FINAL

JOHNSON RANCH RESTORATION STUDY

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Prepared for:

RIVERSIDE COUNTY REGIONAL PARK & OPEN SPACE DISTRICT

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Introduction

Purpose

The Riverside County Regional Park and Open Space District contracted EcoSystems Restoration Associates (ERA) and AMEC Earth & Environmental (AMEC) to conduct a study on the restoration of Riversidian Sage Scrub (RSS) at Johnson Ranch (Figure 1). Johnson Ranch is a 700 acre site located in Riverside County previously used for agricultural purposes. Due to the application of biosolids as fertilizer, soils here have the potential to contain high levels of nutrients, which provide a competitive advantage for non-native weeds over native plants. Remedial measures analyzed in this study included: removal of biosolids (topsoil "scraping"), direct seeding and mycorrhizal inoculation. This produced a 2-way blocked design that was systematically applied, with a control, to 8 plots.

Background Information

Johnson Ranch is a 700 acre site, located in Riverside County, previously used for agricultural purposes. Native RSS was removed, and soils enriched with bio-solids (fertilizer/manure) to facilitate the growing potential of the area. What remains is a fallow field, with little topography, co-dominated by wild oat (*Avena sp*) and rye grass (*Lolium sp*). The persistence of non-native grasses on this site is an important management issue for several reasons: 1) Native RSS has been reduced to a mere fraction of its former coverage due to rapid urbanization in the area (Minnich 1998; Swenson 2000). If reclaimed, Johnson Ranch could serve as an enclave for this habitat type. 2) Non-native annual grasses and forbs are known to increase fire frequency by generating copious amounts of dry standing biomass which carries fire rapidly due to high surface area: volume ratio (D'Antonio 1992; Franklin 2001). To this end, extensive grass invasions, such as Johnson Ranch, may pose a significant threat to neighboring lands, including residential areas. 3) Finally, it is well known that invasion of non-native annuals alters the potential of an area to provide important services, and may have serious negative effects to bordering areas. Loss of ecological services could mean: leaching of nutrients, failure to stop erosion (in fact invasion can ultimately lead to worse erosion and dust), and alterations in the hydrological regime (Vitousek 1997; Franklin 2001). Such alterations are deleterious both to the natural habitat and human economy.

Conversion of Johnson Ranch from RSS to an exotic grassland can be attributed to several factors. Initially, mature RSS plants had to be cleared, and the soil homogenized for farming. Homogenization of soil topography destroys the patchy nature of the landscape, and makes it difficult for native plants to get established. Agricultural areas are not re-colonized by native species, largely because they are excluded for a long enough time that the native seed bank is lost. In addition, consistent soil ripping, fertilization and herbicide application encourages the introduction of disturbance resistant, nutrient-loving invaders, such as those found on the Johnson Ranch Site.

In order to ameliorate these effects, soil structure and function should be returned to a near-natural condition. Several goals should be used when exerting such an effort: 1) reducing nutrient residuals that encourage the proliferation of non-native species 2) returning soil micro-topography via land/seed imprinting in order to provide effective germination sites for native seeds 3) restoring the native seed bank (seed imprinting) 4) knocking back the nonnative seed bank and 5) restoring native soil flora (including mycorrhizae).

A cost effective method to restore the Johnson Ranch area must take these factors into account. Strategies should focus on encouraging the re-colonization of the Johnson Ranch area by native plant species, while simultaneously making it more difficult for exotic species to persist.

Materials and Methods

Eight experimental plots were located on a continuum within the 700 acre Johnson Ranch Site (Figure 2). Initially, the experiment was intended to have 2x3 factorial treatments with a control for a total of 7 sub-plots. However, since suitable topsoil for one of the three soil treatments was not available and it was decided to exclude a crop-plant treatment, the experiment was modified. Instead a 2X2 factorial design was implemented with biosolid removal (e.g. “scraping”) and mycorrhizal innoculum (which replaced imported topsoil) as two levels of treatment. Control for direct seeding was unbalanced, since each treatment subplot received seeds, and only the “ambient” control sub-plot did not. Ultimately, 5 $10m^2$ sub-plots per plot were used to deliver the following treatments: a) biosolid removal (w/seeding), b) existing soil (w/seeding), c) biosolid removal and mycorrhizal innoculum (w/ seeding) d) existing soil and mycorrhizal innoculum (w/seeding) and e) “ambient recruitment” (e.g. no seed or treatment).

Systematic Soil Treatments:

Soil treatment was administered in a 2X2 block design. Treatments were as follows: a) biosolid removal, b) control c) biosolid removal and mycorrhizal innoculum, and d) mycorrhizal innoculum.

Bio-solid removal

Topsoil was scraped from the appropriate subplots using a compact tractor equipped with 8 feet wide scrapping blade. This treatment was aimed at removing the top 8-10 inches of soil where biosolids were concentrated from farming activities. Topsoil was placed at the edges of sub plots, far enough away to avoid encroachment by erosion.

Mycorrhizal Innoculum

Mycorrhizal spores were added to the seed mix used on designated treatment plots. Seed imprinting is the preferred method for inoculating an area, since it used seeds (the primary target of the fungus) as a vector for infiltration of the soil.

Planting Treatment:

Native seeds were directly imprinted into the soil of each treatment sub-plot. Seeds were purchased from S&S Seeds, an accredited native seed supplier. The seed mix included native annual and perennial species, including target woody species, and was applied via land imprinting at a density of approximately 40lbs/acre

Because the size of each plot was too small to use standard land imprinting methods, a “sheep-foot roller” pulled by a compact tractor was utilized instead. Seed was first spread evenly at a rate of 40lbs/acre by a commercial seeder mounted on a tractor. This method resulted in similar imprint pattern and depth as a regular land imprinter. Land imprinting is beneficial in several ways: in addition to ensuring an even spread of seed throughout the entire treatment area, imprinting also helps restore soil structure. At Johnson Ranch, previous farming activity and subsequent invasion had drastically reduced soil micro-topography which can be deleterious to seedling recruitment. Imprinting not only presses seed into the soil, thereby securing it, but also breaks up top soil and forms rivets. The return of micro-topography helps concentrate rain water and allow infiltration, and provides microsites for seed germination. Land imprinting is also ideal for the application of mycorrhizal innoculum, and the most cost effective method when being applied to vast areas of land.

Vegetation Monitoring:

Vegetation monitoring was conducted throughout the spring and summer of 2004. Each sub plot was surveyed systematically at the X=7m, Y = 1m, 5m, 9m vertices. A $1m^2$ quadrat was placed at each location and relative cover, relative frequency, and relative density was recorded. Relative height of native woody species was also recorded when appropriate. Systematic sampling of this nature provides an excellent random sample, since survey locations are decided upon before arrival at the site and plant distribution is typically random at this stage of recruitment. If sampling is conducted in the future it is advisable to reposition the X coordinate for two of the three vertices to avoid sampling non-random patches within the seed shadow of individuals from previous years.

Relative cover

The cover class system described by Daubenmire (1959) was used to estimate relative cover. Visual methods are more time and cost effective than quantitative methods, and observer bias can be eliminated if the same team is used throughout the survey. Cover classes were calculated and averaged for each of the three sampling locations within a subplot.

Relative Frequency

Relative frequency was calculated within each $1m^2$ sampling frame. Percent frequency was calculated for all observations in the same treatment class.

Relative Density

Relative density was estimated by direct counts within each $1m^2$ sampling frame. In order to eliminate bias due to the width of the sampling frame itself, any individual touching the north and/or west edge of the frame was counted. Individuals touching the south and east edges were not. Relative density was averaged among all replicates within the same treatment type.

Relative height

Any native woody perennials present inside sampling frames were measured, and averaged among all replicates with in the same treatment type. The success of this measurement depends largely on germination rates, and therefore on weather and moisture availability.

Soil Sampling:

Soil was sampled in November 2003, before treatments were applied to acquire base line nutrient data. Since treatments had yet to be applied, aggregate samples from each plot were analyzed, instead of individual samples from each sub-plot. Subplots that had biosolids removed and/or mycorrhizae added were then re-sampled in March to explore the effect that each treatment had on soil nutrient levels.

Soil samples were sent to Soil and Plant Laboratory, Inc (Orange, California) for processing. This laboratory specializes in nutrient analysis for agricultural purposes, and provides nutrient standards appropriate for crop farming along with their analysis. Nutrient levels were compared to these benchmarks and initial conditions set by January samples.

Data Analysis and Replication:

A total of 8 plots, each containing 5 sub-plots were replicated systematically across the study area. Sub-plot treatments were applied systematically within plots, along a shallow slope, which could confound results. In order to address this concern, a general linear model was used to compare inter- and intra- plot variation.

Vegetation data was categorized into to four categories: native annual, native perennial, exotic annual and exotic perennial, to provide greater power for data analysis. Raw data by species are provided in appendices following the report.

Soil treatments and vegetation data were treated cautiously due to a relatively small sample size and slightly non-normal distributions. To this end, an Analysis of Variance (ANOVA) was used to first identify if there was any evidence of a treatment effect. This parametric approach was then confirmed by the application of a Kruskal-Wallace Sign-Rank test (KWT), which is non-parametric and more reliable when using small, non-normal data sets. If the ANOVA and KWT yielded similar results and were significant, a general linear model (GLM) was applied to identify the most important factors driving the effect.

Throughout this report, statistical significance will be assumed when the P-value (probability that there is no relationship) drops below 5% (e.g., $P<0.05$ will be interpreted as being significant). If a result lands close to this threshold, but is not technically significant, it will be considered "approaching significance". In general this threshold occurs between 5%-10% (e.g., $0.10>P>0.05$)

Results

Soil Nutrients:

Soil conglomerates taken before the beginning of the experiment suggest that total nitrogen levels (~30ppm) were within the range suggested for farming (43ppm). Soils taken from biosolid removal areas had slightly higher nitrogen levels (~38ppm), but were not significantly different from initial levels as indicated by large confidence intervals and greater variation (Figure 3). Total nitrogen taken from sub plots that received biosolid removal and the addition of mycorrhizae were slightly lower than initial levels, but not significantly so (~27ppm).

Phosphate levels began well below suggested levels for cultivation (16ppm<27ppm). Phosphate declined in biosolid removal areas to ~11ppm, and an additional decrease was encountered when mycorrhizae were added (to about~8ppm). Despite the systematic decline in phosphate, none of the changes were statistically significant from initial levels (Figure 3).

Potassium levels began well above acceptable levels for cultivation (304ppm>164ppm). Potassium was significantly lowered (Figure 3) in biosolid removal plots (~117ppm), but was not significantly changed by the addition of mycorrhizal innoculum (~146ppm).

There was no significant effect of treatment on nitrogen (nitrate, ammonium and total nitrogen), phosphate, calcium, magnesium or salt levels ($P>0.05$). There was an effect, however, on potassium ($P=0.003$). This effect appears to be contingent upon biosolid removal/scraping.

Vegetation Density:

Vegetation density was analyzed in four separate categories: Native annual, non-native annual, native perennial and non-native perennial, to provide a functional aspect to the analysis. The 2004 growing season was truncated two months early in March due to rainfall significantly below average (Figure 4). As a result germination rates (especially of perennial plants) were generally low. Raw values for each species contained in these categories are presented in Appendix 1.

Annual plants

Non-native annuals were the most dense vegetation type. Native seed and/or mycorrhizal additions did not affect non-native annual density (Figure 5). The removal of biosolids did affect the density of non-native annuals. The interaction of biosolid removal and mycorrhizal inoculation added nothing to the effect. This result is repeated when confidence intervals are compared, and is consistent using parametric and non-parametric approaches. Native annuals were not affected by any treatment type, and had a much lower germination rate over all.

Perennial Plants

Exotic perennials were only found in two of the five treatments: biosolid removal and biosolid removal with mycorrhizal innoculum. Although significance testing is suspect due to the preponderance of zeros in the data set, it appears likely that biosolid removal helped non-native perennials establish (Figure 5).

Native perennials were found in all treatments except the mycorrhizal innoculum treatment (no exotic perennials were found in this treatment either) (Figure 5). While this result is significant in parametric and non-parametric tests, it may be a function of omission error. Since the data set was so skewed toward zero, any perennial plant found in a given treatment had a profound affect on the mathematical result, making a plot with no hits appear sparser than it actually is.

Vegetation Cover:

In general the 2004 growing season had less rainfall than average for the region, so germination rates (especially of perennial plants) were generally low. Raw values for each species contained in these categories are presented in Appendix 1.

Annual Plants

Non-native annuals tended to dominate plots in terms of cover; however native annuals did occupy a larger percent cover in plots where biosolids were removed. In other words, although there was less annual cover overall in plots which had biosolids removed, native annuals did significantly better than non-natives in theses plots (Figure 6).

One-way ANOVA and Kruskal-Wallace Sign-Rank testing both indicate that treatment significantly affects the cover of non-native annuals. A generalized linear model indicates that non-native annuals are negatively associated with biosolid removal.

One-way ANOVA and Kruskal-Wallace Sign-Rank testing both indicate that the relationship between treatment and native annuals boarder on significance (0.10>P>0.005). In all likelihood an increased sample size would yield stronger significant results. A general linear model indicates that biosolids removal alone is responsible for this thrust toward significance (P=0.008). In general, native annuals did better when biosolids were removed.

Perennial Plants

Non-native perennials only germinated in the bio-solid removal, and biosolid removal + mycorrhizal treatment plots. Although significance testing is suspect due to the preponderance of zeros in the data set, it appears likely that biosolid removal helped non-native perennials establish. (Figure 6) Soil disturbance or the introduction of seeds on heavy equipment may explain this.

Perennial cover was not present in the mycorrhizal + seed treatment plots. While this result is significant in parametric and non-parametric tests, it may be a function of omission error. Since the data set was so skewed toward zero, any perennial plant found in a given treatment had a profound affect on the mathematical result, making a plot with no hits appear sparser than it actually is.

Native perennials occupied higher cover in most treatment plots (except the mycorrhizae + seeding treatment where no perennials established). Native perennial cover was significantly higher in biosolid removal treatment areas than others. One-way ANOVA and Kruskal-Wallace Sign-Rank testing both indicate that treatment significantly effected the cover of native perennials. A generalized linear model indicates that native perennial cover was strongly positively affected by biosolid removal.

Discussion

A cost-effective method for restoring the 700-acre Johnson Ranch agricultural site to native RSS habitat type is desired. Methods analyzed in this study included the removal of biosolids, inoculation of soil with mycorrhizal spores, and the addition of native seed via land imprinting. Seed was added to all treatment sub-plots except for an ambient control sub-plot which represents the state of Johnson Ranch if left as-is. The interaction of biosolid removal and mycorrhizal addition was also studied.

Biosolid Removal:

Most soil nutrients were not affected by biosolid removal as predicted. Total nitrogen (as well as ammonium and nitrate individually), phosphate, calcium, magnesium and salt did not change significantly when biosolids were removed. However, it should be noted that high variability in soils data may be masking a signal. For instance, a slight increase in total nitrogen from ambient levels, to the biosolid removal + seeding treatment, appears unreasonable since the purpose of biosolid removal was to eliminate excess nutrients from the system. This result is erroneous and most likely due to random chance when a soil core hit a nitrogen rich microsite. Phosphate levels appeared to decrease from ambient, to biosolid + seeding, to biosolid+ seeding and mycorrhizal treatments, but not significantly so due to high variability. Although the sample size was mathematically sufficient, additional samples should be taken to account for extreme soil heterogeneity.

Potassium levels were significantly decreased by biosolid removal. Since potassium levels were just as variable as other nutrients measured at the same scale (ppms) and a relationship was detected, it appears unlikely this result is an error. If additional samples were added to these data, the relationship would probably become even stronger, and suggests that there might be an interaction between the “scraping” and mycorrhizal treatments which remains undetectable at this sample size.

Baring high soil variability alone, the most likely explanation for these results is that the nutrients from biosolids had already escaped topsoil via any number of methods including use/absorption, hydrology or erosion. Although tilling and disking from field maintenance may have mixed biosolids into the topsoil, it is unlikely that such efforts moved them deeper than 10”, which was the depth to which biosolids were scraped. In general, active topsoil exists well above this depth (10cm, approximately 4.5”). Both total nitrogen and phosphate levels appeared below suggested thresholds for cultivation at the beginning of the experiment, which may indicate that these compounds had already been removed from the topsoil. Experimental evidence from other systems (serpentine grassland) indicates that plant monocultures (such as that which exists at Johnson Ranch) lack the ability to retain nutrients since use occurs all at once and there is no method for biomass to hold on to excesses during the off-season(Hooper 1997; Hooper 1998).

Potassium on the other hand appeared to be at recommended levels at the beginning of the experiment and declined throughout. As a general rule of thumb, potassium is added at a much higher ratio than other elemental nutrients, such as magnesium (which may explain why magnesium did not change throughout the experiment, but potassium did).

In general elemental nutrients have a longer incubation period in soil organic matter because they are strongly charged and under less demand than other charged compounds such as nitrate, ammonium and phosphate.

The removal of biosolids had the most dramatic affect on vegetation throughout the experiment. Removing biosolids decreased non-native annual density and cover, and increased the percent native annual cover relative to exotics. In general, removing biosolids effectively decreased non-native annuals, and made room for native annuals to grow and prosper. This is an important first step to restoring the soils and habitat at Johnson Ranch, since native annuals and senescent perennials naturally dominate early successional stages. Gray (1988) describes an herbaceous component of California Sage Scrub as being important for equalizing and establishing nutrient pools. Furthermore, native annuals that make up part of the natural early-season herbaceous component of RSS will provide natural soil structure appropriate for the establishment of later successional stages. The increased cover of native annuals in plots where biosolids were removed may indicate increased overall fitness, and potential for self-proliferation next season—the establishment of a native successional cycle.

Although the biosolid removal treatment appears to be the most effective, the signal may be misleading. Biosolid removal failed to effect nutrient levels significantly as indicated by available data. This suggests that the effect of biosolids had already run their course and that some other hidden variable is responsible for the effect.

Observation suggests that it is not biosolid removal that drives the signal, rather the removal of the invasive annual seed bank. Scraping off the top 8-10 inches of soil would effectively remove any viable seeds present in the soil. Anecdotal and experimental evidence from other RSS fragments suggest that invasive annuals strongly inhibit native seedling establishment (Chalekian 2002; Seabloom 2003; Strahm 2004). Other studies suggest that soil disturbance after early season germination creates microsites ideal for native germination (DeSimone 1999); such disturbance could easily be simulated by the biosolid removal strategy. These data appear to concur; where invasive annuals are the most dense, native annuals occupy less cover.

Experiments using fire to remove invasive annuals and their seed bank tend to yield conflicting results. One explanation may be that fire effectively removes exotic standing biomass, but does not burn intensely enough on these fuels to eradicate the seed bank(D'Antonio 1992; Strahm 2004). To date, mechanical removal of the non-native seed bank and replacement with native seed appears to be the most effective method; however cost may be prohibitive at large sites, such as Johnson Ranch.

Key Points:

- Soil scraping did not significantly affect most soil nutrient levels. This is most likely because excess nutrients had already left the system.
- Soil scraping did affect the density of non-native annuals, most likely via removing the seed bank
- Soil scraping affected non-native annual cover by reducing the number of individuals (density).
- Soil scraping affected native annual cover, most likely by reducing the density and cover of non-native annuals.
- Soil scraping affected non-native perennial density and cover positively, possibly as a function of soil disturbance or introduction via equipment. This result may also be due to omission error and should be considered suspect.

Seeding:

The fact that native seed did not appear to be a factor should not discourage the use of a seeding treatment. Long-term agriculture does not provide for the survival of a native seed bank. Several methods, including fire, plowing, weeding and herbicide application are used to suppress native vegetation in order to encourage target crops. If native seeds are even present in the soil at the end of agriculture, it is extremely unlikely that any are viable. In a large fragment such as Johnson Ranch, the introduction of native seed via wind dispersal, or pre-dispersal occurs at an extremely low rate.

Anecdotal and experimental evidence from elsewhere suggests that the seed bank must be replenished before germination can occur (Chalekian 2002; Seabloom 2003). This conclusion is supported by basic logic: if seeds are absent germination cannot occur. However, germination is contingent upon other factors which were not accounted for. In particular moisture is one of the most limiting factors for germination in Mediterranean systems and RSS is not an exception. The 2004 growing season was truncated by two months beginning in March, by lack of rainfall (average rainfall in March, 2004 = 0.025”/day, vs 0.16”/day long-term average). Chances are the seeding treatment had no effect because there was not enough water this year to see the effect. Seeds still viable from this growing season may persist for several years and show an effect later.

Key Points:

- Seeding did not appear to have an effect, however this result is probably linked to a lack of rainfall.

- Evidence from other systems and RSS indicate that seeding combined with weed removal are both key for native plant establishment

Mycorrhizal Inoculation:

The addition of mycorrhizal spores was intended to simulate the addition of native soils transplanted from another location. There appeared to be no significant effect of mycorrhizal innoculum. This result may be a function of the 2004 growing season being abruptly halted in March.

Key Points:

- Mycorrhizal inoculation did not appear to have a significant effect on native establishment, however this result should also be considered suspect due to low rainfall.

Interaction Terms:

Interaction of variables which were measured appeared insignificant. However, it is likely that had moisture been sufficient for native seedling establishment, an interaction of seeding and biosolid removal/soil scraping would have been extremely significant.

Key Points:

- Seeding, soil removal and mycorrhizal inoculation treatments did not interact with each other in any significant way. This result was also probably affected by low rainfall.

Future investigation:

This experiment has established excellent base line data, and begun to offer insight toward a cost-effective method of reestablishing RSS at the Johnson Ranch Site. To gain an increased understanding of the system and the effect of various treatments, further investigation is warranted. To this end, the 2004 experiment can be used as a pilot study.

Simply following plots will elucidate the long-term effects of the treatments. For example, vegetation data in future years may indicate if increased fitness in scraped plots of native annuals this year leads to better establishment (higher density and cover) of native annuals in subsequent years. Furthermore, perennial height will become a more valuable analytical tool as shrubs grow or die-off.

Reapplication of this study should provide better coverage of soil variables; a minimum of 1 soil core per vegetation sampling frame, or a nested design which takes cores at 5m, 1m and 1/2m vertices, and randomized treatments within plots and provide a full factorial design. In addition other treatments aimed at removing the non-native annual seed bank may be applied as an additional layer. Figure 7 provides an illustrated example of such a design.

Finally, to place more control on the experiment another factor can be added. A water treatment applied to a series of subplots would ensure that low germination rates due to lack of moisture would be accounted for, and give other treatments (such as mychorrhizal inoculation) an opportunity to have an effect if they are being inhibited by extreme dryness.

Key Points:

- A fully factorial design is appropriate
- A watering treatment will provide the ability to establish if some inconclusive results were a function of dryness this year.

Literature Cited

Chalekian, J. S. a. d. D. H. D. (2002). Spatial Ecology in an Invaded California Sage Scrub (CSS) Community: The Emergence of Spatial Pattern From Local Endogenous Processes. Biology. San Diego, San Diego State University.

D'Antonio, C. M., and P.M. Vitousek (1992). "Biological Invasions by Exotic Grasses, the Grass/Fire Cycel, and Global Change." Annual Review of Ecology and Systematics **23**: 63-87.

DeSimone, S. A. a. P. H. Z. (1999). "Shrub Seedling Recruitment in Unbburned Californian Coastal Sage Scrub and Adjacent Grassland." Ecology **80**(6): 2018-2032.

Franklin, J., A.D. Syphard, D.J. Mladenoff, H.S. He, D.K. Simons, R.P. Martin, D. Deutschman, J.F. O'Leary (2001). "Simulating the Effects of Differnt Fire Regimes on Plant Functional Groups in Southern California." Ecological Modelling **142**: 261-283.

Hooper, D. U. a. P. M. V. (1997). "The Effects of Plant Composition and Diversity on Ecosystem Processes." Science **277**: 13021305.

Hooper, D. U. a. P. M. V. (1998). "Effects of Plant Compositionand Diversity on Neutrient Cyceling." Ecological Monographs **68**(1): 121-149.

Minnich, R. A. (1998). "Historical Decline of Coastal Sage Scrub in the Riverside-Perris Plain, California." Western Birds **29**: 366-391.

Seabloom, E. W., E.T. Borer, V. L. Boucher, R.S. Burton, K.L. Cottingham, L. Goldwasser, W.K. Gram, B.E. Kendall and F. Micheli (2003). "Competition, Seed Limitation, Disturbance and Reestablishment of California Native Annual Forbs." Ecological Applications **13**(3): 575-592.

Strahm, S. L. (2004). Invasion, Competition and Small Spatial Pattern in California Coastal Sage Scrub. Biology. San Diego, San Diego State University.

Swenson, J. J. a. J. F. (2000). "The effects of future urban development on habitat fragmentation in the Santa Monica Mountins." Landscape Ecology **15**: 713-730.

Vitousek, P. M., H.A. Mooney, J. Lubchenco and J.M. Melilo (1997). "Human Domination of Earth's Ecosystems." Science **277**: 494-499.

http://www.ipm.ucdavis.edu/WEATHER/wxretrieve.html

Appendix 1: Average Cover Data (by treatment)

		Species	Treatments*				
			A	B	C	D	E
Native	Annual	*Amsinckia menziezii*	1	1.33333	1.14286	1	1.57143
		Deinandra fasciculatum	1	0	1	2	0
		Lasthenia californica	2	0	2.5	0	0
		Plantago erecta	1	0	1	0	0
		Trichostema lanatum	1.16667	0	1.5	0	0
	Perennial	*Artemisia californica*	1	0	1	0	0
		Calystegia macrostegia	0	1	0	0	0
		Datura wrightii	2	0	0	0	0
		Eremocarpus setigerus	1	0	1.16667	0	0
		Erioginum fasciculatum	1	0	1	0	0
		Lotus scoparius	0	0	1	0	0
		Malvella leprosa	0	0	0	0	1.5
		Salvia apiana	2	0	0	0	0
		Salvia mellifera	1	0	0	0	0
NonNative	Annual	*Anagallis arvensis*	1	0	1	0	0
		Avena fatua	1.5	2.95238	1.33333	2.73684	2.57143
		Brassica nigra	1.6087	1.375	1.36364	1.625	2.08333
		Bromus diandrus	1.71429	7.5	1.375	3.19048	3.5
		Chenopodium album	1	1	1.66667	1.5	0
		Erodium cicutarium	1	0	1	2.5	0
		Lolium multiflorum	1.25	1	1.16667	1.5	1.66667
		Polygonum arenastrum	1.85714	0	1.33333	0	0
		Raphanus sativum	0	0	1.5	0	0
		Silene spp.	1	0	2	0	0
		Sonchus oleraceous	0	0	1	0	0
	Perrenial	*Medicago polymorpha*	1	0	1	0	0
unknown		unk 1	1.33333	0	1.33333	0	0
		unk1	1	0	2	0	0
		unkgra	0	1	0	0	0
		unkherb	0	0	1	0	0

* Treatments A through E:

Treatment A – seed + scrape
Treatment B – seed only
Treatment C – seed + scrape + mycorrhizae
Treatment D – seed + mycorrhizae
Treatment E – ambient control

Appendix 2: Hypothesis Testing Results

Density					
Test		Functional Group			
		NA	NNA	NP	NNP
Kruskal wallace		0.125	P>0.001	0.012	0.245
1-way ANOVA		0.855	P>0.001	0.254	0.480
GLM	Seed	0.834	0.302	0.150	cannot estimate
	Scrape	0.684	P>0.001	0.130	0.123
	Mycor	0.978	0.329	0.338	0.601
	Scrape +Mycor	0.460	0.402	0.782	0.601

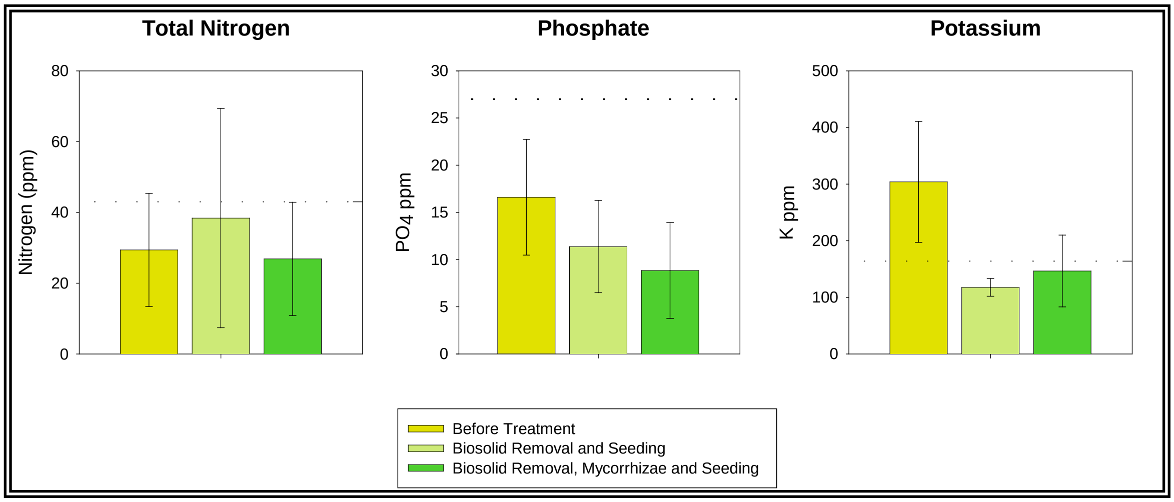
Cover					
Test		Functional Group			
		NA	NNA	NP	NNP
Kruskal wallace		0.076	P>0.001	0.004	0.229
1-way ANOVA		0.082	P>0.001	0.002	0.231
GLM	Seed	0.613	0.748	0.386	cannot estimate
	Scrape	0.008	P>0.001	P>0.001	0.049
	Mycor	0.475	0.140	0.601	0.502
	Scrape +Mycor	0.655	0.839	0.829	0.502

APPENDIX 3: Average Height of Native Perennial species

Species	Treatment				
	A	B	C	D	E
Artemisia californica	2	0	4	0	0
Datura wrightii	22.25	0	0	0	0
Erioginum fasciculatum	6.7	0	3	0	0
Lotus scoparius	0	0	5.5	0	0
Salvia apiana	12	0	0	0	0
Salvia mellifera	4	0	0	0	0

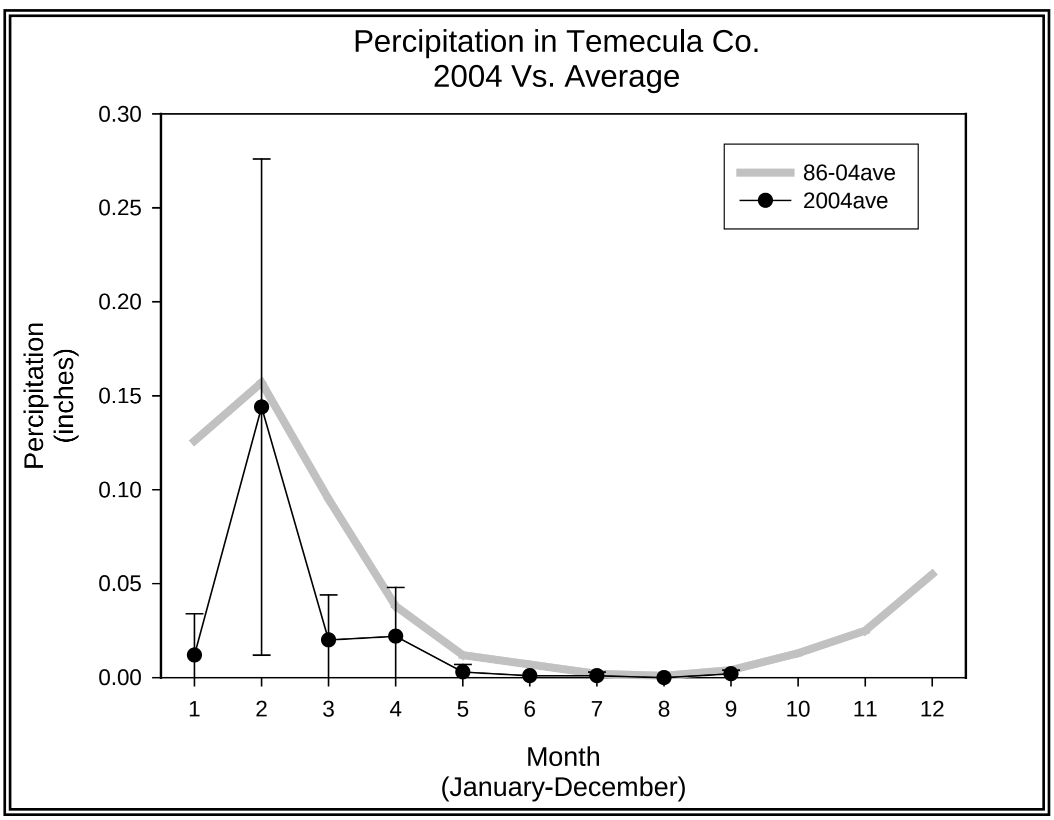
* Treatments A through E:
  Treatment A – seed + scrape
  Treatment B – seed only
  Treatment C – seed + scrape + mycorrhizae
  Treatment D – seed + mycorrhizae
  Treatment E – ambient control

Figure 3. Soil Nutrients



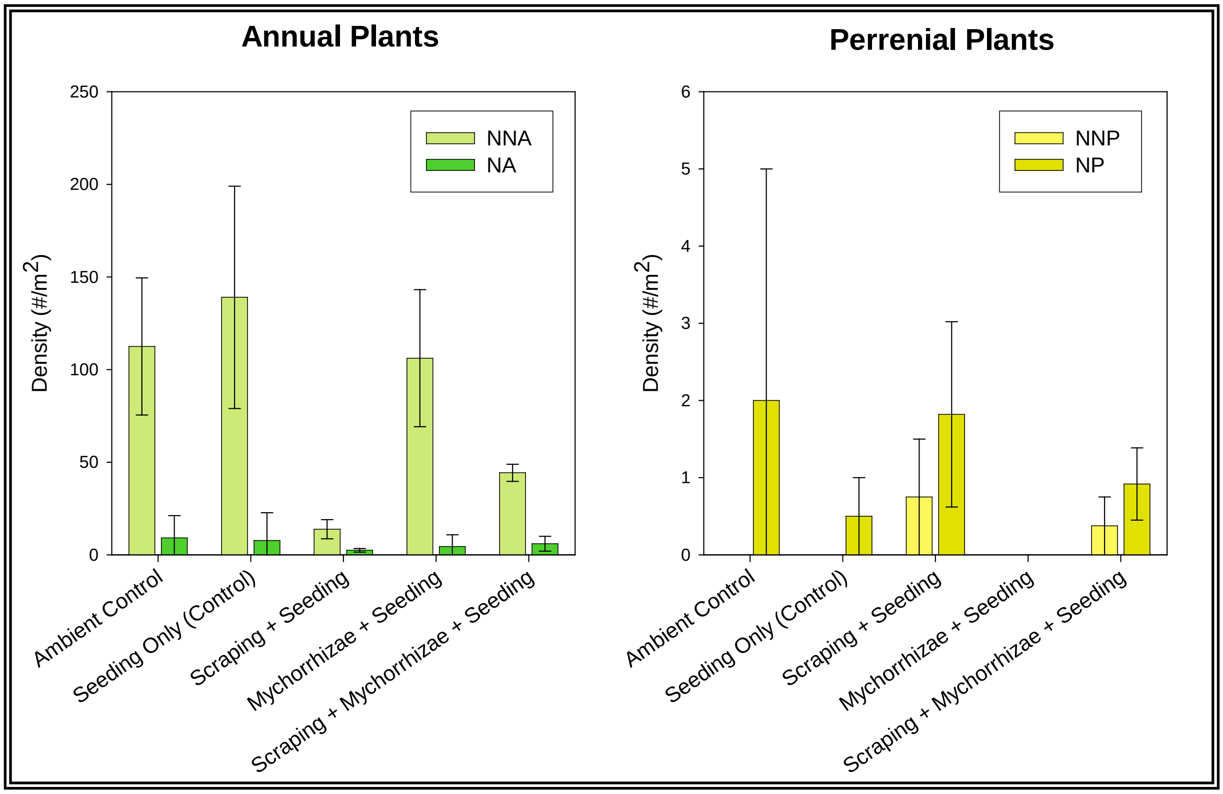
Comparison between different soil levels of total nitrogen, phosphates, and potassium. Bars denote Standard Deviations.

Figure 4. Precipitation



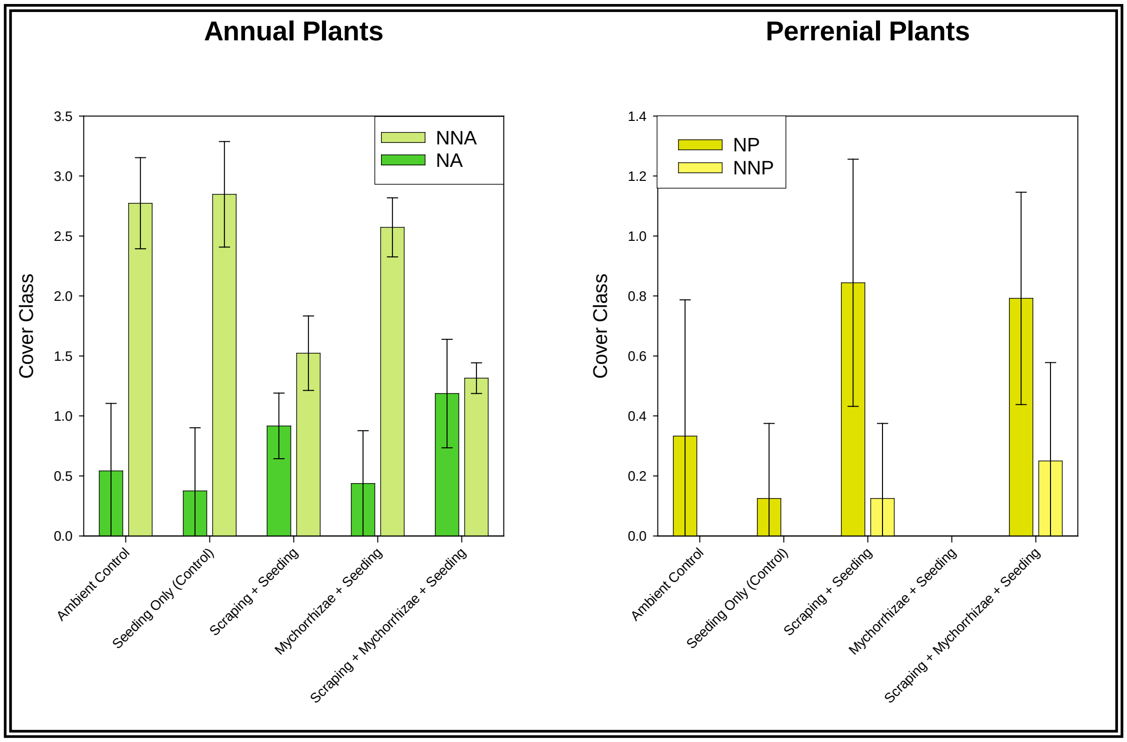
Comparison of precipitation during 2004 and averages in Temecula County.

Figure 5. Density in Annual and Perennial Plants



Comparison of densities between annual and perennial plants.

Figure 6. Cover Classes



Comparison of cover classes between annual and perennial plants

Figure 7. Experimental Design

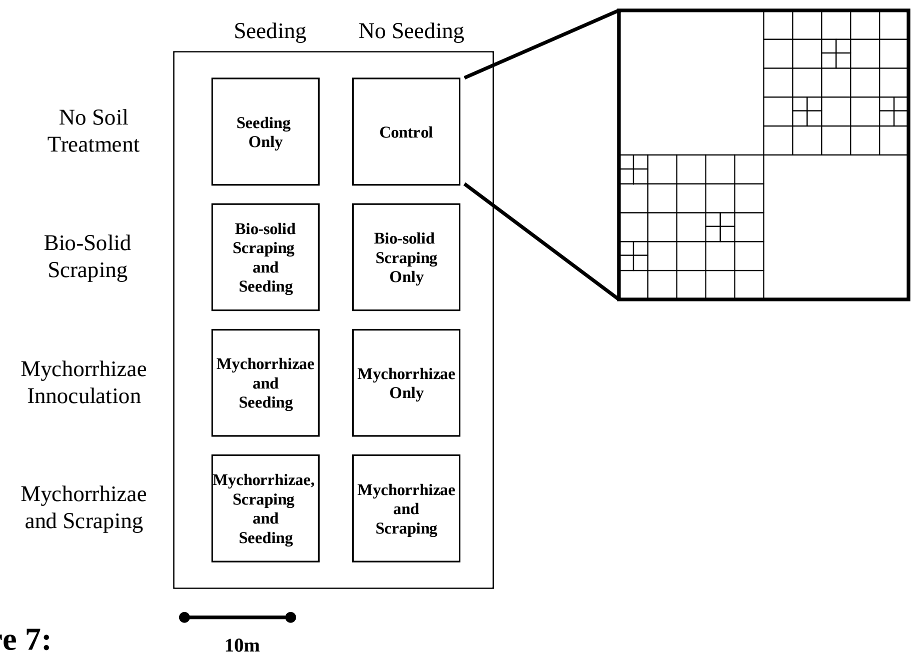


Figure 7:

Recommended Experimental Design and Soil Sampling Strategy for continued research. A) A full factorial design should include 8 treatments: two seeding and four soil treatments. B (cut out)) Soil sampling should be nested on the 5m vertices, 1m vertices and ½ m vertices to provide sufficient data to account for fine scale soil heterogeneity.