forb	N-fixing	1	25,500,000	300,000
<i>Lasthenia californica</i>	Yes	Ann.	Forb		2	200,000,000	4,000,000
<i>Lotus scoparius</i>	Yes	Per.	Shrub	Long-term erosion control	6	14,450,000	170,000
<i>Lupinus bicolor</i>	Yes	Ann.	Forb	N-fixing	2	9,000,000	100,000
<i>Lupinus nanus</i>	Yes	Ann.	Forb	N-fixing	2	3,825,000	45,000
<i>Melica imperfecta</i>	Yes	Per.	Grass	Long-term erosion control	4	24,500,000	350,000
<i>Mimulus aurantiacus</i>	Yes	Per.	Shrub	Colonizer	2	24,000,000	12,000,000
<i>Nassella lepida</i>	Yes	Per.	Grass	Long-term erosion control	4	26,975,000	415,000
<i>Nassella pulchra</i>	Yes	Per.	Grass	Long-term erosion control	4	8,250,000	110,000
<i>Salvia mellifera</i>	Yes	Per.	Grass	Colonizer	4	20,800,000	520,000
<i>Trifolium gracilentus</i>	Yes	Ann.	Forb	N-fixing	2	32,000,000	400,000
<i>Vulpia microstachys</i>	Yes	Ann.	Grass	Erosion control	8	25,500,000	300,000
Total					57.5	490,865,000	25,338,000

Table 38. 2007 seed mix for Test Slope. The winter 2007 hydroseed mix is listed with native status, life cycle, form, special reasons for planting, seed amount per acre, seeds/lb, and pure live seed/lb (Holland and Langford, 1995; USDA, 2008).

There were complications with the hydroseeding application. The L.S. hydroseed mixture had too much water in the mixture and the soil appeared to be hydrophobic. A disaster similar to a mud-slide was caused where the hydroseed mixture slid down the slope. The slide physically moved seeds within the hydroseed mix creating areas without seed mix. In addition, the L.S. hydroseed treatment had a slower drying time overall because there was a higher concentration of water in the mixture. Seeds were seen floating in puddles at the base of the slope (Fig. 33, 34).

Figure 33. Hydroseed application on Test Slope. The hydroseed mixture without L.S. was applied first (Top Left). The hydroseed without L.S. did not have water remaining on the surface after application (Top Right). The hydroseed project was nearly complete (Bottom Left), but the continued application of hydroseed mixture caused a slide (Bottom Right).

Figure 34. Hydroseed application on Test Slope. The hydroseed mixture with the L.S. had water remaining on the surface after application (Top Left). The water began to move down the slope and picked up the hydroseed mixture in its way (Top Right). The crew slowed the movement of hydroseed mixture slide using topsoil (Bottom Left). We covered the slide area with other mulches which were present at the site (Bottom Right).

Cover and composition estimated were planned using point-intercept method (Barbour et al., 1999). However, during hydroseed application, excess water caused the L.S. hydroseed mixture to not adhere to the soil, slide down the hill, and pick up all hydroseed material along the way. The result was a disaster similar to a mud slide. The hydroseed mixture slides moved through the majority of the fire and charate plots. Due to the obvious differences in seed application, none of treatments were quantitatively analyzed. A species list was compiled from multiple surveys of the site throughout the growing season. No quantitative data was gathered, so my results are based on visual examination of both the entire treatment areas and smaller subsections.

Alternative responses exist to L.S. treatments on the hydroseed mix. High germination irrespective of hydroseed treatment and control suggests that no effect exists. None to low germination suggests that the hydroseed mix remained dormant or unviable. Varying germination suggests that the treatment is not the dominant effect on germination. Higher or lower germination may imply that there were higher or lower germination rates from the hydroseed mix or from the soil seed bank. Alternative responses exist to L.S. treatments on the soil seed bank. The only distinctly visible soil seed bank response would be an increase in germination for plants which were not included in the hydroseed mix. Any increase in the soil seed bank species which are same species from the hydroseeded mix would not be discernable.

Results

Differences in cover and composition were striking between hydroseed plots and the control. The hydroseed plots had about 50 to 75% cover and were dominated by *Vulpia microstachys* (Annual fescue) followed by *Lasthenia californica* (Goldfields) and *Eschscholzia californica* (California Poppy). The control plot had less than 5% cover and was not clearly dominated by any species. The hydroseed plots had almost all of the same species present. There was only one plant not found on both hydroseed plots. Two plants of *E. californica* 'Moonglow' were present on the hydroseeded plot without L.S. None of the species from the hydroseed mix were present on the control plot. The hydroseed plots had some of the species from the hydroseed mix present. The control plot had none of the species from the seed mix present. Some species, such as non-native grasses, *Papaver californicum* (Fire Poppy), and *Amsinckia* spp. (Fiddleneck), were present across all treatments. *Salvia mellifera* (Black Sage) and *Trifolium gracilentum* (Clover) were abundant, but they were only present outside of the boundaries of the hydroseed plots where hydroseed mixture was lightly sprayed beyond the boundary. In these areas, Annual Fescue was nearly absent. The charate and fire plots and the area below these plots in the direction of the hydroseed slides were examined closely to determine if species were present in these areas which were not present elsewhere. Like most of the hydroseeded area without L.S., these areas were also dominated by Annual Fescue followed by California Poppy, and no other species were present (Fig. 35, Fig. 36, Table 39).

Figure 35. Spring 2008 plant growth and erosion on the Test Slope. The striking difference in cover between hydroseed plots and the control (to the left) are present.

Figure 36. Co-dominant plants on the Test Slope. *Vulpia microstachys* (Annual Fescue) and *Lasthenia californica* (Goldfields) dominated the hydroseeded plots.

Plant name	Hydroseed	Hydroseed with L.S.	Control
<i>Amsinckia</i> spp.	Present	Present	Present
<i>Bromus hordeaceus</i>	Present	Present	Present
<i>Bromus madritensis</i>	Present	Present	Present
<i>Calandrinia breweri</i>	Present	Present	Present
<i>Claytonia perfoliata</i>	Present	Present	Absent
<i>Eschscholzia californica</i>	Present	Present	Absent
<i>Eschscholzia californica</i> 'Moonglow'	Present	Absent	Absent
<i>Eucrypta chrysanthemifolia</i> var. <i>chrysanthemifolia</i>	Present	Present	Present
<i>Lasthenia californica</i>	Present	Present	Absent
<i>Lotus scoparius</i>	Present	Present	Absent
<i>Lupinus bicolor</i>	Present	Present	Absent
<i>Lupinus nanus</i>	Present	Present	Absent
<i>Papaver californicum</i>	Present	Present	Present
<i>Vulpia microstachys</i>	Present	Present	Absent

Table 39. Species list for all treatments on the Test Slope.

Many of the seeded plants did not germinate during the first spring after hydroseeding.

Some annuals and no perennials had germinated by April 14th, 2008 (Table 40).

Plant name	Life				Seeds	
	Present	cycle	Form	Rational for planting	(lb/acre)	Pure live seed /Lb
<i>Adenostoma fasciculatum</i>	No	Per.	Shrub	Keystone species	1	580,000
<i>Artemisia californica</i>	No	Per.	Shrub	Colonizer	2	5,500,000
<i>Ceanothus cuneatus</i>	No	Per.	Shrub	Climax species	1	45,000
<i>Dendromecon rigida</i>	No	Per.	Shrub	Colonizer	0.5	53,000
<i>Eriogonum fasciculatum</i>	No	Per.	Shrub	Colonizer	12	450,000
<i>Eschscholzia californica</i>	Yes	Ann.	Forb	N-fixing	1	300,000
<i>Lasthenia californica</i>	Yes	Ann.	Forb	Short-term erosion control	2	4,000,000
<i>Lotus scoparius</i>	No	Per.	Shrub	Long-term erosion control	6	170,000
<i>Lupinus bicolor</i>	Yes	Ann.	Forb	N-fixing	2	100,000
<i>Lupinus nanus</i>	Yes	Ann.	Forb	N-fixing	2	45,000
<i>Melica imperfecta</i>	No	Per.	Grass	Long-term erosion control	4	350,000
<i>Mimulus aurantiacus</i>	No	Per.	Shrub	Colonizer	2	12,000,000
<i>Nassella lepida</i>	No	Per.	Grass	Long-term erosion control	4	415,000
<i>Nassella pulchra</i>	No	Per.	Grass	Long-term erosion control	4	110,000
<i>Elymus multisetus</i>	No	Per.	Grass	Long-term erosion control	4	520,000
<i>Trifolium gracilentus</i>	No	Ann.	Forb	N-fixing	2	400,000
<i>Vulpia microstachys</i>	Yes	Ann.	Grass	Short-term erosion control	8	300,000
Total					57.5	25,338,000

Table 40. Species which emerged from hydroseed mix on the Test Slope. The winter 2007 hydroseed mix is listed with the plants which were present on April 16th, 2008, life cycle, form, special reasons for planting, and the seed amount per acre (Holland and Langford, 1995; USDA, 2008).

Erosion occurred on the hydroseeded area and on the control. There were four areas of major topsoil slippage where large portions of topsoil sloughed off on both the hydroseed treatments. There was no topsoil slough on the control. The hydroseed plots and the control both had water which formed ruts (Fig. 37).

Figure 37. Erosion in spring 2008 on the Test Slope. Erosion is visible on all of the plots. The hydroseed plots have areas of ruts and major topsoil slippage. The control only has ruts. From left to right: hydroseed without L.S., hydroseed with L.S., and the control.

Discussion

There was no germination of seeded shrubs, native grasses, and Clover on the hydroseed treatments. This suggests these remain dormant or unviable. Species survey of the site should be continued during the summer of the second growing season. Many of the shrubs did not germinate until the end of the growing season during previous experiments (M. Elster, Personal Communication, 9-26-2007).

Liquid smoke did not appear to stimulate the soil seed bank after one growing season. Both hydroseed treatments had similar species composition. Additives within the hydroseed mix such as fiber may retain L.S. after drying and release it as dry vapors or when moistened by rain, but no environmental effect was seen thus far. In addition, the charate and fire treatments did not stimulate the soil seed bank, and only species from the hydroseed mix were present in the plots and area below the plots. The response from the soil seed bank was negligible. I am concerned that many of the soil seed bank annuals and perennials were rendered unviable after moving and stockpiling the soil. Fire-following herbs should continue to be supplemented with seeding so they remain a vital part of the plant community especially after fires.

Though Fire Poppy, a fire-following native herb, was not included in the hydroseed mix it was present across all treatments (Keeley, 1991). *Calandrinia breweri* (Brewer's Red-maids), a disturbance-following native herb not necessarily associated with fire, was not included in the hydroseed mix and it was present across all treatments (Keeley, 1991; Tyler, 1995; Tyler, 1996). In San Luis Obispo County, CA the species is almost exclusively associated with fire (D. Keil, Personal Communication, 6-10-2009). These species were present in the soil seed bank and germinated. Brewer's Red-maids and Fire

Poppy both occurred in very low abundance, less than 10 individuals per hydroseed treatment and control and were never associated with areas where fire and charate were applied. It was also the only fire-following herb which germinated from the soil seed bank during the first growing season. These plants affirm the presence of some viable seeds in the soil seed bank.

The cover of the site was dominated by annual grasses. Perennial forbs were common but sparse, while perennial shrubs were not present. Black Sage, a perennial shrub, was present outside the boundary of the plots where sparse hydroseed coverage occurred, and Annual Fescue had a visually estimated cover of less than 5%. The origin of the Black Sage may either be from the hydroseed mix or soil seed bank. I am uncertain about the relationship between the presence of Black Sage and Annual fescue. While much research has focused on hydroseeding grasses after wildfire, there has been no published research completed on the effects of hydroseeding with grass or native grass for restoration after mining. After fires, hydroseeding grasses, especially *Lolium multiflorum* (Italian Ryegrass), significantly reduces the abundance of native seedlings (Barro and Conard, 1987; Barro and Conard, 1987; Janicki, 1989; Keeley, 1995; Spittler, 1994; Taskey, 1989). Annuals are better colonizing competitors because they germinate earlier in the season and must establish more above-ground biomass to set seed during the first year. Therefore, perennial plants may not have the opportunity to germinate and survive when competing with fast-growing annuals for resources. The annuals quickly succumb to summer drought leaving behind no live plants with roots to anchor the soil on the restoration site. Without live plants, the site is susceptible to heavy erosion during the following rainy season (Keeley and Bond, 1997; Matesanz and Valladares, 2007). Bert

Wilson, owner and manager of the native plant nursery Los Pilitas in Santa Margarita, CA, does not prescribe hydroseeding for chaparral restoration and instead only plants nursery stock (B. Wilson, Personal Communication, 2/6/2008). Wilson believes the competition from heavily seeded native annual grasses decreases the native plant regeneration. Research based on the effects of hydroseeding on succession after fire supports his hypothesis where competition from grasses may inhibit native perennial plant restoration at RCQ. Annuals affect seedling growth but not survival after natural fires. In a restoration setting, annuals' presence is correlated with decreased germination although not significantly different (Kummerow et al., 1985; Roy, Personal Communication, 5-2-2008). Experiments have evaluated the use of native broad leafed annuals in restoration at RCQ (Roy, Personal Communication, 5-2-2008). Future experiments should evaluate the use of high rates of Annual fescue in restoration at RCQ.

At RCQ it is possible there are no or few viable native fire-following herbs in the soil seed bank due to the movement of soil and stockpiling. It may be necessary to supplement native plant regeneration with annual and/or fire-following herbs which may not be present because they are not available from nursery stock. These herbs from the soil seed bank decrease erosion within a few rain events after fires (Keeley, 1995). These fire-following herbs act as an ecological insurance program which allows resilient plant communities to come back. In the future, hydroseed experiments need to be conducted with different rates of Annual Fescue seed and controls without hydroseed treatments to determine the effect of seeding high rates of Annual fescue. In addition, hydroseeding may contaminate local gene pool with plants, though it may be preferred if there is no local gene pool within a site due to mining (Keeley, 1995).

Eschscholzia californica 'Moonglow' was found only in areas which were hydroseeded. It is probable that the S&S seed mix contained this horticultural variety which is not found in natural areas. In addition, it was only found on the hydroseed treatment without L.S. However, due to the low number of plants, there does not appear to be significant L.S. treatment effect on *E. californica* 'Moonglow', but rather they occurred due to random chance. These individuals were hand-pulled because they were not a native variety.

Historically, hydroseeding does not control erosion before herbs are established. However, advances in hydroseeding technology such as FlexTerra, which adheres to the soil and, acts as a blanket, are supposed to reduce erosion. At RCQ, erosion occurred after applying FlexTerra at the recommended rate for native plant regeneration suggesting a higher rate of FlexTerra is necessary to prevent erosion. In natural environments erosion control is not necessary because deep roots from shrubs hold much soil in place, and herbs quickly germinate after the first rain (Keeley, 1995). FlexTerra did not limit sloughing of the slopes at RCQ when compared to the control. However, at RCQ erosion control may be necessary because there are no roots to hold soil in place. More research is needed to evaluate the use of hydroseed blanket and other materials where they are compared to areas without hydroseeding for erosion control.

The treatment of L.S. time was extended beyond exposure times found in the laboratory to have a positive response in germination. The test slopes were planted after Trial 3 of Experiment A: Breaking Seed Dormancy with Short-term Treatments. The soaking began at 8 a.m., one hour prior to scheduled hydroseeding, to complete the prescribed one-hour treatment. However, several schedule set-backs occurred. The treatment plot was sprayed at 12:30.p.m. In addition, the soil was hydrophobic, and little water was absorbed causing

water accumulation on the soil. Water remained on the surface of the hydroseed slurry for more than one-and-a-half-hours after it was sprayed. I am uncertain how long the slurry remained moist because I could not remain on site due to significant delays throughout the day. Schedule set-backs are common during hydroseeding and may contribute to routine treatment errors for L.S. soaking which begin before the hydroseed crew's arrival. Scheduling problems which increase the amount of time seeds soak may magnify the detrimental effects of long-term soaking. Treatments which do not compromise the success of restoration, such as heat, smoke, or short-term exposure to L.S, should be pursued to increase seed germination.

V. Conclusion

A. Project Goals

The main goal of restoration and management is to create a self-sustaining, native plant community that is similar to the pre-disturbance community on the site. If the community is not self-sustaining, it will gradually deteriorate with time and not be able to perpetuate itself. This goal is especially important in systems with high frequency of disturbances, such as chaparral.

Our results illustrate the challenges of chaparral, coast scrub, and oak woodland restoration at Rocky Canyon Quarry (RCQ). The results indicate that pre-treating seeds from chaparral shrubs with heat and liquid smoke (L.S.) are economically effective ways to increase seed germination. In contrast, treating the stockpiled topsoil spread over the slopes with varying treatments of fire, charate, fertilizer, and L.S. in the field does not appear to enhance seed germination in the seed bank. However, I remain uncertain if native fire-following annuals occur or remain viable in the stockpiled topsoil that was spread over the restoration slopes. Our data do show that seed germination of climax chaparral species, *Salvia mellifera* (Black Sage), *Ceanothus cuneatus* (Buckbrush), and *Adenostoma fasciculatum* (Chamise), is enhanced by pre-treatment with heat, smoke, and charate. Table 41 provides recommended treatments based on the findings of our studies.

Plant name	Recommended pre-treatment		Recommended pre-treatment without heat	
<i>Adenostoma fasciculatum</i>	1 to 10 dilution of L.S. with Heat	347 (145, 717)	Pure L.S.	243 (96, 501)
<i>Ceanothus cuneatus</i>	Pure L.S. with Heat	953 (228, 3281)	1 to 100 L.S.	242 (-47, 2094)*
<i>Salvia mellifera</i>	Heat	354 (172, 657)	1 to 2000 L.S.	185 (63, 397)

Table 41. Recommended seed pre-treatment for species tested. The recommended pre-treatment for *Adenostoma fasciculatum* (Chamise), *Ceanothus cuneatus* (Buckbrush), and *Salvia mellifera* (Black Sage) and an alternative pre-treatment without the use of heat are indicated in the table above. The tabulated values include the percent change in seed germination for the odds ratio and 95% Confidence Interval for the germination of each species where the treatments are compared to the control. *Indicates the treatment is not significantly different from the control and therefore not recommended for restoration.

To date, vegetation cover restoration at RCQ is not meeting all success criteria described by both The Morro Group (1995) and Susie Bernstein (1999). Some of the species in hydroseed mixture at RCQ, such as *Lotus scoparius* (Deerweed) and *Eriogonum fasciculatum* (California Buckwheat), germinate and thrive at restoration sites, whereas shrubs such as Chamise and Buckbrush generally do not do as well. Therefore, increasing seed germination through the use of pre-treatments noted above will aid in reaching the vegetation cover success criteria.

B. Future of Restoration

Increasing seed germination of chaparral shrubs by itself may be insufficient to reach the restoration goals of the project. There are many other limiting factors that affect successful revegetation and restoration, especially on steep slopes. They include, but are not limited to, money, inadequate top soil depth, soil composition (such as nutrients, water-holding potential, bacteria, and fungi), low native seed germination, low native plant survivorship, high weed competition, unnatural frequency of natural disturbances such as fire, drought, flood, and herbivory. There are effective solutions for many of these factors, but it is important to confront the challenges of restoration with rigorous scientific research and analysis to determine the most successful practices. For example, research at RCQ by both Elster (2007) and Roy (Personal Communication, 5-2-2008) indicates that irrigation increases the survivorship of chaparral shrubs. Restoration must be based on both practical and scientific findings.

Several environmental factors listed above have been found to slow successful restoration. Bochet and Garcia-Fayos (2004) found establishing vegetation on 1:1 slopes or slopes with 45% angles is very difficult partly because many seeds may move downhill. They recommend not having such steep slopes and installing a series of terraces similar to the current restoration plan at RCQ. Seed germination micro-sites may be created by increasing soil surface roughness. These micro-sites may hold water longer allowing seeds to germinate and become established on steep slopes, which will also decrease soil erosion. Bochet and Garcia-Fayos (2004) found that the success of plant establishment on slopes less than 45% was determined by the water variability and soil fertility. High rainfall variability at RCQ makes water availability at RCQ a challenge,

especially during dry years. However, irrigation may be used during the early stages of plant establishment in periods of drought (Aronson et al., 1993). Periods of very heavy rain also creates problems. There are few remedies for extremely high volume rain events. Solutions include but are not limited to (1) early fall irrigation, prior to the heavy rain season, allows seedlings to become established, develop strong roots, and help prevents erosion, (2) hydroseed blankets which remain on the slope after hard rains such as Flex-terra, and (3) development of proper drainage systems and barriers that limit soil slippage. The latter two erosion control measures are in use at RCQ. The fertility of the soil is enhanced at RCQ with (1) salvaged plant debris from the site, (2) HydroPost Compost (2,000lb/acre), (3) Biosol 7-2-3 organic fertilizer (1,000 lb/acre), and (4) Mycorrhizal Inoculum (60lb/acre at 3.5 million propagules/acre), which aids plants to absorb nutrients and water. Many of the environmental factors have been mitigated at RCQ, but further research is needed to determine their success and if further mitigation is needed.

Restoration efforts should mimic the complete spectrum of species found during natural succession of chaparral, from colonizer to climax species. This allows revegetation to imitate natural succession events and end in climax communities that are able to recover from natural disturbances in perpetuity and be self-sustaining. If insufficient colonizers exist in the seed bank or seed mix, invasive weeds may colonize the disturbed site and suppress or prevent natural succession (Quinn and Keeley, 2006). In chaparral, fire is the most common disturbance; therefore, fire-following plants may need to be incorporated in the seed mixes used in restoration plans. These colonizers are important to start natural

succession and modify the environment so that it is suitable for establishment of climax species and for the longevity of the system.

Recruitment from nearby undisturbed natural areas may or may not supplement the full natural diversity of chaparral species depending on proximity and seed dispersal. Many potential species may not be able to reach the restoration site due to their mechanism of dispersal. Wind-dispersed and animal-dispersed seeds easily reach and colonize isolated restoration stands; whereas heavy ant-dispersed and gravity-dispersed seeds are far less successful (Dzwonkno and Loster, 1992). In addition, animal dispersed seeds are generally not present until habitats are established (Debussche and Isenmann, 1994; Verdu and Garcia-Fayos, 1996). If natural chaparral stands occur above the restoration sites, heavy-seeded later succession chaparral species may disperse onto the restoration sites below. However, if this is not the case, these species should be included in the seed mix and/or container stock plants used in revegetation (Verdu and Garcia-Fayos, 1996). Very few climax species, such as Chamise and Buckbrush, have become established on restoration sites thus far. Without intervention, such as supplemental seeding and container stock plantings, these species may not establish in high enough numbers to provide the plant cover needed on restoration sites (Herrera, 1984).

Another concern with restoration projects is the invasion of weedy plants that may slow the natural succession of native chaparral. Kummerow et al. (1985) found shrub growth to be negatively affected by the presence of annuals but not by perennial herbaceous plants with up to a 65% cover. Catherine Roy analyzed the effects of herbaceous plants on the growth of Chamise and did separate the effects of annuals or perennials. She had

plots which were planted with fire-following herbs and plots with invasive weeds. She found that both annual grasses (in the volunteer treatment) and dicots (in the planted herb treatment) negatively affected the germination, growth, and survivorship of Chamise. Common species in Roy's experimental plots are listed in Table 42 below (K. Roy, Personal Communication, 5-21-2008).

Plot treatment	Plant name	Life cycle	Form
Volunteer	<i>Avena fatua</i>	Annual	Herb
Volunteer	<i>Bromus madritensis</i>	Annual	Herb
Volunteer	<i>Polygonum aviculare</i> *	Annual/Biennial	Herb
Volunteer	<i>Erodium cicutarium</i> *	Annual/Biennial	Herb
Planted herbs	<i>Lupinus hirsutissimus</i>	Annual	Herb
Planted herbs	<i>Lupinus nanus</i>	Annual	Herb
Planted herbs	<i>Emmenanthe penduliflora</i>	Annual	Herb
Planted herbs	<i>Eriophyllum confertiflorum</i> *	Perennial	Subshrub
Planted herbs	<i>Lotus scoparius</i> *	Perennial	Subshrub

Table 42. Dominant plant species in Roy's herbaceous plots. The plants' life duration and form are noted (USDA, 2008). *These plants were noted as sub-dominates.

Common noxious weeds reported in chaparral areas include *Cistus spp.* (Rock-rose), *Spartium junceum* (Spanish Broom), *Cytisus scoparius* (Scotch Broom), *Genista monspessulana* (French Broom), *Bromus spp.* (Brome), and *Ailanthus altissima* (Tree of Heaven) (Quinn and Keeley, 2006). At RCQ, *Centaurea solstitialis* (Yellow Star Thistle), *Centaurea melitensis* (Tocalote), and *Hirschfeldia incana* (Perennial Mustard), are common weeds in many disturbed areas. All of these species may affect the restoration and succession of chaparral. The weed community, which comes in following disturbance in chaparral, is lower in stature, does not effectively control soil erosion, and may retard natural succession and successful establishment of native chaparral shrubs

(Quinn and Keeley, 2006). Restoration sites should be surveyed every year for noxious weeds. If weeds are present, they should be eradicated or controlled following recommended industry practices.

Based on literature reviews, the results of my research and research by others at RCQ, I have devised some recommendations regarding future restoration at RCQ, which is discussed in the tables below (Table 43, 44, and 45).

	Current prescription	Revised prescription
Restoration site preparation	Prior to mining the hillsides, all vegetation and topsoil is removed and stockpiled. The open pit quarrying methods leaves a bare, granite rock slope with flat terraces above and below the slope. This results in a series of steep slopes, up to 2:1, separated by flat terrace areas from the ridge to the bottom of the hill. After mining and shaping, both are reapplied to the slopes as the beginning of our revegetation efforts. The slopes are hardened with large rocks and boulders to limit soil slippage at the base.	Generally, the same procedure should be followed, but the angle of the slope should be reduced (Bochet and Garcia-Fayos, 2004).

Table 43. Current and revised prescriptions for restoration site preparation.

	Current prescription	Revised prescription
Revegetation	<p>The revegetation process occurs during the late fall. The sites are hydroseeded with amendments HydroPost Compost (2,000lb/acre), fiber and binder (varied), Mycorrhizal Inoculum (60lb/acre at 3.5 million propagules/acre), Biosol 7-2-3 organic fertilizer (1,000 lb/acre), and native seeds of both annual and perennials (Table 38). Container stock shrubs are planted after hydroseeding.</p>	<p>The restoration process should begin during late summer or early fall. Before hydroseeding, holes and basins for the container stock should be dug and marked with pin-flags. Additional planting amendments such as United States Forest Service's Super Absorbent Ag Sorbent water absorbent polymer of gelatinized starch or the additions of small rocks placed around the plantings are not recommended (Elster, 2007). Then the site should be hydroseeded with amendments, perennial herb seeds, and pre-treated shrub seeds (Table 38, 41). Shrubs, such as Chamise and California-lilac, should be planted after seedling establishment. Weeding of non-native plants especially annuals should begin soon after planting (K. Roy, Personal Communication, 5-21-2008).</p> <p>Irrigation should keep the hydroseed blanket and seedling moist until winter rains begin. I recommend using Roy's (unpublished) irrigation techniques where 320° spray emitters were on for 30 minutes once a week (K. Roy, Personal Communication, 5-21-2008) since she reports significant results in terms of Chamise germination, growth, and survivorship. Irrigation should continue until regular winter rains occur and resume once rains diminish. The amount of time and frequency of irrigation should diminish during the summer months (Stratton, 2003). Further research should be completed to determine appropriate summer watering techniques.</p> <p>After perennial herb and shrub seedling establishment, annual herbs should be hand seeded. Research should be completed to determine effective timing (such as late fall, early spring, or one year after initial revegetation) of additional seed planting.</p>

Table 44. Current and revised prescription for revegetation.

	Current prescription	Revised prescription
Monitoring	Restoration areas should be monitored for weed invasion and success criteria.	<p>Sites should be monitored for weed invasions at least twice yearly (late fall and early spring), and all populations should be eradicated or controlled as recommended by industry standards.</p> <p>Monitoring should occur every year, and the vegetation should be sampled using the point-intercept method to determine vegetation cover, shrub cover, herb layer cover, and shrub layer cover as defined in the success criteria (Table 6). In addition, complete species list should be compiled and used to determine the number of native species as required in the success criteria.</p> <p>If success criteria are not met during these surveys, further revegetation must be completed as soon as possible. In addition, the monitoring period may be extended beyond 15 years if goals are not achieved. Ultimately, supplements should continue until the project meets the success criteria.</p>

Table 45. Current and revised prescription for monitoring.

There are many other opportunities to utilize these research results beyond RCQ. In chaparral throughout California, human-caused disturbances such as habitat loss, degradation, and fragmentation are common. Human disturbances include, but are not restricted to, road construction, mining, aqueducts, building development, agriculture and increased fire frequency (Quinn and Keeley, 2006). Private and public restoration practitioners may utilize techniques developed in chaparral restoration throughout the eco-region.

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Appendices

A. Introduction

Plant list	
<i>Adenostoma fasciculatum</i>	Chamise
<i>Ailanthus altissima</i>	Tree of Heaven
<i>Amsinckia</i> spp.	Fiddleneck
<i>Arctostaphylos glauca</i>	Bigberry Manzanita
<i>Arctostaphylos</i> spp.	Manzanita
<i>Artemisia californica</i>	California Sagebrush
<i>Baccharis pilularis</i>	Coyote Brush
<i>Bromus</i> spp.	Brome
<i>Calandrinia breweri</i>	Brewer's Red-maids
<i>Ceanothus cuneatus</i>	Buckbrush
<i>Centaurea melitensis</i>	Tocalote
<i>Centaurea solstitialis</i>	Yellow Star Thistle
<i>Cistus</i> spp.	Rock-rose
<i>Cytisus scoparius</i>	Scotch Broom
<i>Dendromecon rigida</i>	Bush Poppy
<i>Emmenanthe penduliflora</i>	Whispering Bells
<i>Epilobium canum</i> ssp. <i>canum</i>	California Fuchsia
<i>Eriodictyon crassifolium</i>	Thick-leaved Yerba Santa
<i>Eriogonum fasciculatum</i>	California Buckwheat
<i>Eschscholzia californica</i>	California Poppy
<i>Genista monspessulana</i>	French Broom
<i>Hesperoyucca whipplei</i>	Our Lord's Candle
<i>Heteromeles arbutifolia</i>	Toyon
<i>Hirschfeldia incana</i>	Perennial mustard
<i>Lasthenia californica</i>	Goldfields
<i>Lolium multiflorum</i>	Italian Ryegrass
<i>Lotus scoparius</i>	Deerweed
<i>Lupinus hirsutissimus</i>	Stinging Lupine
<i>Lupinus nanus</i>	Sky Lupine
<i>Lupinus</i> spp.	Lupine
<i>Mentzelia dispersa</i>	Blazing Star
<i>Mimulus aurantiacus</i>	Sticky Monkeyflower
<i>Mimulus bolanderi</i>	Bolander's Monkeyflower
<i>Mimulus gracilipes</i>	Slender Stalked Monkeyflower
<i>Nassella</i> spp.	Needlegrass
<i>Papaver californicum</i>	Fire Poppy
<i>Pinus sabiniana</i>	Foothill Pine
<i>Quercus agrifolia</i>	Coast Live Oak
<i>Quercus douglasii</i>	Blue Oak
<i>Quercus lobata</i>	Valley Oak
<i>Salvia mellifera</i>	Black Sage
<i>Spartium junceum</i>	Spanish Broom
<i>Trichostema lanatum</i>	Woolly Bluecurls
<i>Trifolium gracilentum</i>	Clover
<i>Vulpia microstachys</i>	Annual fescue

Table A1. Plant list for scientific and common names used within the text. Plants which were restricted to tables or figures are not included in the plant list.

Rainfall Data

Conversion	Average 1901- 2007	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08
July	0	0	0	0	0	0	0	0	0	0	0	0*	0	0	0	0*
August	0	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0*
September	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0*
October	1	0	2	0	5	0	1	0	3	1	0	0	13	0	2	3*
November	3	2	6	0	5	10	3	2	0	7	6	3	4	2*	1	0*
December	7	3	2	5	15	10	2	1	0	6	11	6	17	6	3	4
January	8	5	29	5	20	8	5	8	11	2	0	2	12	15	2	4*
February	8	9	4	17	0	23	3	15	13	1	5	11	13	3	8	5*
March	6	3	31	5	0	7	7	4	9	4	5	1	8	11	0	0*
April	3	1	0	2	0	5	3	4	2	1	4	1	2	7*	1	2*
May	1	3	1	1	0	5	0	0	0	1	3	0	3	4	0	-
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Growing season total	38	26	79	35	44	68	23	35	39	21	35	24	72	48	16	27

Table A2. Regional monthly rainfall totals (centimeters) for the 1993 through 2008 growing seasons. The majority of data are from the Paso Robles Station (46730) All AccuWeather data are indicated with an asterisk.

Climate Summary

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Average maximum temperature (°C)	16	18	20	23	27	31	34	34	32	27	21	17	25
Average minimum temperature (°C)	1	2	4	4	7	9	11	10	8	6	2	0	5
Average total precipitation (cm)	7.87	8.13	6.10	2.54	0.76	0.25	0	0	0.51	1.52	3.56	6.60	37.62
Average total snow fall (cm)	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25
Average snow depth (cm)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3. Monthly climate summary Climate summary from 10/1/1901 to 6/30/2007 from the Paso Robles Station (046730).

B. Oak Woodland Evaluation

Data

Nat. Form		Plant name	Plot 1		Plot 2		Plot 3		All plots	
			Total	Relative	Total	Relative	Total	Relative	Total	Relative
-	Bare soil	Bare	306	52.22%	186	31.53%	172	29.91%	664	37.92%
-	Bare rock	Rock	28	4.78%	9	1.53%	18	3.13%	55	3.14%
-	Detritous	Grass litter	11	1.88%	106	17.97%	73	12.70%	190	10.85%
-	Detritous	Litter	11	1.88%	23	3.90%	9	1.57%	43	2.46%
-	Detritous	Shrub and grass litter	16	2.73%	45	7.63%	41	7.13%	102	5.83%
-	Detritous	Shrub litter	93	15.87%	76	12.88%	82	14.26%	251	14.33%
-	Detritous	All litter	131	22.35%	250	42.37%	205	35.65%	586	33.47%
-	Moss	Moss	0	0.00%	1	0.17%	0	0.00%	1	0.06%
Yes	Shrub & Tree	<i>Adenostoma fasciculatum</i>	25	4.27%	4	0.68%	13	2.26%	42	2.40%
Yes	Shrub & Tree	<i>Arctostaphylos glauca</i>	61	10.41%	13	2.20%	7	1.22%	81	4.63%
Yes	Shrub & Tree	<i>Baccharis pilularis</i>	5	0.85%	0	0.00%	0	0.00%	5	0.29%
No	Herb	<i>Centaurea mellitus</i>	0	0.00%	1	0.17%	1	0.17%	2	0.11%
No	Herb	<i>Centaurea solstitialis</i>	0	0.00%	0	0.00%	3	0.52%	3	0.17%
Yes	Herb	<i>Epilobium canum</i> ssp. <i>canum</i>	1	0.17%	0	0.00%	0	0.00%	1	0.06%
Yes	Shrub & Tree	<i>Eriogonum fasciculatum</i>	0	0.00%	41	6.95%	89	15.48%	130	7.42%
		<i>Gnaphalium canescens</i> ssp. <i>beneolens</i>	0	0.00%	2	0.34%	0	0.00%	2	0.11%
Yes	Herb	<i>Hesperoyucca whipplei</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
Yes	Shrub & Tree	<i>Heteromeles arbutifolia</i>	5	0.85%	0	0.00%	1	0.17%	6	0.34%
Nat.	Shrub & Tree	<i>Lotus scoparius</i>	16	2.73%	26	4.41%	9	1.57%	51	2.91%
Yes	Herb	<i>Mellica imperfecta</i>	0	0.00%	0	0.00%	1	0.17%	1	0.06%
Yes	Shrub & Tree	<i>Mimulus aurantiacus</i>	0	0.00%	21	3.56%	8	1.39%	29	1.66%
Yes	Herb	<i>Nassella</i> spp.	0	0.00%	1	0.17%	14	2.43%	15	0.86%
Yes	Shrub & Tree	<i>Pinus sabiniana</i>	2	0.34%	16	2.71%	18	3.13%	36	2.06%
Yes	Shrub & Tree	<i>Quercus lobata</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
-	Herb	<i>Rumex</i> sp.	0	0.00%	0	0.00%	1	0.17%	1	0.06%
Yes	Shrub & Tree	<i>Salvia mellifera</i>	0	0.00%	16	2.71%	15	2.61%	31	1.77%
No	Herb	<i>Spergula arvensis</i> ssp. <i>arvensis</i>	0	0.00%	3	0.51%	0	0.00%	3	0.17%
Yes	Shrub & Tree	<i>Trichostema lanatum</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
-	-	All hits	586	100%	590	100%	575	100%	1751	100%
-	-	All plants	121	20.65%	145	24.74%	180	31.30%	446	25.47%
-	-	All native plants	94	16.04%	121	20.65%	152	26.43%	367	20.96%
-	-	All non-native plants	2	0.34%	19	3.24%	15	2.61%	36	2.06%
-	Herb	All herbs	43	7.34%	111	18.94%	137	23.83%	291	16.62%
-	Shrub & Tree	All shrubs	78	13.31%	33	5.63%	43	7.48%	154	8.79%

Table A4. Raw data from oak woodland monitoring from zero to one-half meter.

Total represents the total number of hits for each category. Relative represents the proportion of total hits which were from that category.

Nat.		Plant name	Plot 1		Plot 2		Plot 3		All Plots	
			Total	Relative	Total	Relative	Total	Relative	Total	Relative
-	Detritus	Shrub litter	9	1.54%		0.00%	1	0.17%	10	0.57%
Yes	Shrub & Tree	<i>Adenostoma fasciculatum</i>	21	3.58%	4	0.68%	16	2.78%	41	2.34%
Yes	Shrub & Tree	<i>Arctostaphylos glauca</i>	55	9.39%	23	3.90%	0	0.00%	78	4.45%
Yes	Shrub & Tree	<i>Baccharis pilularis</i>	2	0.34%	2	0.34%	0	0.00%	4	0.23%
Yes	Shrub & Tree	<i>Dendromecon rigida</i>	1	0.17%	0	0.00%	0	0.00%	1	0.06%
Yes	Shrub & Tree	<i>Eriogonum fasciculatum</i>	0	0.00%	18	3.05%	21	3.65%	39	2.23%
Yes	Shrub & Tree	<i>Heteromeles arbutifolia</i>	4	0.68%	0	0.00%	3	0.52%	7	0.40%
Yes	Shrub & Tree	<i>Lotus scoparius</i>	2	0.34%	0	0.00%	3	0.52%	5	0.29%
Yes	Shrub & Tree	<i>Mimulus aurantiacus</i>	0	0.00%	7	1.19%	2	0.35%	9	0.51%
Yes	Herb	<i>Nassella spp.</i>	0	0.00%	0	0.00%	1	0.17%	1	0.06%
Yes	Shrub & Tree	<i>Pinus sabiniana</i>	3	0.51%	17	2.88%	13	2.26%	33	1.88%
Yes	Shrub & Tree	<i>Quercus lobata</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
Yes	Shrub & Tree	<i>Salvia mellifera</i>	0	0.00%	9	1.53%	26	4.52%	35	2.00%
Yes	Shrub & Tree	<i>Trichostema lanatum</i>	1	0.17%	0	0.00%	0	0.00%	1	0.06%
-	-	All plants	91	15.53%	80	13.56%	85	14.78%	256	14.62%
-	-	All native plants	91	15.53%	80	13.56%	85	14.78%	256	14.62%
-	-	All non-native plants	0	0.00%	0	0.00%	0	0.00%	0	0.00%
-	-	All herbs	0	0.00%	0	0.00%	1	0.17%	1	0.06%
-	-	All shrubs	91	15.53%	80	13.56%	85	14.78%	256	14.62%

Table A5. Raw data from oak woodland monitoring from one-half to one meter.
Total represents the total number of hits for each category. Relative represents the proportion of total hits which were from that category.

Nat.		Plant name	Plot 1		Plot 2		Plot 3		All plots	
			Total	Relative	Total	Relative	Total	Relative	Total	Relative
-	Detritus	Shrub litter	7	1.19%	0	0.00%	1	0.17%	8	0.46%
Yes	Shrub & Tree	<i>Adenostoma fasciculatum</i>	10	1.71%	4	0.68%	14	2.43%	28	1.60%
Yes	Shrub & Tree	<i>Arctostaphylos glauca</i>	41	7.00%	23	3.90%	3	0.52%	67	3.83%
Yes	Shrub & Tree	<i>Baccharis pilularis</i>	0	0.00%	2	0.34%	0	0.00%	2	0.11%
Yes	Shrub & Tree	<i>Eriogonum fasciculatum</i>	0	0.00%	3	0.51%	8	1.39%	11	0.63%
Yes	Shrub & Tree	<i>Heteromeles arbutifolia</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
Yes	Shrub & Tree	<i>Mimulus aurantiacus</i>	0	0.00%	1	0.17%	0	0.00%	1	0.06%
Yes	Shrub & Tree	<i>Pinus sabiniana</i>	3	0.51%	16	2.71%	24	4.17%	43	2.46%
Yes	Shrub & Tree	<i>Salvia mellifera</i>	0	0.00%	1	0.17%	19	3.30%	20	1.14%
Yes	Shrub & Tree	<i>Trichostema lanatum</i>	2	0.34%	0	0.00%	0	0.00%	2	0.11%
-	-	All plants	58	9.90%	50	8.47%	68	11.83%	176	10.05%
-	-	All native plants	58	9.90%	50	8.47%	68	11.83%	176	10.05%
-	-	All non-native plants	0	0.00%	0	0.00%	0	0.00%	0	0.00%
-	-	All herbs	0	0.00%	0	0.00%	0	0.00%	0	0.00%
-	-	All shrubs	58	9.90%	50	8.47%	68	11.83%	176	10.05%

Table A6. Raw data from oak woodland monitoring for greater than one meter.
Total represents the total number of hits for each category. Relative represents the proportion of total hits which were from that category.

C. Breaking Seed Dormancy with Short-term Treatments

Adenostoma fasciculatum (Chamise)

Data

Trial	Treatment	Germinated seeds	Trial	Treatment	Germinated seeds	Trial	Treatment	Germinated seeds
1	1 to 100 L.S.	4	3	1 to 1000 L.S.	1	4	1 to 10 L.S.	3
1	1 to 100 L.S.	1	3	1 to 2000 L.S.	0	4	1 to 10 L.S.	3
1	1 to 100 L.S.	0	3	1 to 2000 L.S.	0	4	1 to 10 L.S.	6
1	1 to 1000 L.S.	1	3	1 to 2000 L.S.	0	4	1 to 10 L.S.	9
1	1 to 1000 L.S.	2	3	1 to 2000 L.S.	0	4	1 to 10 L.S. Heat	10
1	1 to 1000 L.S.	0	3	1 to 2000 L.S.	0	4	1 to 10 L.S. Heat	8
1	1 to 2000 L.S.	0	3	18 hr. Pure L.S.	0	4	1 to 10 L.S. Heat	12
1	1 to 2000 L.S.	0	3	18 hr. Pure L.S.	0	4	1 to 10 L.S. Heat	8
1	1 to 2000 L.S.	0	3	18 hr. Pure L.S.	0	4	1 to 10 L.S. Heat	7
1	Control	0	3	18 hr. Pure L.S.	1	4	1 to 100 L.S.	6
1	Control	0	3	18 hr. Pure L.S.	0	4	1 to 100 L.S.	1
1	Control	1	3	18 hr. Pure L.S.	0	4	1 to 100 L.S.	8
2	1 to 100 L.S.	0	3	18 hr. Pure L.S.	0	4	1 to 100 L.S.	6
2	1 to 100 L.S.	0	3	27 hr. Pure L.S.	0	4	1 to 100 L.S. Heat	1
2	1 to 100 L.S.	2	3	27 hr. Pure L.S.	0	4	1 to 100 L.S. Heat	1
2	1 to 1000 L.S.	1	3	27 hr. Pure L.S.	1	4	1 to 100 L.S. Heat	6
2	1 to 1000 L.S.	0	3	27 hr. Pure L.S.	0	4	1 to 100 L.S. Heat	1
2	1 to 1000 L.S.	0	3	27 hr. Pure L.S.	0	4	1 to 100 L.S. Heat	9
2	1 to 1000 L.S.	0	3	27 hr. Pure L.S.	0	4	1 to 100 L.S. Heat	12
2	1 to 2000 L.S.	1	3	30 hr. Pure L.S.	0	4	Control	2
2	1 to 2000 L.S.	0	3	30 hr. Pure L.S.	0	4	Control	2
2	1 to 2000 L.S.	0	3	30 hr. Pure L.S.	0	4	Control	5
2	1 to 2000 L.S.	0	3	30 hr. Pure L.S.	0	4	Control	4
2	Control	0	3	30 hr. Pure L.S.	0	4	Heat	5
2	Control	0	3	30 hr. Pure L.S.	0	4	Heat	4
2	Control	0	3	4 hr. Pure L.S.	2	4	Heat	2
2	Control	0	3	4 hr. Pure L.S.	4	4	Pure L.S.	10
2	Control	0	3	4 hr. Pure L.S.	5	4	Pure L.S.	4
3	1 hr. Pure L.S.	3	3	4 hr. Pure L.S.	1	4	Pure L.S.	10
3	1 hr. Pure L.S.	0	3	4 hr. Pure L.S.	1	4	Pure L.S.	3
3	1 hr. Pure L.S.	3	3	4 hr. Pure L.S.	0	4	Pure L.S.	7
3	1 hr. Pure L.S.	3	3	Control	0	4	Pure L.S.	6
3	1 hr. Pure L.S.	3	3	Control	0	4	Pure L.S. Heat	5
3	1 hr. Pure L.S.	4	3	Control	0	4	Pure L.S. Heat	2
3	1 to 100 L.S.	1	3	Control	0	4	Pure L.S. Heat	8
3	1 to 100 L.S.	1	3	Control	0	4	Pure L.S. Heat	3
3	1 to 100 L.S.	0	3	Pure L.S.	8	4	Pure L.S. Heat	7
3	1 to 100 L.S.	2	3	Pure L.S.	1	4	Pure L.S. Heat	8
3	1 to 1000 L.S.	1	3	Pure L.S.	0	4	Pure L.S. Heat	9
3	1 to 1000 L.S.	0	3	Pure L.S.	7	4	Pure L.S. Heat	8
3	1 to 1000 L.S.	0	3	Pure L.S.	0	4	Pure L.S. Heat	4
3	1 to 1000 L.S.	3	3	Pure L.S.	0			

Table A7. Raw data for *Adenostoma fasciculatum* (Chamise) seed germination.

Statistical Analysis

Treatment	Percent germination	30 hr. Pure L.S.	1 to 2000 L.S.	18 hr. Pure L.S.	27 hr. Pure L.S.	1 to 1000 L.S.	Control	4 hr. Pure L.S.	1 to 100 L.S.	1 hr. Pure L.S.	Heat	Pure L.S.	1 to 100 L.S. Heat	1 to 10 L.S.	Pure L.S. Heat	1 to 10 L.S. Heat
30 hr. Pure L.S.	0%	*														
1 to 2000 L.S.	0%	-	*													
18 hr. Pure L.S.	0%	-	0.08	*												
27 hr. Pure L.S.	1%	-	0.1	0.913	*											
1 to 1000 L.S.	2%	-	0.045	0.094	0.126	*										
Control	4%	-	0.094	0.177	0.229	0.397	*									
4 hr. Pure L.S.	7%	-	0.003	0.007	0.016	0.035	0.001	*								
1 to 100 L.S.	8%	-	0.013	0.032	0.046	0.292	0.008	0.161	*							
1 hr. Pure L.S.	9%	-	0.001	0.004	0.006	0.007	0	0.562	0.039	*						
Heat	12%	-	0.05	0.098	0.131	0.997	0.36	0.047	0.254	0.012	*					
Pure L.S.	16%	-	0.0004	0.01	0.016	0.04	0	0.716	0.092	0.311	0.017	*				
1 to 100 L.S. Heat	17%	-	0.018	0.041	0.058	0.433	0.022	0.143	0.792	0.039	0.339	0.053	*			
1 to 10 L.S.	17%	-	0.018	0.042	0.059	0.441	0.027	0.151	0.801	0.043	0.352	0.068	1	*		
Pure L.S. Heat	20%	-	0.009	0.023	0.034	0.186	0.001	0.319	0.56	0.107	0.017	0.217	0.89	0.403	*	
1 to 10 L.S. Heat	30%	-	0.002	0.005	0.009	0.013	0	0.756	0.013	0.807	0.002	0.273	0.004	0.007	0.021	*

Table A8. Statistical summary for *Adenostoma fasciculatum* (Chamise) seed germination.

The following Minitab output is a power analysis for Chamise:

Power and Sample Size Chamise 20% & 30% sample=150 power=?

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.3

Alpha = 0.05

Sample	Proportion 1	Size	Power
	0.2	150	0.516109

The sample size is for each group.

Power and Sample Size Chamise 50% 150=sample size .9 .95 CI proportion=?

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.5

Alpha = 0.05

Sample	Size	Power	Proportion 1
	150	0.90	0.682730
	150	0.95	0.701844

The sample size is for each group.

Power and Sample Size Chamise 20% 30% sample=?

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.3

Alpha = 0.05

Sample	Target	Proportion 1	Size	Power	Actual Power
		0.2	392(14)	0.90	0.900039
		0.2	485(17)	0.95	0.950257

The sample size is for each group.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and the control is compared to all other treatments.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatment

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds Z	95% CI P Ratio	Lower	Upper
Constant	-3.85296	0.415657	-9.27	0.000		
Trial						
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11 1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42 2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08 9.80
Time Treatment (Control)						
1 to 100 L.S.	0.811858	0.304287	2.67	0.008	2.25	1.24 4.09
1 to 1000 L.S.	0.374785	0.442659	0.85	0.397	1.45	0.61 3.46
1 to 2000 L.S.	-1.74775	1.04223	-1.68	0.094	0.17	0.02 1.34
1 hr. Pure L.S.	1.59660	0.408171	3.91	0.000	4.94	2.22 10.99
Pure L.S.	1.23314	0.286265	4.31	0.000	3.43	1.96 6.01
18 hr. Pure L.S.	-1.41846	1.05014	-1.35	0.177	0.24	0.03 1.90
27 hr. Pure L.S.	-1.26351	1.05052	-1.20	0.229	0.28	0.04 2.22
30 hr. Pure L.S.	-10001.6	74535.6	-0.13	0.893	0.00	0.00 *
4 hr. Pure L.S.	1.37083	0.425343	3.22	0.001	3.94	1.71 9.07
Heat	0.373099	0.407828	0.91	0.360	1.45	0.65 3.23
Pure L.S. Heat	0.958357	0.293095	3.27	0.001	2.61	1.47 4.63
1 to 10 L.S.	0.735214	0.332801	2.21	0.027	2.09	1.09 4.00
1 to 10 L.S. Heat	1.49735	0.307413	4.87	0.000	4.47	2.45 8.17
1 to 100 L.S. Heat	0.735214	0.320557	2.29	0.022	2.09	1.11 3.91

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 15.2906 8 0.054

Deviance 17.2464 8 0.028

Hosmer-Lemeshow 4.5740 7 0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 863077 78.2 Somers' D 0.62

Discordant 181357 16.4 Goodman-Kruskal Gamma 0.65

Ties 59517 5.4 Kendall's Tau-a 0.09

Total 1103951 100.0

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and heat is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P	Ratio	Lower	Upper
Constant	-3.47987	0.509400	-6.83	0.000				
Trial								
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14	
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08	
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80	
Time Treatment (Heat)								
1 hr. Pure L.S.	1.22350	0.487108	2.51	0.012	3.40	1.31	8.83	
1 to 100 L.S.	0.438759	0.384613	1.14	0.254	1.55	0.73	3.30	
4 hr. Pure L.S.	0.997730	0.501585	1.99	0.047	2.71	1.01	7.25	
1 to 1000 L.S.	0.0016855	0.524233	0.00	0.997	1.00	0.36	2.80	
27 hr. Pure L.S.	-1.63661	1.08363	-1.51	0.131	0.19	0.02	1.63	
18 hr. Pure L.S.	-1.79156	1.08326	-1.65	0.098	0.17	0.02	1.39	
1 to 2000 L.S.	-2.12085	1.07977	-1.96	0.050	0.12	0.01	1.00	
30 hr. Pure L.S.	-10001.0	74535.6	-0.13	0.893	0.00	0.00	*	
Control	-0.373099	0.407828	-0.91	0.360	0.69	0.31	1.53	
Pure L.S.	0.860039	0.360535	2.39	0.017	2.36	1.17	4.79	
Pure L.S. Heat	0.585258	0.355971	1.64	0.100	1.80	0.89	3.61	
1 to 10 L.S.	0.362115	0.389316	0.93	0.352	1.44	0.67	3.08	
1 to 10 L.S. Heat	1.12425	0.367850	3.06	0.002	3.08	1.50	6.33	
1 to 100 L.S. Heat	0.362115	0.378903	0.96	0.339	1.44	0.68	3.02	

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 2000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable	Value	Count
Response	Event	313
	Non-event	3527
Trials	Total	3840

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-5.60072	1.03657	-5.40	0.000			
Trial							
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80
Time Treatment (1 to 2000 L.S.)							
30 hr. Pure L.S.	-10001.9	74535.6	-0.13	0.893	0.00	0.00	*
Control	1.74775	1.04223	1.68	0.094	5.74	0.74	44.28
1 to 100 L.S.	2.55961	1.03070	2.48	0.013	12.93	1.72	97.49
1 to 1000 L.S.	2.12254	1.05713	2.01	0.045	8.35	1.05	66.32
1 hr. Pure L.S.	3.34435	1.05009	3.18	0.001	28.34	3.62	221.97
Pure L.S.	2.98089	1.03255	2.89	0.004	19.71	2.60	149.11
18 hr. Pure L.S.	0.329290	1.42789	0.23	0.818	1.39	0.08	22.83
27 hr. Pure L.S.	0.484239	1.42818	0.34	0.735	1.62	0.10	26.67
4 hr. Pure L.S.	3.11858	1.05689	2.95	0.003	22.61	2.85	179.48
Heat	2.12085	1.07977	1.96	0.050	8.34	1.00	69.21
Pure L.S. Heat	2.70611	1.04186	2.60	0.009	14.97	1.94	115.37
1 to 10 L.S.	2.48296	1.05372	2.36	0.018	11.98	1.52	94.47
1 to 10 L.S. Heat	3.24510	1.04598	3.10	0.002	25.66	3.30	199.38
1 to 100 L.S. Heat	2.48296	1.04992	2.36	0.018	11.98	1.53	93.77

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 1000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P	Ratio	Lower	Upper
Constant	-3.47818	0.438420	-7.93	0.000				
Trial								
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14	
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08	
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80	
Time Treatment (1 to 1000 L.S.)								
27 hr. Pure L.S.	-1.63830	1.07019	-1.53	0.126	0.19	0.02	1.58	
18 hr. Pure L.S.	-1.79324	1.06982	-1.68	0.094	0.17	0.02	1.35	
1 to 2000 L.S.	-2.12254	1.05713	-2.01	0.045	0.12	0.02	0.95	
30 hr. Pure L.S.	-10001.0	74535.6	-0.13	0.893	0.00	0.00	*	
Control	-0.374785	0.442659	-0.85	0.397	0.69	0.29	1.64	
1 to 100 L.S.	0.437073	0.415039	1.05	0.292	1.55	0.69	3.49	
1 hr. Pure L.S.	1.22181	0.456419	2.68	0.007	3.39	1.39	8.30	
Pure L.S.	0.858354	0.417469	2.06	0.040	2.36	1.04	5.35	
4 hr. Pure L.S.	0.996045	0.471839	2.11	0.035	2.71	1.07	6.83	
Heat	-0.0016855	0.524233	-0.00	0.997	1.00	0.36	2.79	
Pure L.S. Heat	0.583573	0.440909	1.32	0.186	1.79	0.76	4.25	
1 to 10 L.S.	0.360429	0.468245	0.77	0.441	1.43	0.57	3.59	
1 to 10 L.S. Heat	1.12257	0.450554	2.49	0.013	3.07	1.27	7.43	
1 to 100 L.S. Heat	0.360429	0.459623	0.78	0.433	1.43	0.58	3.53	

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds Ratio	Z	P	95% CI Lower	95% CI Upper
Constant	-3.04111	0.377514	-8.06	0.000			
Trial							
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80
Time Treatment (1 to 100 L.S.)							
4 hr. Pure L.S.	0.558972	0.398708	1.40	0.161	1.75	0.80	3.82
1 to 1000 L.S.	-0.437073	0.415039	-1.05	0.292	0.65	0.29	1.46
27 hr. Pure L.S.	-2.07537	1.04002	-2.00	0.046	0.13	0.02	0.96
18 hr. Pure L.S.	-2.23032	1.03964	-2.15	0.032	0.11	0.01	0.82
1 to 2000 L.S.	-2.55961	1.03070	-2.48	0.013	0.08	0.01	0.58
30 hr. Pure L.S.	-10001.4	74535.6	-0.13	0.893	0.00	0.00	*
Control	-0.811858	0.304287	-2.67	0.008	0.44	0.24	0.81
1 hr. Pure L.S.	0.784739	0.380335	2.06	0.039	2.19	1.04	4.62
Pure L.S.	0.421281	0.250382	1.68	0.092	1.52	0.93	2.49
Heat	-0.438759	0.384613	-1.14	0.254	0.64	0.30	1.37
Pure L.S. Heat	0.146500	0.259823	0.56	0.573	1.16	0.70	1.93
1 to 10 L.S.	-0.0766439	0.303907	-0.25	0.801	0.93	0.51	1.68
1 to 10 L.S. Heat	0.685496	0.275872	2.48	0.013	1.98	1.16	3.41
1 to 100 L.S. Heat	-0.0766439	0.290447	-0.26	0.792	0.93	0.52	1.64

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds Z	95% CI P Ratio	Lower	Upper
Constant	-3.11775	0.442629	-7.04	0.000		
Trial						
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11 1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42 2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08 9.80
Time Treatment (1 to 100 L.S. Heat)						
Pure L.S.	0.497925	0.257718	1.93	0.053	1.65	0.99 2.73
Heat	-0.362115	0.378903	-0.96	0.339	0.70	0.33 1.46
1 hr. Pure L.S.	0.861383	0.416781	2.07	0.039	2.37	1.05 5.36
1 to 100 L.S.	0.0766439	0.290447	0.26	0.792	1.08	0.61 1.91
4 hr. Pure L.S.	0.635616	0.433613	1.47	0.143	1.89	0.81 4.42
1 to 1000 L.S.	-0.360429	0.459623	-0.78	0.433	0.70	0.28 1.72
27 hr. Pure L.S.	-1.99873	1.05390	-1.90	0.058	0.14	0.02 1.07
18 hr. Pure L.S.	-2.15367	1.05351	-2.04	0.041	0.12	0.01 0.92
1 to 2000 L.S.	-2.48296	1.04992	-2.36	0.018	0.08	0.01 0.65
30 hr. Pure L.S.	-10001.4	74535.6	-0.13	0.893	0.00	0.00 *
Control	-0.735214	0.320557	-2.29	0.022	0.48	0.26 0.90
Pure L.S. Heat	0.223144	0.251293	0.89	0.375	1.25	0.76 2.05
1 to 10 L.S.	-0.0000000	0.296648	-0.00	1.000	1.00	0.56 1.79
1 to 10 L.S. Heat	0.762140	0.267854	2.85	0.004	2.14	1.27 3.62

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 10 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Odds 95% CI

Predictor Coef SE Coef Z P Ratio Lower Upper

Constant -3.11775 0.451576 -6.90 0.000

Trial

2 -1.05574 0.607033 -1.74 0.082 0.35 0.11 1.14

3 -0.0709092 0.408749 -0.17 0.862 0.93 0.42 2.08

4 1.50831 0.394868 3.82 0.000 4.52 2.08 9.80

Time Treatment (1 to 10 L.S.)

1 to 10 L.S. Heat 0.762140 0.282393 2.70 0.007 2.14 1.23 3.73

Pure L.S. Heat 0.223144 0.266736 0.84 0.403 1.25 0.74 2.11

1 to 100 L.S. Heat -0.0000000 0.296648 -0.00 1.000 1.00 0.56 1.79

Pure L.S. 0.497925 0.272797 1.83 0.068 1.65 0.96 2.81

Heat -0.362115 0.389316 -0.93 0.352 0.70 0.32 1.49

1 hr. Pure L.S. 0.861383 0.426270 2.02 0.043 2.37 1.03 5.46

1 to 100 L.S. 0.0766439 0.303907 0.25 0.801 1.08 0.60 1.96

4 hr. Pure L.S. 0.635616 0.442741 1.44 0.151 1.89 0.79 4.50

1 to 1000 L.S. -0.360429 0.468245 -0.77 0.441 0.70 0.28 1.75

27 hr. Pure L.S. -1.99873 1.05768 -1.89 0.059 0.14 0.02 1.08

18 hr. Pure L.S. -2.15367 1.05730 -2.04 0.042 0.12 0.01 0.92

1 to 2000 L.S. -2.48296 1.05372 -2.36 0.018 0.08 0.01 0.66

30 hr. Pure L.S. -10001.4 74535.6 -0.13 0.893 0.00 0.00 *

Control -0.735214 0.332801 -2.21 0.027 0.48 0.25 0.92

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 15.2906 8 0.054

Deviance 17.2464 8 0.028

Hosmer-Lemeshow 4.5740 7 0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group

Value 1 2 3 4 5 6 7 8 9 Total

Event

Obs 1 2 3 13 34 45 76 94 45 313

Exp 0.7 2.3 6.8 14.7 28.5 40.1 76.3 98.6 45.0

Non-event

Obs 449 478 507 467 416 375 374 356 105 3527

Exp 449.3 477.7 503.2 465.3 421.5 379.9 373.7 351.4 105.0

Total 450 480 510 480 450 420 450 450 150 3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 863077 78.2 Somers' D 0.62

Discordant 181357 16.4 Goodman-Kruskal Gamma 0.65

Ties 59517 5.4 Kendall's Tau-a 0.09

Total 1103951 100.0

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 10 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-2.35561	0.433205	-5.44	0.000			
Trial							
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80
Time Treatment (1 to 10 L.S. Heat)							
Pure L.S. Heat	-0.538997	0.234295	-2.30	0.021	0.58	0.37	0.92
1 to 10 L.S.	-0.762140	0.282393	-2.70	0.007	0.47	0.27	0.81
1 to 100 L.S. Heat	-0.762140	0.267854	-2.85	0.004	0.47	0.28	0.79
Pure L.S.	-0.264215	0.241173	-1.10	0.273	0.77	0.48	1.23
Heat	-1.12425	0.367850	-3.06	0.002	0.32	0.16	0.67
1 hr. Pure L.S.	0.0992425	0.406759	0.24	0.807	1.10	0.50	2.45
1 to 100 L.S.	-0.685496	0.275872	-2.48	0.013	0.50	0.29	0.87
4 hr. Pure L.S.	-0.126524	0.423988	-0.30	0.765	0.88	0.38	2.02
1 to 1000 L.S.	-1.12257	0.450554	-2.49	0.013	0.33	0.13	0.79
27 hr. Pure L.S.	-2.76087	1.04997	-2.63	0.009	0.06	0.01	0.50
18 hr. Pure L.S.	-2.91581	1.04959	-2.78	0.005	0.05	0.01	0.42
1 to 2000 L.S.	-3.24510	1.04598	-3.10	0.002	0.04	0.01	0.30
30 hr. Pure L.S.	-10001.1	74535.6	-0.13	0.893	0.00	0.00	*
Control	-1.49735	0.307413	-4.87	0.000	0.22	0.12	0.41

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-2.61983	0.411437	-6.37	0.000			
Trial							
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80
Time Treatment (Pure L.S.)							
1 to 10 L.S.	-0.497925	0.272797	-1.83	0.068	0.61	0.36	1.04
1 to 10 L.S. Heat	0.264215	0.241173	1.10	0.273	1.30	0.81	2.09
Pure L.S. Heat	-0.274781	0.222635	-1.23	0.217	0.76	0.49	1.18
1 to 100 L.S. Heat	-0.497925	0.257718	-1.93	0.053	0.61	0.37	1.01
Heat	-0.860039	0.360535	-2.39	0.017	0.42	0.21	0.86
1 hr. Pure L.S.	0.363458	0.358618	1.01	0.311	1.44	0.71	2.90
1 to 100 L.S.	-0.421281	0.250382	-1.68	0.092	0.66	0.40	1.07
4 hr. Pure L.S.	0.137691	0.378049	0.36	0.716	1.15	0.55	2.41
1 to 1000 L.S.	-0.858354	0.417469	-2.06	0.040	0.42	0.19	0.96
27 hr. Pure L.S.	-2.49665	1.03228	-2.42	0.016	0.08	0.01	0.62
18 hr. Pure L.S.	-2.65160	1.03189	-2.57	0.010	0.07	0.01	0.53
1 to 2000 L.S.	-2.98089	1.03255	-2.89	0.004	0.05	0.01	0.38
30 hr. Pure L.S.	-10001.9	74535.6	-0.13	0.893	0.00	0.00	*
Control	-1.23314	0.286265	-4.31	0.000	0.29	0.17	0.51

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 15.2906 8 0.054

Deviance 17.2464 8 0.028

Hosmer-Lemeshow 4.5740 7 0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group										
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
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Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 863077 78.2 Somers' D 0.62

Discordant 181357 16.4 Goodman-Kruskal Gamma 0.65

Ties 59517 5.4 Kendall's Tau-a 0.09

Total 1103951 100.0

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and pure L.S. with heat is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P	Ratio	Lower	Upper
Constant	-2.89461	0.423165	-6.84	0.000				
Trial								
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14	
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08	
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80	
Time Treatment (Pure L.S. Heat)								
1 to 10 L.S.	-0.223144	0.266736	-0.84	0.403	0.80	0.47	1.35	
1 to 100 L.S. Heat	-0.223144	0.251293	-0.89	0.375	0.80	0.49	1.31	
Pure L.S.	0.274781	0.222635	1.23	0.217	1.32	0.85	2.04	
Heat	-0.585258	0.355971	-1.64	0.100	0.56	0.28	1.12	
1 hr. Pure L.S.	0.638239	0.396049	1.61	0.107	1.89	0.87	4.11	
1 to 100 L.S.	-0.146500	0.259823	-0.56	0.573	0.86	0.52	1.44	
4 hr. Pure L.S.	0.412472	0.413725	1.00	0.319	1.51	0.67	3.40	
1 to 1000 L.S.	-0.583573	0.440909	-1.32	0.186	0.56	0.24	1.32	
27 hr. Pure L.S.	-2.22187	1.04587	-2.12	0.034	0.11	0.01	0.84	
18 hr. Pure L.S.	-2.37682	1.04549	-2.27	0.023	0.09	0.01	0.72	
1 to 2000 L.S.	-2.70611	1.04186	-2.60	0.009	0.07	0.01	0.51	
30 hr. Pure L.S.	-10001.6	74535.6	-0.13	0.893	0.00	0.00	*	
Control	-0.958357	0.293095	-3.27	0.001	0.38	0.22	0.68	
1 to 10 L.S. Heat	0.538997	0.234295	2.30	0.021	1.71	1.08	2.71	

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	7	8	9	Total
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Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
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Total	450	480	510	480	450	420	450	450	150	3840

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Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 1 hr. pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P	Ratio	Lower	Upper
Constant	-2.25637	0.485462	-4.65	0.000				
Trial								
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14	
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08	
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80	
Time Treatment (1 hr. Pure L.S.)								
1 to 100 L.S.	-0.784739	0.380335	-2.06	0.039	0.46	0.22	0.96	
4 hr. Pure L.S.	-0.225767	0.389241	-0.58	0.562	0.80	0.37	1.71	
1 to 1000 L.S.	-1.22181	0.456419	-2.68	0.007	0.29	0.12	0.72	
27 hr. Pure L.S.	-2.86011	1.03643	-2.76	0.006	0.06	0.01	0.44	
18 hr. Pure L.S.	-3.01506	1.03604	-2.91	0.004	0.05	0.01	0.37	
1 to 2000 L.S.	-3.34435	1.05009	-3.18	0.001	0.04	0.00	0.28	
30 hr. Pure L.S.	-10001.2	74535.6	-0.13	0.893	0.00	0.00	*	
Control	-1.59660	0.408171	-3.91	0.000	0.20	0.09	0.45	
Pure L.S.	-0.363458	0.358618	-1.01	0.311	0.70	0.34	1.40	
Heat	-1.22350	0.487108	-2.51	0.012	0.29	0.11	0.76	
Pure L.S. Heat	-0.638239	0.396049	-1.61	0.107	0.53	0.24	1.15	
1 to 10 L.S.	-0.861383	0.426270	-2.02	0.043	0.42	0.18	0.97	
1 to 10 L.S. Heat	-0.0992425	0.406759	-0.24	0.807	0.91	0.41	2.01	
1 to 100 L.S. Heat	-0.861383	0.416781	-2.07	0.039	0.42	0.19	0.96	

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 4 hr. pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds Ratio	95% CI	Z	P	Lower	Upper
Constant	-2.48214	0.499987	-4.96	0.000				
Trial								
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14	
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08	
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80	
Time Treatment (4 hr. Pure L.S.)								
1 to 1000 L.S.	-0.996045	0.471839	-2.11	0.035	0.37	0.15	0.93	
27 hr. Pure L.S.	-2.63434	1.04331	-2.52	0.012	0.07	0.01	0.55	
18 hr. Pure L.S.	-2.78929	1.04293	-2.67	0.007	0.06	0.01	0.47	
1 to 2000 L.S.	-3.11858	1.05689	-2.95	0.003	0.04	0.01	0.35	
30 hr. Pure L.S.	-10001.0	74535.6	-0.13	0.893	0.00	0.00	*	
Control	-1.37083	0.425343	-3.22	0.001	0.25	0.11	0.58	
1 to 100 L.S.	-0.558972	0.398708	-1.40	0.161	0.57	0.26	1.25	
1 hr. Pure L.S.	0.225767	0.389241	0.58	0.562	1.25	0.58	2.69	
Pure L.S.	-0.137691	0.378049	-0.36	0.716	0.87	0.42	1.83	
Heat	-0.997730	0.501585	-1.99	0.047	0.37	0.14	0.99	
Pure L.S. Heat	-0.412472	0.413725	-1.00	0.319	0.66	0.29	1.49	
1 to 10 L.S.	-0.635616	0.442741	-1.44	0.151	0.53	0.22	1.26	
1 to 10 L.S. Heat	0.126524	0.423988	0.30	0.765	1.13	0.49	2.61	
1 to 100 L.S. Heat	-0.635616	0.433613	-1.47	0.143	0.53	0.23	1.24	

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 18 hr. pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor			Odds		95% CI		
	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-5.27143	1.08253	-4.87	0.000			
Trial							
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80
Time Treatment (18 hr. Pure L.S.)							
1 to 2000 L.S.	-0.329290	1.42789	-0.23	0.818	0.72	0.04	11.82
30 hr. Pure L.S.	-10001.2	74535.6	-0.13	0.893	0.00	0.00	*
Control	1.41846	1.05014	1.35	0.177	4.13	0.53	32.35
1 to 100 L.S.	2.23032	1.03964	2.15	0.032	9.30	1.21	71.38
1 to 1000 L.S.	1.79324	1.06982	1.68	0.094	6.01	0.74	48.91
1 hr. Pure L.S.	3.01506	1.03604	2.91	0.004	20.39	2.68	155.35
Pure L.S.	2.65160	1.03189	2.57	0.010	14.18	1.88	107.14
27 hr. Pure L.S.	0.154948	1.41788	0.11	0.913	1.17	0.07	18.80
4 hr. Pure L.S.	2.78929	1.04293	2.67	0.007	16.27	2.11	125.64
Heat	1.79156	1.08326	1.65	0.098	6.00	0.72	50.14
Pure L.S. Heat	2.37682	1.04549	2.27	0.023	10.77	1.39	83.59
1 to 10 L.S.	2.15367	1.05730	2.04	0.042	8.62	1.08	68.44
1 to 10 L.S. Heat	2.91581	1.04959	2.78	0.005	18.46	2.36	144.46
1 to 100 L.S. Heat	2.15367	1.05351	2.04	0.041	8.62	1.09	67.94

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 15.2906 8 0.054

Deviance 17.2464 8 0.028

Hosmer-Lemeshow 4.5740 7 0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 863077 78.2 Somers' D 0.62

Discordant 181357 16.4 Goodman-Kruskal Gamma 0.65

Ties 59517 5.4 Kendall's Tau-a 0.09

Total 1103951 100.0

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 27 hr. pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P	Ratio	95% CI	Lower	Upper
Constant	-5.11648	1.08290	-4.72	0.000					
Trial									
2	-1.05574	0.607033	-1.74	0.082	0.35	0.11	1.14		
3	-0.0709092	0.408749	-0.17	0.862	0.93	0.42	2.08		
4	1.50831	0.394868	3.82	0.000	4.52	2.08	9.80		
Time Treatment (27 hr. Pure L.S.)									
18 hr. Pure L.S.	-0.154948	1.41788	-0.11	0.913	0.86	0.05	13.79		
1 to 2000 L.S.	-0.484239	1.42818	-0.34	0.735	0.62	0.04	10.12		
30 hr. Pure L.S.	-10001.4	74535.6	-0.13	0.893	0.00	0.00	*		
Control	1.26351	1.05052	1.20	0.229	3.54	0.45	27.73		
1 to 100 L.S.	2.07537	1.04002	2.00	0.046	7.97	1.04	61.18		
1 to 1000 L.S.	1.63830	1.07019	1.53	0.126	5.15	0.63	41.92		
1 hr. Pure L.S.	2.86011	1.03643	2.76	0.006	17.46	2.29	133.15		
Pure L.S.	2.49665	1.03228	2.42	0.016	12.14	1.61	91.83		
4 hr. Pure L.S.	2.63434	1.04331	2.52	0.012	13.93	1.80	107.69		
Heat	1.63661	1.08363	1.51	0.131	5.14	0.61	42.97		
Pure L.S. Heat	2.22187	1.04587	2.12	0.034	9.22	1.19	71.65		
1 to 10 L.S.	1.99873	1.05768	1.89	0.059	7.38	0.93	58.66		
1 to 10 L.S. Heat	2.76087	1.04997	2.63	0.009	15.81	2.02	123.82		
1 to 100 L.S. Heat	1.99873	1.05390	1.90	0.058	7.38	0.94	58.23		

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	863077	78.2	Somers' D 0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma 0.65
Ties	59517	5.4	Kendall's Tau-a 0.09
Total	1103951	100.0	

* NOTE * 10 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Chamise with all treatments from all trials where Trial 1 is compared to all other trials and 30 hr. pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: And fas Response, Trials versus Trial, Time Treatme

* WARNING * Problem fitting model. Variance/Covariance matrix of estimated coefficients does not exist at current iteration. Try using a different model or different starting estimates. The current results are displayed and may not be reliable.

Link Function: Logit Response Information

Variable Value Count

Response Event 313

Non-event 3527

Trials Total 3840

Logistic Regression Table

SE	95% CI					
	SE	95% CI				
Predictor	Coef	Coef	Z	P	Odds Ratio	Lower Upper
Constant	-62.5761	*	*	*		
Trial						
2	-1.05574	*	*	*	0.35	* *
3	-0.0709092	*	*	*	0.93	* *
4	1.50831	*	*	*	4.52	* *
Time Treatment (30 hr. Pure L.S.)						
Control	58.7232	*	*	*	3.18533E+25	* *
1 to 100 L.S.	59.5350	*	*	*	7.17364E+25	* *
1 to 1000 L.S.	59.0980	*	*	*	4.63363E+25	* *
1 to 2000 L.S.	56.9754	*	*	*	5.54774E+24	* *
1 hr. Pure L.S.	60.3198	*	*	*	1.57234E+26	* *
Pure L.S.	59.9563	*	*	*	1.09320E+26	* *
18 hr. Pure L.S.	57.3047	*	*	*	7.71125E+24	* *
27 hr. Pure L.S.	57.4597	*	*	*	9.00364E+24	* *
4 hr. Pure L.S.	60.0940	*	*	*	1.25458E+26	* *
Heat	59.0963	*	*	*	4.62583E+25	* *
Pure L.S. Heat	59.6815	*	*	*	8.30546E+25	* *
1 to 10 L.S.	59.4584	*	*	*	6.64437E+25	* *
1 to 10 L.S. Heat	60.2205	*	*	*	1.42379E+26	* *
1 to 100 L.S. Heat	59.4584	*	*	*	6.64437E+25	* *

Log-Likelihood = -890.203

Test that all slopes are zero: G = 388.756, DF = 17, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	15.2906	8	0.054
Deviance	17.2464	8	0.028
Hosmer-Lemeshow	4.5740	7	0.712

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group									
Value	1	2	3	4	5	6	7	8	9	Total
Event										
Obs	1	2	3	13	34	45	76	94	45	313
Exp	0.7	2.3	6.8	14.7	28.5	40.1	76.3	98.6	45.0	
Non-event										
Obs	449	478	507	467	416	375	374	356	105	3527
Exp	449.3	477.7	503.2	465.3	421.5	379.9	373.7	351.4	105.0	
Total	450	480	510	480	450	420	450	450	150	3840

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures	
Concordant	863077	78.2	Somers' D	0.62
Discordant	181357	16.4	Goodman-Kruskal Gamma	0.65
Ties	59517	5.4	Kendall's Tau-a	0.09
Total	1103951	100.0		

Ceanothus cuneatus (Buckbrush)

Data

		Germinated
Trial	Treatment	Seeds
4	1 to 10 L.S. with Heat	1
4	1 to 10 L.S. with Heat	1
4	1 to 10 L.S. with Heat	8
4	1 to 10 L.S. with Heat	1
4	1 to 10 L.S. with Heat	0
4	1 to 10 L.S. with Heat	1
1	1 to 100 L.S.	0
1	1 to 100 L.S.	0
1	1 to 100 L.S.	0
2	1 to 100 L.S.	1
2	1 to 100 L.S.	1
2	1 to 100 L.S.	0
2	1 to 100 L.S.	0
2	1 to 100 L.S.	0
2	1 to 100 L.S.	0
2	1 to 100 L.S.	0
2	1 to 100 L.S.	3
4	1 to 100 L.S. with Heat	1
4	1 to 100 L.S. with Heat	0
4	1 to 100 L.S. with Heat	0
4	1 to 100 L.S. with Heat	1
4	1 to 100 L.S. with Heat	0
1	1 to 1000 L.S.	0
1	1 to 1000 L.S.	0
1	1 to 1000 L.S.	0
2	1 to 1000 L.S.	0
2	1 to 1000 L.S.	1
2	1 to 1000 L.S.	1
2	1 to 1000 L.S.	0
2	1 to 1000 L.S.	0
1	1 to 2000 L.S.	0
1	1 to 2000 L.S.	0
2	1 to 2000 L.S.	0
2	1 to 2000 L.S.	0

		Germinated
Trial	Treatment	Seeds
2	1 to 2000 L.S.	0
2	1 to 2000 L.S.	0
2	1 to 2000 L.S.	0
2	1 to 2000 L.S.	0
1	Control	0
1	Control	0
1	Control	0
2	Control	0
2	Control	0
2	Control	0
2	Control	0
2	Control	2
4	Control	1
4	Control	0
4	Control	1
4	Control	0
4	Control	0
4	Heat	0
4	Heat	0
4	Heat	0
4	Heat	3
4	Heat	0
4	Heat	9
4	Pure L.S. with Heat	5
4	Pure L.S. with Heat	3
4	Pure L.S. with Heat	8
4	Pure L.S. with Heat	10
4	Pure L.S. with Heat	8
4	Pure L.S. with Heat	1
4	Pure L.S. with Heat	1
4	Pure L.S. with Heat	1
4	Pure L.S. with Heat	11
4	Pure L.S. with Heat	3

Table A9. Raw data for *Ceanothus cuneatus* (Buckbrush) seed germination.

Statistical Analysis

Treatment	Percent germination	1 to 2000 L.S.	1 to 1000 L.S.	Control	1 to 100 L.S. Heat	1 to 100 L.S.	1 to 10 L.S. Heat	Heat	Pure L.S. Heat
1 to 2000 L.S.	0%	*							
1 to 1000 L.S.	1%	-	*						
Control	1%	-	0.609	*					
1 to 100 L.S. Heat	1%	-	0.504	0.69	*				
1 to 100 L.S.	2%	-	0.432	0.195	0.207	*			
1 to 10 L.S. Heat	7%	-	0.553	0.045	0.031	0.948	*		
Heat	7%	-	0.553	0.045	0.031	0.948	1	*	
Pure L.S. Heat	17%	-	0.14	0*	0	0.287	0.002	0.002	*

Table A10. Statistical summary for *Ceanothus cuneatus* (Buckbrush) seed germination.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and control is compared to all other treatments.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		88
Non-event		1922
events Total		2010

Logistic Regression Table

Predictor	Coef	SE Coef	95% Odds CI			
			Z	P	Ratio	Lower
Constant	-6.37847	1.52739	-4.18	0.000		
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79
Treatment (Control)						
1 to 100 L.S.	1.22978	0.948232	1.30	0.195	3.42	0.53
1 to 1000 L.S.	0.568278	1.11023	0.51	0.609	1.77	0.20
1 to 2000 L.S.	-10001.3	60858.1	-0.16	0.869	0.00	0.00
Heat	1.30058	0.648134	2.01	0.045	3.67	1.03
1 to 10 L.S. with Heat	1.30058	0.648134	2.01	0.045	3.67	1.03
1 to 100 L.S. with Heat	-0.364429	0.915177	-0.40	0.690	0.69	0.12
Pure L.S. with Heat	2.35401	0.595328	3.95	0.000	10.53	3.28

Predictor	Upper
Constant	
Trial	4.27
Treatment	
1 to 100 L.S.	21.94
1 to 1000 L.S.	15.55
1 to 2000 L.S.	*
Heat	13.08
1 to 10 L.S. with Heat	13.08
1 to 100 L.S. with Heat	4.18
Pure L.S. with Heat	33.81

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	3.92781	4	0.416
Deviance	5.23266	4	0.264
Hosmer-Lemeshow	0.55364	5	0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group	1	2	3	4	5	6	7	Total
Value								
Event								
Obs	0	2	2	4	5	24	51	88
Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
Non-event								
Obs	270	328	238	296	205	336	249	1922
Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
Total	270	330	240	300	210	360	300	2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	127887	75.6	Somers' D 0.66
Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
Ties	24482	14.5	Kendall's Tau-a 0.06
Total	169136	100.0	

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and heat is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	88
	Non-event	1922
events	Total	2010

Logistic Regression Table

Predictor	Coef	SE Coef	95% Odds CI		Z	P	Ratio	Lower
Constant	-5.07789	1.74509	-2.91	0.004				
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79		
Treatment (Heat)								
1 to 10 L.S. with Heat	0.0000000	0.422577	0.00	1.000	1.00	0.44		
1 to 100 L.S. with Heat	-1.66501	0.772038	-2.16	0.031	0.19	0.04		
Pure L.S. with Heat	1.05343	0.336020	3.14	0.002	2.87	1.48		
Control	-1.30058	0.648134	-2.01	0.045	0.27	0.08		
1 to 100 L.S.	-0.0708022	1.08642	-0.07	0.948	0.93	0.11		
1 to 1000 L.S.	-0.732301	1.23577	-0.59	0.553	0.48	0.04		
1 to 2000 L.S.	-10001.6	60858.1	-0.16	0.869	0.00	0.00		

Predictor Upper

Constant

Trial 4.27

Treatment

1 to 10 L.S. with Heat 2.29

1 to 100 L.S. with Heat 0.86

Pure L.S. with Heat 5.54

Control 0.97

1 to 100 L.S. 7.83

1 to 1000 L.S. 5.42

1 to 2000 L.S. *

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
--------	------------	----	---

Pearson	3.92781	4	0.416
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Deviance	5.23266	4	0.264
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Hosmer-Lemeshow	0.55364	5	0.990
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Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group

Value	1	2	3	4	5	6	7	Total
-------	---	---	---	---	---	---	---	-------

Event

Obs	0	2	2	4	5	24	51	88
-----	---	---	---	---	---	----	----	----

Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
-----	-----	-----	-----	-----	-----	------	------	--

Non-event

Obs	270	328	238	296	205	336	249	1922
-----	-----	-----	-----	-----	-----	-----	-----	------

Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
-----	-------	-------	-------	-------	-------	-------	-------	--

Total	270	330	240	300	210	360	300	2010
-------	-----	-----	-----	-----	-----	-----	-----	------

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
-------	--------	---------	------------------

Concordant	127887	75.6	Somers' D 0.66
------------	--------	------	----------------

Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
------------	-------	-----	----------------------------

Ties	24482	14.5	Kendall's Tau-a 0.06
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Total	169136	100.0	
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* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 2000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

* WARNING * Problem fitting model. Variance/Covariance matrix of estimated coefficients does not exist at current iteration. Try using a different model or different starting estimates. The current results are displayed and may not be reliable.

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	88
	Non-event	1922
events	Total	2010

Logistic Regression Table

Predictor	SE	95% CI	Coef	Coef	Z	P	Odds Ratio	Lower	Upper
Constant			-78.7819		*	*	*		
Trial			0.609707		*	*	*	1.84	*
Treatment (1 to 2000 L.S.)									
Heat			73.7040		*	*	*	1.02153E+32	*
1 to 10 L.S. with Heat			73.7040		*	*	*	1.02153E+32	*
1 to 100 L.S. with Heat			72.0390		*	*	*	1.93262E+31	*
Pure L.S. with Heat			74.7575		*	*	*	2.92920E+32	*
Control			72.4034		*	*	*	2.78238E+31	*
1 to 100 L.S.			73.6332		*	*	*	9.51702E+31	*
1 to 1000 L.S.			72.9717		*	*	*	4.91152E+31	*

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	3.92781	4	0.416
Deviance	5.23266	4	0.264
Hosmer-Lemeshow	0.55364	5	0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group							
Value	1	2	3	4	5	6	7	Total
Event								
Obs	0	2	2	4	5	24	51	88
Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
Non-event								
Obs	270	328	238	296	205	336	249	1922
Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
Total	270	330	240	300	210	360	300	2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	127887	75.6	Somers' D 0.66
Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
Ties	24482	14.5	Kendall's Tau-a 0.06
Total	169136	100.0	

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 1000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		88
Non-event		1922
events Total		2010

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	95% Odds CI	
					Ratio	Lower
Constant	-5.81019	1.03530	-5.61	0.000		
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79
Treatment (1 to 1000 L.S.)						
1 to 2000 L.S.	-10001.9	60858.1	-0.16	0.869	0.00	0.00
Heat	0.732301	1.23577	0.59	0.553	2.08	0.18
1 to 10 L.S. with Heat	0.732301	1.23577	0.59	0.553	2.08	0.18
1 to 100 L.S. with Heat	-0.932707	1.39449	-0.67	0.504	0.39	0.03
Pure L.S. with Heat	1.78573	1.20891	1.48	0.140	5.96	0.56
Control	-0.568278	1.11023	-0.51	0.609	0.57	0.06
1 to 100 L.S.	0.661499	0.841823	0.79	0.432	1.94	0.37

Predictor	Upper
Constant	
Trial	4.27
Treatment	
1 to 2000 L.S.	*
Heat	23.44
1 to 10 L.S. with Heat	23.44
1 to 100 L.S. with Heat	6.05
Pure L.S. with Heat	63.76
Control	4.99
1 to 100 L.S.	10.09

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	3.92781	4	0.416
Deviance	5.23266	4	0.264
Hosmer-Lemeshow	0.55364	5	0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group	1	2	3	4	5	6	7	Total
Value								
Event								
Obs	0	2	2	4	5	24	51	88
Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
Non-event								
Obs	270	328	238	296	205	336	249	1922
Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
Total	270	330	240	300	210	360	300	2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	127887	75.6	Somers' D 0.66
Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
Ties	24482	14.5	Kendall's Tau-a 0.06
Total	169136	100.0	

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable Value Count

Total Event 88

Non-event 1922

events Total 2010

Logistic Regression Table

Predictor	Coef	SE Coef	95% Odds CI		Z	P	Ratio	Lower	Upper
Constant	-5.14869	0.898752	-5.73	0.000					
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79			
Treatment (1 to 100 L.S.)									
1 to 1000 L.S.	-0.661499	0.841823	-0.79	0.432	0.52	0.10			
1 to 2000 L.S.	-10001.5	60858.1	-0.16	0.869	0.00	0.00			
Heat	0.0708022	1.08642	0.07	0.948	1.07	0.13			
1 to 10 L.S. with Heat	0.0708022	1.08642	0.07	0.948	1.07	0.13			
1 to 100 L.S. with Heat	-1.59421	1.26403	-1.26	0.207	0.20	0.02			
Pure L.S. with Heat	1.12423	1.05577	1.06	0.287	3.08	0.39			
Control	-1.22978	0.948232	-1.30	0.195	0.29	0.05			

Predictor Upper

Constant

Trial 4.27

Treatment

1 to 1000 L.S. 2.69

1 to 2000 L.S. *

Heat 9.03

1 to 10 L.S. with Heat 9.03

1 to 100 L.S. with Heat 2.42

Pure L.S. with Heat 24.37

Control 1.88

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 3.92781 4 0.416

Deviance 5.23266 4 0.264

Hosmer-Lemeshow 0.55364 5 0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group

Value 1 2 3 4 5 6 7 Total

Event

Obs 0 2 2 4 5 24 51 88

Exp 0.0 1.6 2.5 4.9 4.0 24.0 51.0

Non-event

Obs 270 328 238 296 205 336 249 1922

Exp 270.0 328.4 237.5 295.1 206.0 336.0 249.0

Total 270 330 240 300 210 360 300 2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 127887 75.6 Somers' D 0.66

Discordant 16767 9.9 Goodman-Kruskal Gamma 0.77

Ties 24482 14.5 Kendall's Tau-a 0.06

Total 169136 100.0

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for *Ceanothus cuneatus* Total, events versus Trial, Treatment where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: *Ceanothus cuneatus* Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	88
	Non-event	1922
events	Total	2010

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-6.74289	1.86086	-3.62	0.000			
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79	4.27
Treatment (1 to 100 L.S. with Heat)							
Pure L.S. with Heat	2.71844	0.728272	3.73	0.000	15.16	3.64	63.17
Control	0.364429	0.915177	0.40	0.690	1.44	0.24	8.66
1 to 100 L.S.	1.59421	1.26403	1.26	0.207	4.92	0.41	58.66
1 to 1000 L.S.	0.932707	1.39449	0.67	0.504	2.54	0.17	39.09
1 to 2000 L.S.	-10002.0	60858.1	-0.16	0.869	0.00	0.00	*
Heat	1.66501	0.772038	2.16	0.031	5.29	1.16	24.00
1 to 10 L.S. with Heat	1.66501	0.772038	2.16	0.031	5.29	1.16	24.00

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	3.92781	4	0.416
Deviance	5.23266	4	0.264
Hosmer-Lemeshow	0.55364	5	0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group	1	2	3	4	5	6	7	Total
Value								
Event								
Obs	0	2	2	4	5	24	51	88
Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
Non-event								
Obs	270	328	238	296	205	336	249	1922
Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
Total	270	330	240	300	210	360	300	2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	127887	75.6	Somers' D 0.66
Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
Ties	24482	14.5	Kendall's Tau-a 0.06
Total	169136	100.0	

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 10 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		88
Non-event		1922
events Total		2010

Logistic Regression Table

								95%	
								95%	
								Odds	CI
Predictor	Coef	SE Coef	Z	P	Ratio	Lower			
Constant	-5.07789	1.74509	-2.91	0.004					
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79			
Treatment (1 to 10 L.S. with Heat)									
1 to 100 L.S. with Heat	-1.66501	0.772038	-2.16	0.031	0.19	0.04			
Pure L.S. with Heat	1.05343	0.336020	3.14	0.002	2.87	1.48			
Control	-1.30058	0.648134	-2.01	0.045	0.27	0.08			
1 to 100 L.S.	-0.0708022	1.08642	-0.07	0.948	0.93	0.11			
1 to 1000 L.S.	-0.732301	1.23577	-0.59	0.553	0.48	0.04			
1 to 2000 L.S.	-10001.6	60858.1	-0.16	0.869	0.00	0.00			
Heat	0.0000000	0.422577	0.00	1.000	1.00	0.44			

Predictor Upper

Constant

Trial 4.27

Treatment

1 to 100 L.S. with Heat 0.86

Pure L.S. with Heat 5.54

Control 0.97

1 to 100 L.S. 7.83

1 to 1000 L.S. 5.42

1 to 2000 L.S. *

Heat 2.29

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
--------	------------	----	---

Pearson	3.92781	4	0.416
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Deviance	5.23266	4	0.264
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Hosmer-Lemeshow	0.55364	5	0.990
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Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group

Value	1	2	3	4	5	6	7	Total
-------	---	---	---	---	---	---	---	-------

Event

Obs	0	2	2	4	5	24	51	88
-----	---	---	---	---	---	----	----	----

Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0	
-----	-----	-----	-----	-----	-----	------	------	--

Non-event

Obs	270	328	238	296	205	336	249	1922
-----	-----	-----	-----	-----	-----	-----	-----	------

Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0	
-----	-------	-------	-------	-------	-------	-------	-------	--

Total	270	330	240	300	210	360	300	2010
-------	-----	-----	-----	-----	-----	-----	-----	------

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
-------	--------	---------	------------------

Concordant	127887	75.6	Somers' D 0.66
------------	--------	------	----------------

Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
------------	-------	-----	----------------------------

Ties	24482	14.5	Kendall's Tau-a 0.06
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Total	169136	100.0	
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* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Buckbrush with all treatments from all trials where Trial 1 is compared to all other trials and pure L.S. with heat is compared to all other treatments and the control.

Binary Logistic Regression: Ceanothus cuneatus Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	88
	Non-event	1922
events	Total	2010

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-4.02446	1.72618	-2.33	0.020			
Trial	0.609707	0.429830	1.42	0.156	1.84	0.79	4.27
Treatment (Pure L.S. with Heat)							
Control	-2.35401	0.595328	-3.95	0.000	0.09	0.03	0.31
1 to 100 L.S.	-1.12423	1.05577	-1.06	0.287	0.32	0.04	2.57
1 to 1000 L.S.	-1.78573	1.20891	-1.48	0.140	0.17	0.02	1.79
1 to 2000 L.S.	-10001.7	60858.1	-0.16	0.869	0.00	0.00	*
Heat	-1.05343	0.336020	-3.14	0.002	0.35	0.18	0.67
1 to 10 L.S. with Heat	-1.05343	0.336020	-3.14	0.002	0.35	0.18	0.67
1 to 100 L.S. with Heat	-2.71844	0.728272	-3.73	0.000	0.07	0.02	0.27

Log-Likelihood = -293.672

Test that all slopes are zero: G = 135.372, DF = 8, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	3.92781	4	0.416
Deviance	5.23266	4	0.264
Hosmer-Lemeshow	0.55364	5	0.990

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Group	Value	1	2	3	4	5	6	7	Total
Event									
Obs	0	2	2	4	5	24	51		88
Exp	0.0	1.6	2.5	4.9	4.0	24.0	51.0		
Non-event									
Obs	270	328	238	296	205	336	249		1922
Exp	270.0	328.4	237.5	295.1	206.0	336.0	249.0		
Total	270	330	240	300	210	360	300		2010

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	127887	75.6	Somers' D 0.66
Discordant	16767	9.9	Goodman-Kruskal Gamma 0.77
Ties	24482	14.5	Kendall's Tau-a 0.06
Total	169136	100.0	

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

Salvia mellifera (Black Sage)

Data

Trial Treatment		Germinated seeds
1	Control	1
1	Control	0
1	Control	1
2	Control	0
2	Control	1
3	Control	0
3	Control	2
3	Control	0
3	Control	0
4	Control	11
4	Control	7
4	Control	4
4	Control	2
4	Control	5
4	Heat	17
4	Heat	11
4	Heat	11
4	Heat	10
4	Heat	14
4	Pure L.S.	4
4	Pure L.S.	8
4	Pure L.S.	1
4	Pure L.S.	14
4	Pure L.S.	12
4	Pure L.S. Heat	11
4	Pure L.S. Heat	9
4	Pure L.S. Heat	16
4	Pure L.S. Heat	12
4	Pure L.S. Heat	12
4	Pure L.S. Heat	8
4	Pure L.S. Heat	8
4	Pure L.S. Heat	4
4	Pure L.S. Heat	15
4	Pure L.S. Heat	8
4	1 to 10 L.S.	9
4	1 to 10 L.S.	10
4	1 to 10 L.S.	9
4	1 to 10 L.S.	3
4	1 to 10 L.S.	2
4	1 to 10 L.S. Heat	11
4	1 to 10 L.S. Heat	10
4	1 to 10 L.S. Heat	10
4	1 to 10 L.S. Heat	5
1	1 to 100 L.S.	9

Trial Treatment		Germinated seeds
1	1 to 100 L.S.	9
1	1 to 100 L.S.	5
2	1 to 100 L.S.	5
2	1 to 100 L.S.	1
2	1 to 100 L.S.	2
3	1 to 100 L.S.	2
3	1 to 100 L.S.	1
3	1 to 100 L.S.	3
3	1 to 100 L.S.	2
3	1 to 100 L.S.	3
4	1 to 100 L.S.	6
4	1 to 100 L.S.	5
4	1 to 100 L.S.	0
4	1 to 100 L.S.	6
4	1 to 100 L.S.	16
4	1 to 100 L.S. Heat	13
4	1 to 100 L.S. Heat	15
4	1 to 100 L.S. Heat	7
4	1 to 100 L.S. Heat	7
4	1 to 100 L.S. Heat	6
1	1 to 1000 L.S.	3
1	1 to 1000 L.S.	8
1	1 to 1000 L.S.	5
2	1 to 1000 L.S.	0
2	1 to 1000 L.S.	0
2	1 to 1000 L.S.	1
2	1 to 1000 L.S.	2
2	1 to 1000 L.S.	3
3	1 to 1000 L.S.	2
3	1 to 1000 L.S.	0
3	1 to 1000 L.S.	4
3	1 to 1000 L.S.	1
3	1 to 1000 L.S.	0
1	1 to 2000 L.S.	8
1	1 to 2000 L.S.	10
1	1 to 2000 L.S.	4
2	1 to 2000 L.S.	2
2	1 to 2000 L.S.	2
2	1 to 2000 L.S.	0
3	1 to 2000 L.S.	1
3	1 to 2000 L.S.	2
3	1 to 2000 L.S.	1
3	1 to 2000 L.S.	5
3	1 to 2000 L.S.	3

Table A11. Raw data for *Salvia mellifera* (Black Sage) seed germination.

Statistical Analysis

Treatment	Percent germination	1 to 1000 L.S.	Control	1 to 2000 L.S.	1 to 100 L.S.	1 to 10 L.S.	Pure L.S.	1 to 10 L.S. Heat	1 to 100 L.S. Heat	Pure L.S. Heat	Heat
1 to 1000 L.S.	7%	*									
Control	8%	0.036	*								
1 to 2000 L.S.	12%	0.11	0	*							
1 to 100 L.S.	15%	0.349	0	0.47	*						
1 to 10 L.S.	22%	0.876	0.044	0.161	0.246	*					
Pure L.S.	26%	0.634	0.004	0.44	0.749	0.418	*				
1 to 10 L.S. Heat	30%	0.303	0.001	0.862	0.648	0.135	0.466	*			
1 to 100 L.S. Heat	32%	0.179	0	0.917	0.381	0.052	0.253	0.724	*		
Pure L.S. Heat	34%	0.075	0	0.646	0.125	0.008	0.074	0.394	0.621	*	
Heat	42%	0.008	0	0.15	0.006	0	0.004	0.043	0.074	0.113	*

Table A12. Statistical summary for *Salvia mellifera* (Black Sage) seed germination.

The following Minitab output is a power analysis for Black Sage:

Power and Sample Size for Salvia mellifera Heat 42% V Pure LS Heat 34% with 150 sample size power=?

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.34

Alpha = 0.05

Sample	Proportion 1	Size	Power
	0.42	150	0.296863

The sample size is for each group.

Power and Sample Size Salvia mellifera Heat 42% V Pure LS Heat 34% sample size=? .9 .95 CI

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.34

Alpha = 0.05

Sample	Target	Proportion 1	Size	Power	Actual Power
		0.42	772(26)	0.90	0.900174
		0.42	954(32)	0.95	0.950045

The sample size is for each group.

Power and Sample Size Salvia mellifera 50% 150=sample size .9 .95 CI proportion=?

Test for Two Proportions

Testing proportion 1 = proportion 2 (versus not =)

Calculating power for proportion 2 = 0.5

Alpha = 0.05

Sample	Size	Power	Proportion 1
	150	0.90	0.682730
	150	0.95	0.701844

The sample size is for each group.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and control is compared to all other treatments.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	497
	Non-event	2143
events	Total	2640

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-2.25460	0.237217	-9.50	0.000			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment (Control)							
1 to 10 L.S. Heat	0.987550	0.283803	3.48	0.001	2.68	1.54	4.68
1 to 100 L.S. Heat	1.08108	0.267393	4.04	0.000	2.95	1.75	4.98
Heat	1.51207	0.261207	5.79	0.000	4.54	2.72	7.57
Pure L.S. Heat	1.18637	0.235895	5.03	0.000	3.28	2.06	5.20
1 to 10 L.S.	0.569182	0.282333	2.02	0.044	1.77	1.02	3.07
1 to 100 L.S.	0.868814	0.225064	3.86	0.000	2.38	1.53	3.71
1 to 2000 L.S.	1.04692	0.283804	3.69	0.000	2.85	1.63	4.97
Pure L.S.	0.788880	0.274794	2.87	0.004	2.20	1.28	3.77
1 to 1000 L.S.	0.623939	0.297475	2.10	0.036	1.87	1.04	3.34

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group								
Value	1	2	3	4	5	6	7	8	Total
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and heat is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event	497	
Non-event	2143	
events Total	2640	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P Ratio	Odds	95% CI Lower	Upper
Constant	-0.742521	0.285528	-2.60	0.009			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment (Heat)							
Pure L.S. Heat	-0.325701	0.205310	-1.59	0.113	0.72	0.48	1.08
1 to 10 L.S.	-0.942893	0.257327	-3.66	0.000	0.39	0.24	0.64
1 to 100 L.S.	-0.643261	0.235261	-2.73	0.006	0.53	0.33	0.83
1 to 2000 L.S.	-0.465152	0.323357	-1.44	0.150	0.63	0.33	1.18
Pure L.S.	-0.723195	0.249033	-2.90	0.004	0.49	0.30	0.79
1 to 1000 L.S.	-0.888136	0.335276	-2.65	0.008	0.41	0.21	0.79
Control	-1.51207	0.261207	-5.79	0.000	0.22	0.13	0.37
1 to 10 L.S. Heat	-0.524524	0.258940	-2.03	0.043	0.59	0.36	0.98
1 to 100 L.S. Heat	-0.430998	0.240841	-1.79	0.074	0.65	0.41	1.04

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 2000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event	497	
Non-event	2143	
events Total	2640	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.20767	0.203867	-5.92	0.000			
Trial							
2	-1.44513	0.275991	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230767	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232722	1.80	0.071	1.52	0.96	2.40
Treatment (1 to 2000 L.S.)							
Pure L.S.	-0.258043	0.334429	-0.77	0.440	0.77	0.40	1.49
1 to 1000 L.S.	-0.422984	0.265031	-1.60	0.110	0.66	0.39	1.10
Control	-1.04692	0.283806	-3.69	0.000	0.35	0.20	0.61
1 to 10 L.S. Heat	-0.0593726	0.341870	-0.17	0.862	0.94	0.48	1.84
1 to 100 L.S. Heat	0.0341535	0.328375	0.10	0.917	1.03	0.54	1.97
Heat	0.465152	0.323357	1.44	0.150	1.59	0.84	3.00
Pure L.S. Heat	0.139451	0.303278	0.46	0.646	1.15	0.63	2.08
1 to 10 L.S.	-0.477741	0.340650	-1.40	0.161	0.62	0.32	1.21
1 to 100 L.S.	-0.178109	0.246370	-0.72	0.470	0.84	0.52	1.36

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 1000 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		497
Non-event		2143
events Total		2640

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-1.63066	0.223727	-7.29	0.000			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment(1 to 1000 L.S.)							
Control	-0.623939	0.297475	-2.10	0.036	0.54	0.30	0.96
1 to 10 L.S. Heat	0.363612	0.353165	1.03	0.303	1.44	0.72	2.87
1 to 100 L.S. Heat	0.457138	0.340118	1.34	0.179	1.58	0.81	3.08
Heat	0.888136	0.335276	2.65	0.008	2.43	1.26	4.69
Pure L.S. Heat	0.562435	0.315955	1.78	0.075	1.75	0.94	3.26
1 to 10 L.S.	-0.0547566	0.351984	-0.16	0.876	0.95	0.47	1.89
1 to 100 L.S.	0.244875	0.261709	0.94	0.349	1.28	0.76	2.13
1 to 2000 L.S.	0.422984	0.265030	1.60	0.110	1.53	0.91	2.57
Pure L.S.	0.164941	0.345966	0.48	0.634	1.18	0.60	2.32

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group								
Value	1	2	3	4	5	6	7	8	Total
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event	497	
Non-event	2143	
events Total	2640	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-1.38578	0.195964	-7.07	0.000			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment (1 to 100 L.S.)							
1 to 2000 L.S.	0.178109	0.246369	0.72	0.470	1.19	0.74	1.94
Pure L.S.	-0.0799341	0.250261	-0.32	0.749	0.92	0.57	1.51
1 to 1000 L.S.	-0.244875	0.261709	-0.94	0.349	0.78	0.47	1.31
Control	-0.868814	0.225064	-3.86	0.000	0.42	0.27	0.65
1 to 10 L.S. Heat	0.118737	0.260121	0.46	0.648	1.13	0.68	1.87
1 to 100 L.S. Heat	0.212263	0.242111	0.88	0.381	1.24	0.77	1.99
Heat	0.643261	0.235261	2.73	0.006	1.90	1.20	3.02
Pure L.S. Heat	0.317560	0.206798	1.54	0.125	1.37	0.92	2.06
1 to 10 L.S.	-0.299632	0.258516	-1.16	0.246	0.74	0.45	1.23

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 100 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		497
Non-event		2143
events Total		2640

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-1.17352	0.291199	-4.03	0.000			
Trial							
2	-1.44513	0.275991	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230767	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232722	1.80	0.071	1.52	0.96	2.40
Treatment (1 to 100 L.S. Heat)							
Heat	0.430998	0.240841	1.79	0.074	1.54	0.96	2.47
Pure L.S. Heat	0.105297	0.213125	0.49	0.621	1.11	0.73	1.69
1 to 10 L.S.	-0.511895	0.263604	-1.94	0.052	0.60	0.36	1.00
1 to 100 L.S.	-0.212263	0.242111	-0.88	0.381	0.81	0.50	1.30
1 to 2000 L.S.	-0.0341535	0.328375	-0.10	0.917	0.97	0.51	1.84
Pure L.S.	-0.292197	0.255514	-1.14	0.253	0.75	0.45	1.23
1 to 1000 L.S.	-0.457138	0.340119	-1.34	0.179	0.63	0.33	1.23
Control	-1.08108	0.267393	-4.04	0.000	0.34	0.20	0.57
1 to 10 L.S. Heat	-0.0935261	0.265179	-0.35	0.724	0.91	0.54	1.53

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 10 L.S. dilution is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event	497	
Non-event	2143	
events Total	2640	

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.68541	0.304974	-5.53	0.000			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment (1 to 10 L.S.)							
1 to 100 L.S.	0.299632	0.258516	1.16	0.246	1.35	0.81	2.24
1 to 2000 L.S.	0.477741	0.340650	1.40	0.161	1.61	0.83	3.14
Pure L.S.	0.219698	0.271109	0.81	0.418	1.25	0.73	2.12
1 to 1000 L.S.	0.0547566	0.351984	0.16	0.876	1.06	0.53	2.11
Control	-0.569182	0.282333	-2.02	0.044	0.57	0.33	0.98
1 to 10 L.S. Heat	0.418369	0.280237	1.49	0.135	1.52	0.88	2.63
1 to 100 L.S. Heat	0.511895	0.263604	1.94	0.052	1.67	1.00	2.80
Heat	0.942893	0.257327	3.66	0.000	2.57	1.55	4.25
Pure L.S. Heat	0.617192	0.231592	2.66	0.008	1.85	1.18	2.92

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and 1 to 10 L.S. dilution with heat is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable Value Count

Total Event 497

Non-event 2143

events Total 2640

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.26705	0.306336	-4.14	0.000			
Trial							
2	-1.44513	0.275991	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230767	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232722	1.80	0.071	1.52	0.96	2.40
Treatment (1 to 10 L.S. Heat)							
1 to 100 L.S. Heat	0.0935261	0.265179	0.35	0.724	1.10	0.65	1.85
Heat	0.524524	0.258940	2.03	0.043	1.69	1.02	2.81
Pure L.S. Heat	0.198823	0.233383	0.85	0.394	1.22	0.77	1.93
1 to 10 L.S.	-0.418369	0.280237	-1.49	0.135	0.66	0.38	1.14
1 to 100 L.S.	-0.118737	0.260121	-0.46	0.648	0.89	0.53	1.48
1 to 2000 L.S.	0.0593726	0.341870	0.17	0.862	1.06	0.54	2.07
Pure L.S.	-0.198671	0.272640	-0.73	0.466	0.82	0.48	1.40
1 to 1000 L.S.	-0.363612	0.353166	-1.03	0.303	0.70	0.35	1.39
Control	-0.987550	0.283803	-3.48	0.001	0.37	0.21	0.65

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method Chi-Square DF P

Pearson 16.7520 7 0.019

Deviance 18.6011 7 0.010

Hosmer-Lemeshow 9.1903 6 0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group								
Value	1	2	3	4	5	6	7	8	Total
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs Number Percent Summary Measures

Concordant 744570 69.9 Somers' D 0.46

Discordant 259050 24.3 Goodman-Kruskal Gamma 0.48

Ties 61451 5.8 Kendall's Tau-a 0.14

Total 1065071 100.0

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and pure L.S. is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total Event		497
Non-event		2143
events Total		2640

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.46572	0.298009	-4.92	0.000			
Trial							
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40
Treatment (Pure L.S.)							
1 to 1000 L.S.	-0.164941	0.345966	-0.48	0.634	0.85	0.43	1.67
Control	-0.788880	0.274794	-2.87	0.004	0.45	0.27	0.78
1 to 10 L.S. Heat	0.198671	0.272640	0.73	0.466	1.22	0.71	2.08
1 to 100 L.S. Heat	0.292197	0.255514	1.14	0.253	1.34	0.81	2.21
Heat	0.723195	0.249033	2.90	0.004	2.06	1.27	3.36
Pure L.S. Heat	0.397494	0.222340	1.79	0.074	1.49	0.96	2.30
1 to 10 L.S.	-0.219698	0.271109	-0.81	0.418	0.80	0.47	1.37
1 to 100 L.S.	0.0799341	0.250261	0.32	0.749	1.08	0.66	1.77
1 to 2000 L.S.	0.258043	0.334428	0.77	0.440	1.29	0.67	2.49

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

The following Minitab output is for Black Sage with all treatments from all trials where Trial 1 is compared to all other trials and pure L.S. with heat is compared to all other treatments and the control.

Binary Logistic Regression: Salvia mellifera Total, events versus Trial, Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Total	Event	497
	Non-event	2143
events	Total	2640

Logistic Regression Table

Predictor	Coef	SE Coef	Odds Ratio	95% CI	Z	P	Lower	Upper
Constant	-1.06822	0.262572	-4.07	0.000				
Trial								
2	-1.44513	0.275988	-5.24	0.000	0.24	0.14	0.40	
3	-1.29351	0.230766	-5.61	0.000	0.27	0.17	0.43	
4	0.419748	0.232721	1.80	0.071	1.52	0.96	2.40	
Treatment (Pure L.S. Heat)								
1 to 10 L.S.	-0.617192	0.231592	-2.66	0.008	0.54	0.34	0.85	
1 to 100 L.S.	-0.317560	0.206798	-1.54	0.125	0.73	0.49	1.09	
1 to 2000 L.S.	-0.139451	0.303277	-0.46	0.646	0.87	0.48	1.58	
Pure L.S.	-0.397494	0.222340	-1.79	0.074	0.67	0.43	1.04	
1 to 1000 L.S.	-0.562435	0.315955	-1.78	0.075	0.57	0.31	1.06	
Control	-1.18637	0.235895	-5.03	0.000	0.31	0.19	0.48	
1 to 10 L.S. Heat	-0.198823	0.233383	-0.85	0.394	0.82	0.52	1.30	
1 to 100 L.S. Heat	-0.105297	0.213125	-0.49	0.621	0.90	0.59	1.37	
Heat	0.325701	0.205310	1.59	0.113	1.39	0.93	2.07	

Log-Likelihood = -1134.386

Test that all slopes are zero: G = 285.093, DF = 12, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	16.7520	7	0.019
Deviance	18.6011	7	0.010
Hosmer-Lemeshow	9.1903	6	0.163

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

	Group								
Value	1	2	3	4	5	6	7	8	Total
Event									
Obs	9	26	18	67	94	69	151	63	497
Exp	11.4	22.3	25.8	53.4	92.7	77.4	151.0	63.0	
Non-event									
Obs	321	364	312	263	296	201	299	87	2143
Exp	318.6	367.7	304.2	276.6	297.3	192.6	299.0	87.0	
Total	330	390	330	330	390	270	450	150	2640

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	744570	69.9	Somers' D 0.46
Discordant	259050	24.3	Goodman-Kruskal Gamma 0.48
Ties	61451	5.8	Kendall's Tau-a 0.14
Total	1065071	100.0	

* NOTE * 6 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

Lotus scoparius (Deerweed)

Data

Treatment	Germinted seeds	Treatment	Germinted seeds
Control	1	1 to 10 L.S.	5
Control	1	1 to 10 L.S.	3
Control	4	1 to 10 L.S.	3
Control	4	1 to 10 L.S.	3
Control	6	1 to 10 L.S.	4
Control	0	1 to 10 L.S.	1
Heat	8	1 to 10 L.S.	2
Heat	1	1 to 10 L.S.	8
Heat	3	1 to 100 L.S.	2
Heat	0	1 to 100 L.S.	4
Pure L.S. with Heat	1	1 to 100 L.S.	2
Pure L.S. with Heat	0	1 to 100 L.S.	14
Pure L.S. with Heat	1	1 to 100 L.S.	3
Pure L.S. with Heat	0	1 to 100 L.S.	2
Pure L.S. with Heat	0	1 to 100 L.S.	7
Pure L.S. with Heat	1	1 to 100 L.S.	1
Pure L.S. with Heat	1	1 to 100 L.S.	4
Pure L.S. with Heat	0	1 to 100 L.S.	2
Pure L.S. with Heat	1	Heat	8
Pure L.S. with Heat	0	Heat	1
1 to 10 L.S.	2	Heat	3
1 to 10 L.S.	4	Heat	0

Table A13. Raw data for *Lotus scoparius* (Deerweed) seed germination.

Statistical Analysis

The following Minitab output is for Deerweed with all treatments where the control is compared to all other treatments.

Binary Logistic Regression: Events, Trial versus Treatment

Link Function: Logit

Response Information

Variable	Value	Count
Events	Event	109
	Non-event	1091
Trial	Total	1200

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-2.02438	0.179847	-11.26	0.000			
Treatment							
1 to 100 L.S.	0.181126	0.246163	0.74	0.462	1.20	0.74	1.94
Control	-0.302896	0.317715	-0.95	0.340	0.74	0.40	1.38
Heat	-0.172843	0.353465	-0.49	0.625	0.84	0.42	1.68
Pure L.S. with Heat	-2.05316	0.485525	-4.23	0.000	0.13	0.05	0.33

Log-Likelihood = -346.161

Test that all slopes are zero: G = 38.385, DF = 4, P-Value = 0.000

* NOTE * No goodness of fit test performed.

* NOTE * The model uses all degrees of freedom.

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	64185	54.0	Somers' D 0.29
Discordant	29445	24.8	Goodman-Kruskal Gamma 0.37
Ties	25289	21.3	Kendall's Tau-a 0.05
Total	118919	100.0	

* NOTE * 4 time(s) the standardized Pearson residuals, delta chi-square, delta deviance, delta beta (standardized) and delta beta could not be computed because leverage (Hi) is equal to 1.

D. Seed Bank of RCQ: Potential for Recovery

Data

Table A14. Results from Soil Seed Study. The density of plants for species, clades (Monocot (M) or Dicot (D)), and nativity (yes or no) are included in the table.

			Trial 1																Trial 2															
Clade	Native	Treatment	Control				Heat				Heat/Charate				Charate				Control				Heat				Heat/Charate				Charate			
		Experimental unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
D	Yes	<i>Antirrhinum</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	2	4	2	7	2	3	1	0	0	0	1	0	0	4
M	No	<i>Bromus arenarius</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	1	3	0	3	6
M	No	<i>Bromus madritensis</i> ssp. <i>madritensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	3	0	1	2	0
D	No	<i>Centaurea melitensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	1	2	1	0	3	0	0	0	2	0	0	0
D	No	<i>Centaurea solstitialis</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	3	1	0	1	0
D	No	<i>Conium maculatum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Yes	<i>Cryptantha</i> sp.	0	0	1	2	1	1	0	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	No	<i>Erodium</i> sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
D	No	<i>Hirschfeldia incana</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
D	Yes	<i>Lotus scoparius</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	Yes	<i>Mimulus auranticus</i>	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	No	<i>Oxalis corniculata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	5	0	6	0	5	0	11	2	2	2	3	6	4	1
D	No	<i>Picris echioides</i>	1	0	1	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
M	No	<i>Polypogon interruptus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	4	0	0	4	0	2	0	5	2
D	No	<i>Senecio vulgaris</i>	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	No	<i>Spergula arvensis</i>	2	6	2	21	21	10	2	68	2	1	0	8	12	0	12	9	10	5	5	2	7	35	2	3	1	6	20	0	14	4	14	0
D	No	<i>Stellaria pallida</i>	0	1	0	2	1	1	3	3	1	0	0	4	0	0	0	0	0	2	1	1	2	3	1	0	0	0	3	0	0	0	4	0
D	Unknown	<i>Unknown dicot</i>	3	8	0	8	0	6	5	4	6	0	0	8	3	0	1	7	1	4	1	0	2	4	1	5	3	0	4	0	0	1	1	0
M	No	<i>Vulpia myruos</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	2	6	9	8	7	0	0	6	5	7	6	1	8
Total non-native monocots			4	20	22	34	8	16	22	4	4	0	0	7	4	1	4	21	4	2	4	2	10	10	9	12	1	1	10	9	12	7	12	16
Total monocots			4	20	22	34	8	16	22	4	4	0	0	7	4	1	4	21	4	2	4	2	10	10	9	13	1	1	10	9	12	7	12	16
Total non-native dicots			3	9	4	25	23	12	7	71	4	1	0	12	13	0	13	9	21	16	11	4	16	40	10	3	15	8	25	5	21	11	23	1
Total native dicots			0	0	5	2	1	1	0	2	0	0	0	0	5	0	0	0	3	4	2	4	2	7	2	3	1	0	0	0	1	0	0	4
Total dicots			6	17	9	35	24	19	12	77	10	1	0	20	21	0	14	17	23	24	14	17	20	52	12	11	17	9	31	5	21	12	27	7
Total native			0	0	5	2	1	1	0	2	0	0	0	0	5	0	0	0	3	4	2	4	2	7	2	3	1	0	0	0	1	0	0	4
Total non-native			7	29	26	59	31	28	29	75	8	1	0	19	17	1	17	30	25	18	15	6	26	50	19	15	16	9	35	14	33	18	35	17

Statistical Analysis

The following Minitab output is for non-native dicots.

Binary Logistic Regression: Non-native dicots, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
Total non-native Dicots	Event	443
	Non-event	335
count	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-0.310938	0.152223	-2.04	0.041			
trt_txt							
(1:2)	0.735640	0.186335	3.95	0.000	2.09	1.45	3.01
(1:3)	0.871375	0.260360	3.35	0.001	2.39	1.43	3.98
(1:4)	0.200979	0.208868	0.96	0.336	1.22	0.81	1.84
Trial							
2	0.330192	0.152149	2.17	0.030	1.39	1.03	1.87

Log-Likelihood = -517.174

Test that all slopes are zero: G = 29.149, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	23.9212	3	0.000
Deviance	24.1528	3	0.000
Hosmer-Lemeshow	20.3947	4	0.000

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group						Total
	1	2	3	4	5	6	
Event							
Obs	41	87	58	113	90	54	443
Exp	54.1	71.9	59.9	101.0	102.9	53.2	
Non-event							
Obs	87	60	50	54	63	21	335
Exp	73.9	75.1	48.1	66.0	50.1	21.8	
Total	128	147	108	167	153	75	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	80525	54.3	Somers' D 0.22
Discordant	47669	32.1	Goodman-Kruskal Gamma 0.26
Ties	20211	13.6	Kendall's Tau-a 0.11
Total	148405	100.0	

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

The following Minitab output is for monocots.

Binary Logistic Regression: Monocot, total plants versus Block, trt_txt

Link Function: Logit

Response Information

Variable	Value	Count
monocot	Event	291
	Non-event	487
total plants per eu	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	0.998320	0.251908	3.96	0.000			
Block							
2	-0.620754	0.312810	-1.98	0.047	0.54	0.29	0.99
3	-1.73523	0.275022	-6.31	0.000	0.18	0.10	0.30
4	-1.58286	0.253218	-6.25	0.000	0.21	0.13	0.34
trt_txt							
(1:2)	-0.460680	0.198824	-2.32	0.021	0.63	0.43	0.93
(1:3)	-0.286667	0.267641	-1.07	0.284	0.75	0.44	1.27
(1:4)	-0.0345315	0.220759	-0.16	0.876	0.97	0.63	1.49

Log-Likelihood = -476.570

Test that all slopes are zero: G = 75.483, DF = 6, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	60.9817	9	0.000
Deviance	63.5914	9	0.000
Hosmer-Lemeshow	35.6182	6	0.000

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group								Total
	1	2	3	4	5	6	7	8	
Event									
Obs	12	40	28	38	47	12	47	67	291
Exp	25.3	32.5	27.1	26.7	37.8	27.6	47.0	67.0	
Non-event									
Obs	97	85	66	45	61	65	39	29	487
Exp	83.7	92.5	66.9	56.3	70.2	49.4	39.0	29.0	
Total	109	125	94	83	108	77	86	96	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	89035	62.8	Somers' D 0.34
Discordant	41145	29.0	Goodman-Kruskal Gamma 0.37
Ties	11537	8.1	Kendall's Tau-a 0.16
Total	141717	100.0	

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

The following Minitab output is for total native plants where the control is compared to all other treatments.

Binary Logistic Regression: total native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
total native Dicots	Event	47
	Non-event	731
total plants per eu	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-2.69557	0.301534	-8.94	0.000			
trt_txt							
(1:2)	-0.561462	0.342417	-1.64	0.101	0.57	0.29	1.12
(1:3)	-2.73689	1.03804	-2.64	0.008	0.06	0.01	0.50
(1:4)	-1.06468	0.440267	-2.42	0.016	0.34	0.15	0.82
Trial							
2	0.996760	0.324518	3.07	0.002	2.71	1.43	5.12

Log-Likelihood = -166.383

Test that all slopes are zero: G = 22.154, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	11.0594	3	0.011
Deviance	9.0603	3	0.028
Hosmer-Lemeshow	2.8489	4	0.583

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	1	2	3	4	5	6	Total
Event							
Obs	1	9	3	7	14	13	47
Exp	1.0	7.8	6.4	8.1	11.8	11.9	
Non-event							
Obs	102	228	105	121	111	64	731
Exp	102.0	229.2	101.6	119.9	113.2	65.1	
Total	103	237	108	128	125	77	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	21696	63.1	Somers' D 0.40
Discordant	8062	23.5	Goodman-Kruskal Gamma 0.46
Ties	4599	13.4	Kendall's Tau-a 0.05
Total	34357	100.0	

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

The following Minitab output is for total native plants where the heat treatment is compared to all other treatments.

Binary Logistic Regression: total native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
total native Dicots	Event	47
	Non-event	731
total plants per eu	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend: trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Odds	Z	P Ratio	95% CI	Lower	Upper
Constant	-3.25703	0.321639		-10.13	0.000			
trt_txt								
(1:3)	-2.17543	1.03769	-2.10	0.036	0.11	0.01	0.87	
(1:4)	-0.503217	0.440867	-1.14	0.254	0.60	0.25	1.43	
(1:1)	0.561462	0.342417	1.64	0.101	1.75	0.90	3.43	
Trial								
2	0.996760	0.324518	3.07	0.002	2.71	1.43	5.12	

Log-Likelihood = -166.383

Test that all slopes are zero: G = 22.154, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	11.0594	3	0.011
Deviance	9.0603	3	0.028
Hosmer-Lemeshow	2.8489	4	0.583

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group						Total
	1	2	3	4	5	6	
Event							
Obs	1	9	3	7	14	13	47
Exp	1.0	7.8	6.4	8.1	11.8	11.9	
Non-event							
Obs	102	228	105	121	111	64	731
Exp	102.0	229.2	101.6	119.9	113.2	65.1	
Total	103	237	108	128	125	77	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	21696	63.1	Somers' D 0.40
Discordant	8062	23.5	Goodman-Kruskal Gamma 0.46
Ties	4599	13.4	Kendall's Tau-a 0.05
Total	34357	100.0	

The following Minitab output is for total native plants where the heat/charate treatment is compared to all other treatments.

Binary Logistic Regression: total native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
total native Dicots	Event	47
	Non-event	731
total plants per eu	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-5.43246	1.04498	-5.20	0.000			
trt_txt							
(1:4)	1.67221	1.06935	1.56	0.118	5.32	0.65	43.30
(1:1)	2.73689	1.03804	2.64	0.008	15.44	2.02	118.09
(1:2)	2.17543	1.03769	2.10	0.036	8.81	1.15	67.31
Trial							
2	0.996760	0.324518	3.07	0.002	2.71	1.43	5.12

Log-Likelihood = -166.383

Test that all slopes are zero: G = 22.154, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	11.0594	3	0.011
Deviance	9.0603	3	0.028
Hosmer-Lemeshow	2.8489	4	0.583

Table of Observed and Expected Frequencies:
(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

		Group						
Value		1	2	3	4	5	6	Total
Event								
Obs		1	9	3	7	14	13	47
Exp		1.0	7.8	6.4	8.1	11.8	11.9	
Non-event								
Obs		102	228	105	121	111	64	731
Exp		102.0	229.2	101.6	119.9	113.2	65.1	
Total		103	237	108	128	125	77	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	21696	63.1	Somers' D 0.40
Discordant	8062	23.5	Goodman-Kruskal Gamma 0.46
Ties	4599	13.4	Kendall's Tau-a 0.05
Total	34357	100.0	

The following Minitab output is for total native plants where the charate treatment is compared to all other treatments.

Binary Logistic Regression: total native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
total native Dicots	Event	47
	Non-event	731
total plants per eu	Total	778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-3.76024	0.445409	-8.44	0.000			
trt_txt							
(1:1)	1.06468	0.440267	2.42	0.016	2.90	1.22	6.87
(1:2)	0.503217	0.440867	1.14	0.254	1.65	0.70	3.92
(1:3)	-1.67221	1.06935	-1.56	0.118	0.19	0.02	1.53
Trial							
2	0.996760	0.324518	3.07	0.002	2.71	1.43	5.12

Log-Likelihood = -166.383

Test that all slopes are zero: G = 22.154, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	11.0594	3	0.011
Deviance	9.0603	3	0.028
Hosmer-Lemeshow	2.8489	4	0.583

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

		Group						
Value		1	2	3	4	5	6	Total
Event								
Obs		1	9	3	7	14	13	47
Exp		1.0	7.8	6.4	8.1	11.8	11.9	
Non-event								
Obs		102	228	105	121	111	64	731
Exp		102.0	229.2	101.6	119.9	113.2	65.1	
Total		103	237	108	128	125	77	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	21696	63.1	Somers' D 0.40
Discordant	8062	23.5	Goodman-Kruskal Gamma 0.46
Ties	4599	13.4	Kendall's Tau-a 0.05
Total	34357	100.0	

The following Minitab output is for total non-native plants where the control is compared to all other treatments.

Binary Logistic Regression: Total Non-native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
GrandTotalNon-native Event		732
Non-event		46
total plants per eu Total		778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	2.65587	0.299323	8.87	0.000			
trt_txt							
(1:2)	0.751828	0.357918	2.10	0.036	2.12	1.05	4.28
(1:3)	2.71505	1.03816	2.62	0.009	15.11	1.97	115.57
(1:4)	0.812040	0.410721	1.98	0.048	2.25	1.01	5.04
Trial							
2	-0.926318	0.326883	-2.83	0.005	0.40	0.21	0.75

Log-Likelihood = -164.575

Test that all slopes are zero: G = 20.258, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	6.34517	3	0.096
Deviance	5.56830	3	0.135
Hosmer-Lemeshow	5.37852	5	0.371

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group							Total
	1	2	3	4	5	6	7	
Event								
Obs	64	114	103	121	163	139	28	732
Exp	65.4	115.4	100.1	119.6	161.6	142.0	27.9	
Non-event								
Obs	13	11	5	7	4	6	0	46
Exp	11.6	9.6	7.9	8.4	5.4	3.0	0.1	
Total	77	125	108	128	167	145	28	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	20289	60.3	Somers' D 0.37
Discordant	7809	23.2	Goodman-Kruskal Gamma 0.44
Ties	5574	16.6	Kendall's Tau-a 0.04
Total	33672	100.0	

The following Minitab output is for total non-native plants where the heat treatment compared to all other treatments.

Binary Logistic Regression: Total Non-native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
GrandTotalNon-native Event		732
Non-event		46
total plants per eu Total		778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	3.40770	0.337185	10.11	0.000			
trt_txt							
(1:3)	1.96323	1.04300	1.88	0.060	7.12	0.92	55.01
(1:4)	0.0602121	0.424493	0.14	0.887	1.06	0.46	2.44
(1:1)	-0.751828	0.357918	-2.10	0.036	0.47	0.23	0.95
Trial							
2	-0.926318	0.326883	-2.83	0.005	0.40	0.21	0.75

Log-Likelihood = -164.575

Test that all slopes are zero: G = 20.258, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	6.34517	3	0.096
Deviance	5.56830	3	0.135
Hosmer-Lemeshow	5.37852	5	0.371

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

		Group							
Value		1	2	3	4	5	6	7	Total
Event									
Obs	64	114	103	121	163	139	28	732	
Exp	65.4	115.4	100.1	119.6	161.6	142.0	27.9		
Non-event									
Obs	13	11	5	7	4	6	0	46	
Exp	11.6	9.6	7.9	8.4	5.4	3.0	0.1		
Total	77	125	108	128	167	145	28	778	

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	20289	60.3	Somers' D 0.37
Discordant	7809	23.2	Goodman-Kruskal Gamma 0.44
Ties	5574	16.6	Kendall's Tau-a 0.04
Total	33672	100.0	

The following Minitab output is for total non-native plants where the heat treatment is compared to all other treatments.

Binary Logistic Regression: Total Non-native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
GrandTotalNon-native Event		732
Non-event		46
total plants per eu Total		778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	5.37093	1.04481	5.14	0.000			
trt_txt							
(1:4)	-1.90301	1.05759	-1.80	0.072	0.15	0.02	1.19
(1:1)	-2.71505	1.03816	-2.62	0.009	0.07	0.01	0.51
(1:2)	-1.96323	1.04300	-1.88	0.060	0.14	0.02	1.08
Trial							
2	-0.926318	0.326883	-2.83	0.005	0.40	0.21	0.75

Log-Likelihood = -164.575

Test that all slopes are zero: G = 20.258, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	6.34517	3	0.096
Deviance	5.56830	3	0.135
Hosmer-Lemeshow	5.37852	5	0.371

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group							Total
	1	2	3	4	5	6	7	
Event								
Obs	64	114	103	121	163	139	28	732
Exp	65.4	115.4	100.1	119.6	161.6	142.0	27.9	
Non-event								
Obs	13	11	5	7	4	6	0	46
Exp	11.6	9.6	7.9	8.4	5.4	3.0	0.1	
Total	77	125	108	128	167	145	28	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	20289	60.3	Somers' D 0.37
Discordant	7809	23.2	Goodman-Kruskal Gamma 0.44
Ties	5574	16.6	Kendall's Tau-a 0.04
Total	33672	100.0	

The following Minitab output is for total non-native plants where the charate treatment is compared to all other treatments.

Binary Logistic Regression: Total Non-native, total plants versus trt_txt, Trial

Link Function: Logit

Response Information

Variable	Value	Count
GrandTotalNon-native Event		732
Non-event		46
total plants per eu Total		778

* NOTE * 31 cases were used

* NOTE * 1 cases contained missing values

Legend:	
trt_txt	Treatment
(1:1)	Control
(1:2)	Heat
(1:3)	Heat/Charate
(1:4)	Charate

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	3.46791	0.414678	8.36	0.000			
trt_txt							
(1:1)	-0.812040	0.410721	-1.98	0.048	0.44	0.20	0.99
(1:2)	-0.0602121	0.424493	-0.14	0.887	0.94	0.41	2.16
(1:3)	1.90301	1.05759	1.80	0.072	6.71	0.84	53.30
Trial							
2	-0.926318	0.326883	-2.83	0.005	0.40	0.21	0.75

Log-Likelihood = -164.575

Test that all slopes are zero: G = 20.258, DF = 4, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P	Meets expectations!
Pearson	6.34517	3	0.096	
Deviance	5.56830	3	0.135	
Hosmer-Lemeshow	5.37852	5	0.371	

Table of Observed and Expected Frequencies:

(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

Value	Group							Total
	1	2	3	4	5	6	7	
Event								
Obs	64	114	103	121	163	139	28	732
Exp	65.4	115.4	100.1	119.6	161.6	142.0	27.9	
Non-event								
Obs	13	11	5	7	4	6	0	46
Exp	11.6	9.6	7.9	8.4	5.4	3.0	0.1	
Total	77	125	108	128	167	145	28	778

Measures of Association:

(Between the Response Variable and Predicted Probabilities)

Pairs	Number	Percent	Summary Measures
Concordant	20289	60.3	Somers' D 0.37
Discordant	7809	23.2	Goodman-Kruskal Gamma 0.44
Ties	5574	16.6	Kendall's Tau-a 0.04
Total	33672	100.0	

Field Survey

Figure A1. Relative density of shrubs and perennials recruited in 2006 (Elster, 2007).

Figure A2. Relative density of shrubs and perennials recruited in 2007 (Elster, 2007).

Figure A3. Relative cover of shrubs and perennials in 2007 (Elster, 2007).

E. In Situ Effects of Seeding and Charate

Data and Statistical Summary

Row	Column	Seed	Charate	Native	Non-native	Total	Residual of non-native	Residual of native	Residual of total
1	A	1	0	4	2	4	-0.125	1.5	0.75
1	B	1	1	0	2	2	-0.125	-0.75	-0.25
1	C	0	0	0	2	2	0.375	-0.25	-4.44E-16
1	D	0	1	0	2	2	-0.125	-0.5	-0.5
2	A	0	1	0	2	2	0.375	-1	-0.25
2	B	0	0	0	1	1	0.125	0.25	0.25
2	C	1	1	2	1	2	-0.375	0.75	0
2	D	1	0	2	1	2	-0.125	4.44E-16	0
3	A	1	1	2	2	2	0.375	-0.25	8.88E-16
3	B	0	1	2	1	2	-0.375	1	0.25
3	C	1	0	2	1	2	-0.125	-1	-0.5
3	D	0	0	0	1	1	0.125	0.25	0.25
4	A	0	0	1	1	1	-0.625	-0.25	-0.5
4	B	1	0	2	2	2	0.375	-0.5	-0.25
4	C	0	1	2	2	3	0.125	0.5	0.5
4	D	1	1	2	2	2	0.125	0.25	0.25

Table A15. Data for In Situ Effects of Seeding and Charate. Blocks, factorial treatments, cover class data for all categories, and residuals for all cover class categories based on blocks.

Statistical Analysis

The following Minitab output is for the cover of non-native plants for factorial treatments with charate and seed blocked by both row and column.

General Linear Model: non-native versus row, column, seed, charate

Factor Type Levels Values
row fixed 4 1, 2, 3, 4
column fixed 4 A, B, C, D
seed fixed 2 0, 1
charate fixed 2 0, 1

Analysis of Variance for non-native, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
row	3	1.6875	1.6875	0.5625	2.45	0.161
column	3	0.1875	0.1875	0.0625	0.27	0.843
seed	1	0.0625	0.0625	0.0625	0.27	0.620
charate	1	0.5625	0.5625	0.5625	2.45	0.168
seed*charate	1	0.0625	0.0625	0.0625	0.27	0.620
Error	6	1.3750	1.3750	0.2292		
Total	15	3.9375				

S = 0.478714 R-Sq = 65.08% R-Sq(adj) = 12.70%

Unusual Observations for non-native

Obs	non-native	Fit	SE Fit	Residual	St Resid
13	1.00000	1.62500	0.37846	-0.62500	-2.13 R

R denotes an observation with a large standardized residual.

Expected Mean Squares, using Adjusted SS

Source	Expected Mean Square for Each Term
row	0.5625
column	0.0625
seed	0.0625
charate	0.5625
seed*charate	0.0625
Error	0.2292
Total	3.9375

1	row	(6) + Q[1]
2	column	(6) + Q[2]
3	seed	(6) + Q[3, 5]
4	charate	(6) + Q[4, 5]
5	seed*charate	(6) + Q[5]
6	Error	(6)

Error Terms for Tests, using Adjusted SS

Source	Error DF	Error MS	of Error MS
1 row	6.00	0.2292	(6)
2 column	6.00	0.2292	(6)
3 seed	6.00	0.2292	(6)
4 charate	6.00	0.2292	(6)
5 seed*charate	6.00	0.2292	(6)

Variance Components, using Adjusted SS

Source	Value
Error	0.2292

Least Squares Means for non-native

seed	Mean	SE Mean
0	1.500	0.1693
1	1.625	0.1693

charate	Mean	SE Mean
0	1.375	0.1693
1	1.750	0.1693

seed*charate	Mean	SE Mean
0 0	1.250	0.2394
0 1	1.750	0.2394
1 0	1.500	0.2394
1 1	1.750	0.2394

The following Minitab output is for the cover of native plants for factorial treatments with charate and seed blocked by both row and column.

General Linear Model: native versus row, column, seed, charate

Factor Type Levels Values
row fixed 4 1, 2, 3, 4
column fixed 4 A, B, C, D
seed fixed 2 0, 1
charate fixed 2 0, 1

Analysis of Variance for Native, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Column	3	1.688	1.687	0.562	0.56	0.655
Seed	1	7.562	7.562	7.562	7.51	0.023
Charate	1	0.062	0.062	0.062	0.06	0.809
Seed*Charate	1	3.062	3.062	3.062	3.04	0.115
Error	9	9.063	9.063	1.007		
Total	15	21.438				

S = 1.00347 R-Sq = 57.73% R-Sq(adj) = 29.54%

Least Squares Means for Native

Seed	Mean	SE Mean
0	0.6250	0.3548
1	2.0000	0.3548

Charate	Mean	SE Mean
0	1.3750	0.3548
1	1.2500	0.3548

Seed*Charate	Mean	SE Mean
0 0	0.2500	0.5017
0 1	1.0000	0.5017
1 0	2.5000	0.5017
1 1	1.5000	0.5017

Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable Native
All Pairwise Comparisons among Levels of Seed

Seed = 0 subtracted from:

Seed	Lower	Center	Upper
1	0.2400	1.375	2.510

-----+-----+-----+-----+
 (-----*-----)
 -----+-----+-----+-----+
 0.70 1.40 2.10

Tukey 95.0% Simultaneous Confidence Intervals
 Response Variable Native
 All Pairwise Comparisons among Levels of Seed
 Seed = 0 subtracted from:

Seed	Lower	Center	Upper
1	0.2400	1.375	2.510

-----+-----+-----+-----+
 (-----*-----)
 -----+-----+-----+-----+
 0.70 1.40 2.10

Bonferroni 90.0% Simultaneous Confidence Intervals (Fisher 5%)
 Response Variable Native
 All Pairwise Comparisons among Levels of Seed
 Seed = 0 subtracted from:

Seed	Lower	Center	Upper
1	0.2978	1.375	2.452

-----+-----+-----+-----+
 (-----*-----)
 -----+-----+-----+-----+
 0.60 1.20 1.80 2.40

The following Minitab output is for the total cover plants for factorial treatments with charate and seed blocked by both row and column.

General Linear Model: total versus row, column, seed, charate

Factor Type Levels Values
row fixed 4 1, 2, 3, 4
column fixed 4 A, B, C, D
seed fixed 2 0, 1
charate fixed 2 0, 1

Analysis of Variance for total, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
row	3	1.5000	1.5000	0.5000	1.50	0.307
column	3	1.0000	1.0000	0.3333	1.00	0.455
seed	1	1.0000	1.0000	1.0000	3.00	0.134
charate	1	0.2500	0.2500	0.2500	0.75	0.420
seed*charate	1	2.2500	2.2500	2.2500	6.75	0.041
Error	6	2.0000	2.0000	0.3333		
Total	15	8.0000				

S = 0.577350 R-Sq = 75.00% R-Sq(adj) = 37.50%

Unusual Observations for total

Obs	total	Fit	SE Fit	Residual	St Resid
1	4.00000	3.25000	0.45644	0.75000	2.12 R

R denotes an observation with a large standardized residual.

Expected Mean Squares, using Adjusted SS

Source	Expected Mean Square for Each Term
1 row	(6) + Q[1]
2 column	(6) + Q[2]
3 seed	(6) + Q[3, 5]
4 charate	(6) + Q[4, 5]
5 seed*charate	(6) + Q[5]
6 Error	(6)

Error Terms for Tests, using Adjusted SS

Synthesis			
Source	Error DF	Error MS	of Error MS
1 row	6.00	0.3333 (6)	
2 column	6.00	0.3333 (6)	
3 seed	6.00	0.3333 (6)	
4 charate	6.00	0.3333 (6)	
5 seed*charate	6.00	0.3333 (6)	

Variance Components, using Adjusted SS

Estimated	
Source	Value
Error	0.3333

Least Squares Means for total

seed	Mean	SE Mean
0	1.750	0.2041
1	2.250	0.2041
charate		
0	1.875	0.2041
1	2.125	0.2041
seed*charate		
0 0	1.250	0.2887
0 1	2.250	0.2887
1 0	2.500	0.2887
1 1	2.000	0.2887

Bonferroni 95.0% Simultaneous Confidence Intervals

Response Variable Total

All Pairwise Comparisons among Levels of Seed*Charate

Seed = 0

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
0	1	-0.5771	1.0000	2.577	(-----*-----)
1	0	-0.3271	1.2500	2.827	(-----*-----)
1	1	-0.8271	0.7500	2.327	(-----*-----)

-----+-----+-----+-----+-----
-1.5 0.0 1.5 3.0

Seed = 0

Charate = 1 subtracted from:

Seed	Charate	Lower	Center	Upper	
1	0	-1.327	0.2500	1.827	(-----*-----)
1	1	-1.827	-0.2500	1.327	(-----*-----)

-----+-----+-----+-----+-----
-1.5 0.0 1.5 3.0

Seed = 1

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
1	1	-2.077	-0.5000	1.077	(-----*-----)

-----+-----+-----+-----+-----
-1.5 0.0 1.5 3.0

Tukey 95.0% Simultaneous Confidence Intervals

Response Variable Total

All Pairwise Comparisons among Levels of Seed*Charate

Seed = 0

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
0	1	-0.4145	1.0000	2.415	(-----*-----)
1	0	-0.1645	1.2500	2.665	(-----*-----)
1	1	-0.6645	0.7500	2.165	(-----*-----)

-----+-----+-----+-----+-----
-1.5 0.0 1.5 3.0

Seed = 0

Charate = 1 subtracted from:

Seed	Charate	Lower	Center	Upper	
1	0	-1.165	0.2500	1.665	(-----*-----)

1	1	-1.665	-0.2500	1.165	(-----*-----)
					-----+-----+-----+-----+-----
					-1.5 0.0 1.5 3.0

Seed = 1

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
1	1	-1.915	-0.5000	0.9145	(-----*-----)
					-----+-----+-----+-----+-----
					-1.5 0.0 1.5 3.0

Bonferroni 80.0% Simultaneous Confidence Intervals (Fisher 5%)

Response Variable Total

All Pairwise Comparisons among Levels of Seed*Charate

Seed = 0

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
0	1	-0.1223	1.0000	2.122	(-----*-----)
1	0	0.1277	1.2500	2.372	(-----*-----)
1	1	-0.3723	0.7500	1.872	(-----*-----)
					-----+-----+-----+-----+-----

Seed	Charate	Lower	Center	Upper	
1	0	-0.872	0.2500	1.3723	(-----*-----)
1	1	-1.372	-0.2500	0.8723	(-----*-----)
					-----+-----+-----+-----+-----
					-1.2 0.0 1.2 2.4

Seed = 1

Charate = 0 subtracted from:

Seed	Charate	Lower	Center	Upper	
1	1	-1.622	-0.5000	0.6223	(-----*-----)
					-----+-----+-----+-----+-----
					-1.2 0.0 1.2 2.4

F. Fire Effects on a Restored Area a Decade after Seeding

Data

	Plant Density		Native Plant Density		Non-native Plant Density		Density of Preferred Plants		Species Richness	
Treatment	0.5 m	1 m	0.5 m	1 m	0.5 m	1 m	0.5 m	1 m	0.5 m	1 m
Control	1	2	0	0	0	0	0	0	1	1
Control	21	2	0	0	0	2	0	0	1	1
Control	31	114	1	19	5	30	0	0	3	3
Control	5	9	5	9	0	0	0	1	2	2
Fertilizer	15	43	5	5	0	3	0	5	2	3
Fertilizer	87	340	0	1	2	4	0	0	3	4
Fertilizer	48	163	0	15	0	0	0	15	1	2
Fertilizer	0	2	0	0	0	0	0	0	0	1
Fertilizer	86	271	1	4	35	167	0	1	5	7
Fertilizer	5	0	5	0	0	0	5	0	1	0
Fire	0	12	0	0	0	0	0	0	0	1
Fire	1	4	1	1	0	0	0	1	1	2
Fire	21	95	5	9	1	31	3	5	6	6
Fire	22	140	6	7	1	21	0	6	4	6
Fire	0	1	0	1	0	0	0	0	0	1
Fire	0	6	0	0	0	0	0	0	0	1
Low	3	41	1	13	0	2	0	0	2	3
Low	1	0	1	0	0	0	0	0	1	0
Low	3	9	0	0	0	0	0	0	1	1
Low	4	54	3	8	1	1	0	2	3	5
Moderate	2	9	0	1	0	0	0	1	1	2
Moderate	11	31	1	1	0	0	0	1	2	2
Moderate	25	42	0	1	0	0	0	1	1	2
Moderate	1	1	0	1	0	0	0	0	1	1
High	37	105	0	3	2	2	0	3	2	3
High	5	7	0	0	0	0	0	0	1	1
High	12	41	0	3	0	0	0	0	1	3
High	9	25	0	0	0	1	0	0	2	3

Table A16. Summarized data for Fire Effects on a Restored Area a Decade after Seeding.

Statistical Analysis

Kruskal-Wallis Test: 0.5 m sq plot plant density versus Treatment

Kruskal-Wallis Test on 0.5 m

Treatment	N	Median	Ave Rank	Z
-----------	---	--------	----------	---

Control	4	13.0000	16.3	0.46
---------	---	---------	------	------

Fertilizer	6	31.5000	19.4	1.65
------------	---	---------	------	------

Fire	6	0.5000	9.4	-1.71
------	---	--------	-----	-------

High	4	10.5000	18.3	0.98
------	---	---------	------	------

Low	4	3.0000	9.9	-1.21
-----	---	--------	-----	-------

Moderate	4	6.5000	13.9	-0.16
----------	---	--------	------	-------

Overall	28		14.5	
---------	----	--	------	--

H = 6.73 DF = 5 P = 0.241

H = 6.78 DF = 5 P = 0.237 (adjusted for ties)

Kruskal-Wallis Test: 1 m sq plot plant density versus Treatment

Kruskal-Wallis Test on 1 m

Treatment	N	Median	Ave Rank	Z
-----------	---	--------	----------	---

Control	4	5.500	12.0	-0.66
---------	---	-------	------	-------

Fertilizer	6	103.000	18.1	1.20
------------	---	---------	------	------

Fire	6	9.000	13.6	-0.31
------	---	-------	------	-------

High	4	33.000	16.4	0.49
------	---	--------	------	------

Low	4	25.000	13.0	-0.39
-----	---	--------	------	-------

Moderate	4	20.000	12.6	-0.49
----------	---	--------	------	-------

Overall	28		14.5	
---------	----	--	------	--

H = 2.13 DF = 5 P = 0.831

H = 2.14 DF = 5 P = 0.830 (adjusted for ties)

Kruskal-Wallis Test: 0.5 m sq plot cover class versus Treatment

Kruskal-Wallis Test on cover class

trt	N	Median	Ave Rank	Z
-----	---	--------	----------	---

Control	4	0.5000	14.5	-0.24
---------	---	--------	------	-------

Fertilizer	6	2.0000	23.3	2.44
------------	---	--------	------	------

Fire	6	0.2500	12.3	-1.01
------	---	--------	------	-------

High	5	0.5000	14.7	-0.22
------	---	--------	------	-------

Low	4	0.5000	14.5	-0.24
-----	---	--------	------	-------

Moderate	5	0.5000	12.4	-0.86
----------	---	--------	------	-------

Overall	30		15.5	
---------	----	--	------	--

H = 6.33 DF = 5 P = 0.275

H = 7.18 DF = 5 P = 0.208 (adjusted for ties)

Kruskal-Wallis Test: 1 m sq plot cover class versus Treatment

Kruskal-Wallis Test on cover class_1

trt_1	N	Median	Ave Rank	Z
-------	---	--------	----------	---

Control	4	0.5000	12.5	-0.63
---------	---	--------	------	-------

Fertilizer	5	1.0000	22.7	2.22
------------	---	--------	------	------

Fire	6	0.5000	16.2	0.38
------	---	--------	------	------

High	5	0.5000	13.3	-0.49
------	---	--------	------	-------

Low	4	0.5000	14.0	-0.25
-----	---	--------	------	-------

Moderate	5	0.5000	10.4	-1.33
----------	---	--------	------	-------

Overall	29		15.0	
---------	----	--	------	--

H = 6.26 DF = 5 P = 0.282

H = 8.27 DF = 5 P = 0.142 (adjusted for ties)