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Gypsum Soil Restoration and Revegetation in Lake Mead National Recreation Area: Treatments, Monitoring, and Management Activities

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PURPOSE AND SCOPE

Gypsiferous soil habitat in Lake Mead National Recreation Area (LMNRA) supports unique plant communities, rare plant species, such as the Las Vegas bearpoppy (*Arctomecon californica* Torrey & Frémont) and southwestern ringstem (*Anulocaulis leiosolenus* (Torrey) Standley) (Figure 1), and unique biocrust communities (Figure 2). Within the eastern Mojave Desert of the southwestern United States gypsiferous soils are mostly *Typic Petrogypsids*, *Leptic Haplogypsids*, or *Typic Calcigypsids*, alluvium or residuum in origin and derived from a Pleistocene marsh environment, which occur in an aridic moisture regime and thermic to hyperthermic temperature regime (See text box 1). These soils are often in association with Calcids soils. Gypsiferous soil habitats are considered especially fragile and susceptible to damage. Information about soil-biota interactions is crucial for land managers that are required to maintain, mitigate, restore, assess and monitor ecological functions. Cost- and ecologically effective strategies are needed for rehabilitating and restoring disturbed arid lands, including activities related to revegetation, ecosystem restoration after a large disturbance, or promoting establishment of rare species.

The University of Nevada, Las Vegas (UNLV) and the National Park Service (NPS) have collaborated to conduct surveys and to implement experiments testing methods of restoration for the vegetative community and surface structure in gypsum-derived soils (including biocrusts), examine undisturbed gypsiferous soil communities to identify specific species-soil relationships, and identify key areas that may assist with the development of the Las Vegas bearpoppy populations in LMNRA. This information provides land managers with a valuable tool to guide their management decisions. A master restoration plan and suggested guidelines for gypsum habitat has been developed using knowledge gained from the activities above. Information gained from this project will help the NPS conserve rare plant habitat damaged from construction and other disturbances at LMNRA and conduct restoration-related activities post-disturbance.



Figure 1 Las Vegas bearpoppy (*Arctomecon californica* Torrey & Frémont) individual (left; photo credit: Lindsay Chiquoine, University of Nevada, Las Vegas) and southwestern ringstem (*Anulocaulis leiosolenus* (Torrey) Standley (right; photo credit E. Cayenne Engel, University of Nevada, Las Vegas) along Northshore Rd, Lake Mead National Recreation Area, Mojave Desert, USA.



Figure 2 Biocrust specimen from a gypsiferous soil community, Northshore Rd and Overton Beach Rd intersection, Lake Mead National Recreation Area, eastern Mojave Desert, USA. Specimen contains the macroscopic lichens *Collema coccophorum*, *C. tenax*, *Placidium* spp., *Peltula richardsii* and the mosses *Synthrichia cananervis* and *Aloina bifrons*, and the macroscopic cyanobacteria *Microcoleus vaginatus*, *Phoridium* spp., *Scytonema* spp., and *Letplyngbya* spp. identified through light microscopy. Ruler marks = 1 mm. Photo credit: Lindsay Chiquoine, University of Nevada, Las Vegas.

ACCOMPLISHMENTS

During the collaboration period, UNLV and NPS personnel have accomplished the following:

- Conducted site assessments in disturbed and undisturbed gypsiferous areas and surrounding habitats within and around LMNRA and Bureau of Land Management-administered lands;
- Complied newly collected and existing soil and plant site information to determine the occurrence of plant-soil gradients, indicator species, and identification of unique environments and/or rare plant species habitat;
- Established, maintained, and surveyed survival restoration projects in which the feasibility of different methods was compared;
- Assessed feasibility of establishing Las Vegas bearpoppy at disturbed, restored/rehabilitated and undisturbed sites which fit the profile of Las Vegas bearpoppy habitat;
- Assessed native undisturbed biocrust communities in gypsiferous soils in LMNRA and tested techniques for establishing biocrusts on disturbed sites; and
- Examined the population of arthropods in the gypsiferous soil environments.

INTRODUCTION

Impacts of Disturbance

Ecosystem disruption by anthropogenic activities has important implications including the loss of species diversity, biomass and cover of soil biota, the negative influence on vegetation communities by impacts to seed and vegetation ecology or the introduction of non-native, invasive species, and the decrease of ecosystem functioning, integrity, and resilience, such as through altering hydrology, ecosystem fragmentation, subdivision or isolation of populations, and wildlife access (Anderson 1990; Anderson et al 1982; Belnap and Eldridge 2001; Belnap et al. 1994; Eldridge 1998). Many types of past and present land uses have modified or eradicated native vegetation and sensitive biological soil crusts (biocrusts), resulting in habitat loss for native wildlife species, increased soil erosion, ecosystem simplification, and other negative ecological effects (Lovich and Bainbridge 1999). Some of the many disturbance types and land uses that have removed native vegetation in the Mojave Desert include road construction, creation of power line and utility corridors, introduction of exotic herbivores (e.g., feral burros, horses, and cattle), mining and military activities, agricultural clearing, water drawdown, legal and illegal off-road driving, and urban-suburban construction (Lovich and Bainbridge 1999). The impacts of disturbances depend on such factors as soil properties, vegetation diversity and density, biocrust presence, climate characteristics, and the type and severity of the disturbance.

Text box 1:

Eastern Mojave Desert Soils

The common soil orders under the USA soil taxonomy which occur in the southern Nevada and the Lake Mead region include mostly Aridisols and with a smaller component composed of Entisols. Aridisols (*aridus*, Latin for "dry") form in arid and semi-arid climates and dominate deserts and xeric shurblands that occupy one third of the Earth's land surface. Usually, these soils have low concentrations of organic material and often have very low vegetation production and cover. The limited leaching in Aridisols results in one or more subsurface soil horizons containing suspended or dissolved minerals of silicate clays, sodium, calcium carbonate, gypsum, or other soluble salts. The two common suborders which occur in the Lake Mead area and support populations of the Las Vegas bearpoppy include Gypsids and Calcids. Gypsids are Aridisols that have a gypsic or petrogypsic horizon within 100 cm of the soil surface. Initially crystal gypsum aggregates form in voids in the soils which grow and aggregate by accretion eventually displacing the enclosed soil material. Gypsids may have calcic or related horizons which overlay the gypsic horizon. Calcids soils are those that were formed from calcium carbonate parent materials. Carbonates tend to leach through soils. The upper boundary of a calcic or petrocalcic horizon is normally within 50 cm of the soil surface. A common Entisols suborder found in the region are Orthents, which usually occur on recent erosional surfaces that may be geologic or may have been induced by cultivation, mining, or other factors. These soils have a texture of loamy very fine sand or finer or percent (by volume) or more rock fragments in some layer within the particle-size control section and do not have fragments of diagnostic horizons that can be identified.

Disturbances and Natural Recovery

Arid lands cover one-third of the earth's surface and support human life, as well as diverse ecosystems. Disturbances to these systems are problematic due to the length of time which may be required for natural recovery after an anthropogenic or natural disturbance event, and due to the negative impacts to surrounding undisturbed systems, wildlife, and human communities. The rate and composition of natural revegetation and biocrust community recovery following disturbance varies with climate and seasonal and yearly fluctuations, plant propagule and seed availability, soil fertility and type, proximity to biocrust inoculants, disturbance type and subsequent disturbance regimes, and other factors (Abella 2010; Belnap and Lange 2001; Webb et al. 1988). Precipitation in the Mojave Desert is limited and/or unpredictable season to season, causing suitable conditions for seed germination and seedling survival to be rare. For example September 2006 through March 2007 in the Las Vegas region received only 49% of average precipitation (Las Vegas, Nevada weather station, 1937-2010 records; Western Regional Climate Center, Reno, NV, USA) resulting in little to no annual plant emergence. In some instances, vegetation cover and density may already be very low (<4-60%; 100-500 plants/ha; see Section 1 of this report), resulting in low seed availability and natural seeding rate for areas close to disturbances, such as along dirt roads in arid environment (Figure 3).



Figure 3 Road 108, Blue Point Spring Rd, located in the Blue Point Spring and Roger's Spring Area along Northshore Rd in Lake Mead National Recreation Area. Rd 108 was closed in 2002. Displayed are portions of the road seven years after closure (2009) with little to no vegetation or biocrust recovery and obvious high disturbance to surface soils. The full study is located in Section III of this report.

Vegetation

De-vegetation causes a loss in individual plant species genetic diversity, a decrease in species richness, simplifying the vegetation structure (Wallace et al. 1980), and a reduction in seed sources, which can impact wildlife such as the federally listed (USA Endangered Species Act) desert tortoise (*Gopherus agassizii*) in the Mojave Desert (Esque et al. 2003). Additional problems, such as herbivory of recovering vegetation by an array of organisms, including insects, small mammals, and larger herbivores, including non-native grazers, can damage or kill plants and reduce reproductive output (Hunter 1987). Granivory by seed-eating organisms may consume 75% to nearly all of natural annual seed production (Brown et al. 1979), reducing opportunities for seed establishment. Many native perennial plants also do not form large soil seed banks and have stringent germination requirements, making them susceptible to seed and germination limitations following disturbance. In the absence of nurse plants, species must germinate and establish with full exposure to sunlight, wind, and herbivory. Disturbances may alter which pioneer species colonize or may alter successional pathways compared to natural succession due to changes in the soil environment or proximity to vegetation (Abella 2010; Knapp 1991; Webb et al. 1987; Webb and Wilshire 1980). Disturbances that are large and that severely impact soil properties or eradicate seed sources are the slowest to revegetate. Knapp (1991) found that after 77 years following removal of active disturbance on abandoned roadways in Montana there was still a significant difference in the plant community structure. Webb and Wilshire (1980) found that 51 years after the removal of disturbance, soil compaction still hindered recovery and their evidence suggests after the common native shrub creosote bush (*Larrea tridentata* (DC.) Coville) was unable to reestablish. Bolling and Walker (2000) found that bladed and 'track' roads abandoned at different time periods but were within the same vegetative species assemblages and soil type in LMNRA had different soil and vegetation properties.

Biocrusts

Disturbance also removes surface biota and negatively affects the soil environment (see text box 2). Eckert et al. (1979) observed that disturbance decreased soil porosity and water infiltration, and Vollmer et al. (1976) observed a decrease in soil stabilization from disturbance to or removal of surface vegetation, rock, or soil biota. Large disturbances cause an increase in fugitive dust contributing to public health hazards (Grantz et al. 1998). Undisturbed biocrusts greatly reduce the potential for wind erosion (Belnap and Gillette 1997; 1998) and create a texturized surface that contributes to aeolian deposition containing plant essential nutrients (Belnap et al. 2003). Disturbances to biocrusts limits nitrogen and carbon inputs in interspaces were biocrust communities have been covered or removed (Barger et al. 2006). Biocrusts, composed of highly desiccation tolerance organisms, are only biologically active when wet (Kershaw and Rouse 1971) and require species-specific lengths of time of hydration and specific seasons of sunlight exposure for positive carbon balance to occur, which is required for growth. For biocrust communities, recovery may also take a considerable amount of time with implications to the recovering vegetation community. Biocrust organisms have different rates of recovery. Belnap and

Warren (2002) observed the famous Patton's tracks from military tank maneuver exercises in the Mojave Desert during World War II and found that the cyanobacterial component had recovered after 55 years from 46-65% in tracks compared to contents found in adjacent undisturbed areas and that lichen cover recovery was much slower and impacts on lichens were species specific, with the common cyanolichen *Collema tenax* only a recovery of 6% and a common phycolichen *Placidium squamulosum* only a recovery of 3%. Anderson et al. (1982) also observed that lichen, moss, and algal cover was greatly reduced by domestic grazing and after exclusion increased cover from 4% to 15% during the first 14-18 years and an additional 1% over the following 20 years. Barger et al. (2006) observed that dissolved organic carbon, dissolved organic nitrogen, and ammonium were significantly reduced at sites where the biological soil surface layer was trampled. Significant impacts to biocrusts may influence vegetation recovery.

Text box 2:

What are biocrusts?

Biocrusts, also known as cryptogams, crytobiotic crust, biogenic crust, microbial crust, or biological soil crust (BSC), make up 70 to 80 % of the living cover in arid systems across the world and are an almost continuous photosynthetic and nitrogen-fixing surface layer in the plant interspaces. Biocrusts are composed of a diversity of organisms including lichens, a symbiotic relationship between a fungus (mycobiont) and a photosynthetic partner (photobiont; either a green algae or cyanobacteria), mosses, fungi, free-living cyanobacteria, a diversity of other bacteria, archaea, free-living green algae or other algae, and other eukaryotic and prokaryotic microfauna. This bio-rich zone varies in thickness and is a part of a complex matrix associated with grains, voids and cracks, and sedimentary rock deposits formed during sedimentation by precipitation or recrystallization minerals. Biocrusts contribute to surface stabilization, reduce potential erosion, and influence surface hydrology and the vegetation community. Biocrust organisms also play important roles in the nitrogen and carbon cycle, as well as act as dust traps, which capture nutrient-rich dust.

Observations of Natural Recovery

Where successful, restoration activities can reverse or slow deleterious trends and dramatically improve the condition and capabilities of arid lands (Allen and Jackson 1992). However, many of the same difficulties that make natural recovery slow in arid environments make active revegetation through human actions challenging (Virginia and Bainbridge 1987). Implementation of seeding and revegetation projects may fail due to the same adverse conditions impacting natural recovery, and the likelihood of failure may be increased due to implementation during an inappropriate season (Malo et al. 2009). Some of the gypsum areas within LMNRA have shallow soils on top of caliche layers, which impede plant roots and plant establishment. During disturbances the gypsiferous soil surface environment is altered and may be easily compacted due to the low bulk density soils, which impact seed infiltration, seedling emergence, and plant-soil nutrient cycling. Additionally, gypsiferous soils form a physical crust on the soil surface, which reduces the surface soil texture, decreases water infiltration, reduces the ability for native soil organisms to establish, and reduces seed infiltration into surface soils and seedling emergence (Belnap 2001). Plants may have a soil preference and/or require specific treatments to optimize survival initially after planting. Also, targeting optimal seeding and planting times may not coincide with infrastructure construction schedules or seasonal precipitation lower. Seeds may require specific environmental conditions or scarification prior to germination. Another important aspect of restoration is the removal and prevention of subsequent disturbances, which also hinder plant establishment; for example, removal of non-native feral herbivores which may impede seedling or plant establishment (Figure 4).



Figure 4 Feral cattle trampling to an outplanting project along Northshore Rd at the Overton Beach Rd intersection, Lake Mead National Recreation Area, Mojave Desert, in 2010. Due to the lowering water levels of Lake Mead, cattle were able to cross the northern section of the Overton Arm of Lake Mead into the recreation area.

The Opportunity for Research, Education, and Active Restoration

The Mojave Desert exemplifies many regions where revegetation is needed, but research on species performance and treatment effectiveness is not that common. This hinders the planning of management and revegetation activities in this region, as well as reduces the opportunity for public education opportunities and public outreach. Specifically, in our study region within LMNRA, road construction and other disturbances de-vegetate areas and destroy soil structure. For example, from 2008-2010 the Federal Highway Administration (FHWA) conducted the Rehabilitate Northshore Rd Project (Northshore project) in LMNRA The project was part of ongoing, multi-year FHWA, Federal Lands Division work and NPS cyclic road maintenance (Dey 2006). The purposes of the FHWA project were to rehabilitate and reconstruct segments of road to improve pavement conditions and rehabilitate deteriorated and inadequate drainage (United States 2003). The realignment of Northshore Rd was of particular concern due to the impacts in sensitive gypsiferous soil habitats, which support rare plant species and sensitive and ecologically important biocrusts. However, the Northshore Project within LMNRA has provided opportunities and an area for the study of disturbed and undisturbed gypsiferous soil communities and related restoration research, as well as provided opportunities for public involvement in restoration, care, and maintenance of public lands (Figure 5).



Figure 5 Volunteers, Nevada Conservation Corps members, NPS personnel, and UNLV research assistants establishing an outplanting treatment as part of the Gypsum Soil and Vegetation Research after completion of the Northshore Rd realignment, Lake Mead National Recreation Area, Mojave Desert, USA. Photo credit: Janis Lee, Lake Mead National Recreation Area.

Another example is the now closed road 108 or Blue Point Bay Rd (Figure 6). This unpaved road was closed in 2002 to vehicle traffic and portions of the road were ripped by construction machinery to loosen the highly compacted surface soil. This road closure provides an opportunity to compare natural recovery after the removal of disturbance and compare the recovery of vegetation and biocrust communities in ripped and not ripped road segments. The Rd 108 project has provided several opportunities for students from UNLV to participate in research studies as well as develop their own studies (Figure 6). Restoration of these systems can provide multiple benefits including rehabilitating vegetation, biocrust populations, and wildlife communities, reduce soil erosion, assist with the reestablishment of ecosystem functions and services such as nutrient cycling, and provide educational and public outreach opportunities. An additional benefit of restoration is fulfilling the NPS's mission of maintaining and reducing trammeled areas and restoring the visual consistency of the landscape. The Organic Act states that the purpose of the NPS is to "conserve the scenery and the natural and historic objects and the wildlife therein… by such means as will leave them unimpaired for the enjoyment of future generations" ((39 Stat.535), 16 U.S.C. 1,3,9a,460 1-6a(e), 462(k); C.F.R. Title 36 Chpt I, (Pt 1-199)). As a result, disturbances and destruction of habitats within the national parks should be mitigated and restored as well as feasible to the visual consistency and functional roles of ecosystems close to its natural state.



Figure 6 Entrance to Rd 108 in 2002 prior to road closure. Closed Rd 108 (Blue Point Bay Rd) is located in the Blue Point Spring Area of Lake Mead National Recreation Area, eastern Mojave Desert.

PROJECT REPORT DESCRIPTION AND PRODUCTS

This report is in five sections which include: 1) a synthesis of gypsiferous soil community characteristics and adjacent soil communities within LMNRA complied from data from several projects; 2) information gained from several projects relating to the rare Las Vegas bearpoppy; 3) documentation on the effects of disturbance to gypsiferous soil vegetation and biocrust communities; 4) results of active restoration projects that were supported by this cooperative agreement project; and 5) the results of a survey of arthropod communities in gypsiferous soil communities in LMNRA. A summary of projects included within this document are located in Appendix A.

Products resulting from this research include the following:

1) A general restoration plan for gypsiferous soil habitats in LMNRA, including guide tables for vegetation and soil characteristics based on elevation and parent material, with a specific concentration on gypsiferous soil habitats;

2) A digital database for ArcGIS containing appropriate files for identifying soil types relevant to this report, as well as all project site locations (attachments; not in report);

3) A summary of vegetation and soil characteristics related to Las Vegas bearpoppy habitat, including an analysis on the residual effects of previous year annual precipitation on populations;

4) A detailed analysis of the Las Vegas bearpoppy sites soil seed bank, as well as a photo-library of the seeds extracted from seed bank samples;

5) Results of the both active and passive road rehabilitation conducted along closed Rd 108, including recommendations for future research as well as management recommendations for future projects within gypsiferous soil habitats;

6) Results from the Rehabilitate Northshore Rd Project, including the survival results of the perennial plant salvage, nursery care and maintenance, transplanting and outplanting, along with watering treatments, which provide a guide for future focus on species for salvage and outplanting operations in LMNRA and the results of the biocrust restoration experiment;

7) A photo-library and field guide of invertebrates found in gypsiferous soil habitat.

EXECTIVE SUMMARY

Gypsiferous Soil Synthesis

- Gypsids-origin soils are distinct soils in LMNRA and exhibited greater soil electroconductivity and higher concentrations of total S, Ni, SO_4, Ca, Fe and Mg than other soil types of non-Gypsids origin and were classified by the presence of the rare perennial forb species *Arctomecon californica,* as well as *Atriplex* spp., *Astragalus preussii, Isocoma acradenia, Psorothamnus fremontii, Suaeda moquinii* and *Pleuraphis rigida.*

Las Vegas Bearpoppy (*Arctomecon californica*)

- Most of the Las Vegas bearpoppy populations in LMNRA are found in soils with gypsum-derived parent material; few populations are found in other soil types, although it is still unknown whether these soil types can support future populations.
- Soil parameters P, K, Mn, and Sr had a wide range across bearpoppy sites.
- The number of living bearpoppy plants appears to be dependent on lag precipitation.
- More work is required to elucidate methods for germinating bearpoppy and to develop a protocol to ensure survival of any germinated seedlings.
- Seed bank extraction from gypsiferous soil samples detected orders of magnitude greater seed densities than the emergence method.

Closed Rd 108

- Based on analysis of Rd 108, not ripped road sites had significantly less species richness and total cover for all plant species compared to undisturbed sites, and ripped road sites were not significantly different from either not ripped or undisturbed sites. Ripped road site soils were more similar to undisturbed sites than not ripped were to undisturbed sites due to several soil properties including some soil macronutrients and micronutrients.

Rehabilitate Northshore Rd Project, Federal Highways: Salvage and Outplanting

- Overall perennial plant salvage survival was 46% and perennial plant outplanting survival was 49%. Additional treatment of perennial plants during salvage did not impact overall survival; qualitative response to treatments was species specific. Watering plants throughout the outplanting maintenance period significantly increased outplanting survival.
- Watering treatment increased survival by 16%, with DriWater improving survival by 12% and hand watering by 21%. These benefits of DriWater and hand watering should be weighed against the added effort and cost of simply planting more plants.
- *Ambrosia dumosa, Sphaeralcea ambigua,* and *Stephanomeria pauciflora* exhibited the greatest survival in outplanting and are recommended species for revegetating gypsum soil along Northshore Road.

Rehabilitate Northshore Rd Project, Federal Highways: BioCrust Restoration

- Salvaged biocrust organisms survive salvage and 2-4 years in storage, with decreasing photosynthetic efficiency with longer storage times.
- Inoculation with salvaged biocrust resulted in greater biocrust cover and recovery of cyanobacteria and macro-species.
- Topsoil re-application resulted in increased species richness and density of cyanobacteria species.
- Biocrust inoculation resulted in higher available nitrogen and greater soil stability

Arthropods: Beetle and Ants

- There was a greater abundance of ants sampled in non-gypsum (desert pavement) soils compared to gypsum soils.
- There were two confirmed species new to science of flightless scarab beetles (Family Scarabidae) in the genera *Phyllophaga* and *Diplotaxis*
- The most abundant of the 23 beetle families were sampled in both gypsum and desert pavement habitats

SECTION I. VEGETATION-ENVIRONMENTAL GRADIENTS IN LAKE MEAD NATIONAL RECREATION AREA, EASTERN MOJAVE DESERT, USA



KEY FINDINGS AND MANAGEMENT IMPLICATIONS

- Gypsids-origin soils are distinct soils in Lake Mead National Recreation Area (LMNRA). They consist of *Typic Petrogypsids*, *Leptic Haplogypsids*, or *Typic Calcigypsids* often in association with Calcids soils, alluvium or residuum in origin

- Gypsids exhibit greater soil EC, and higher concentrations of total S, Ni, SO_4, Ca, Fe and Mg than other soil types of non-Gypsids origin

- There is not a great variation in vegetation across gypsum or gypsum-affiliated soils, although richness decreases with increased elevation. This variability represents an important reference condition that can be considered when planning restoration projects on gypsum soil

- Gypsids are classified by the presence of the rare perennial forb species *Arctomecon californica,* as well as *Atriplex* spp., *Astragalus preussii*, *Isocoma acradenia, Psorothamnus fremontii*, *Suaeda moquinii* and the perennial grass *Pleuraphis rigida*

- Gypsids at lower elevation have a lower vegetative cover compared to other soil types but have equivalent species richness compared to other soil types

- With increasing elevation, Gypsids have an increasing presence of perennial forb species included in the overall species richness, although shrub species dominate the overall total vegetative cover

PROJECT PURPOSE

The purpose of this synthesis was to develop a reference tool to guide future restoration activities and research, particularly within gypsiferous soil habitats in LMNRA and the eastern Mojave Desert. Information presented provides richness, density, and cover of perennial plant species categorized into groups within soil taxonomic units or within elevation categories and parent material with a particular concentration on the gypsiferous soil communities and their associated vegetation communities. Also included are results of indicator species analyses and soil properties that statistically appear to delineate vegetation-soil communities. Characteristic soil properties that are easily are identified per soil taxonomic unit or within soil categories. Additional analyses were used to identify specific soil-plant interactions, species fidelity, or soil parameters that may most influence species occurrence.

INTRODUCTION

Site assessments provide vegetation, seed bank and soil information for an area and provide the information necessary to identify an area's main soil-vegetation metrics. Above ground vegetation assessments of species richness and density provide a picture of what species are dominant within the soil types and specific habitats of interest, such as in bearpoppy habitat. Vegetation data provide information on what species contribute to the native seed bank and which species are more likely to establish successfully in specific soil types, and this information can be applied to active restoration seeding and planting treatments. Seed banks are a keystone ecosystem component in Mojave Desert ecosystems and play a major role in vegetation dynamics. Characterizing seed banks is recognized as one of the more challenging measurements of the plant community (Warr et al. 1993). They also constitute a key part of the food web by providing food for insects and granivorous animals. Developing a picture of the seed bank ecology is critical for accurately planning operational aspects of restoration projects that include soil salvage or seeding post disturbance. Seed bank analyses, both emergence and extraction, provide information on which species seeds are present in soils and hence a partial measure (together with seed rain) on what propagules are available to re-colonize disturbed areas such in the case of Northshore Rd reconstruction or road closures. This information also is helpful for determining which species are lacking in seed banks compared to above-group vegetation and which species may require active seeding or planting. Soil analysis provides the chemical and physical properties of soil which then can be combined with vegetation data to identify soil-vegetation interactions and also contribute to rehabilitation efforts in disturbed areas by identifying soil characteristics which may most influence a vegetation community or identifying plant species which will most likely survive in specific soil habitats.

Project Region

LMNRA is located within the eastern portion of the Mojave Desert and is situated northeast of Las Vegas, NV with most of the project activities within LMNRA (Figure 7). This study focuses on gypsiferous soil habitats within LMNRA (Figure 8). The study area encompasses a large portion of the northern end of the recreation area with concentrations in several undisturbed and disturbed gypsiferous soil-dominated areas including previously identified gypsiferous soil disturbance areas, such as the Northshore Rd construction (2008-2010) closed road 108 (2002), and the surround undisturbed areas.

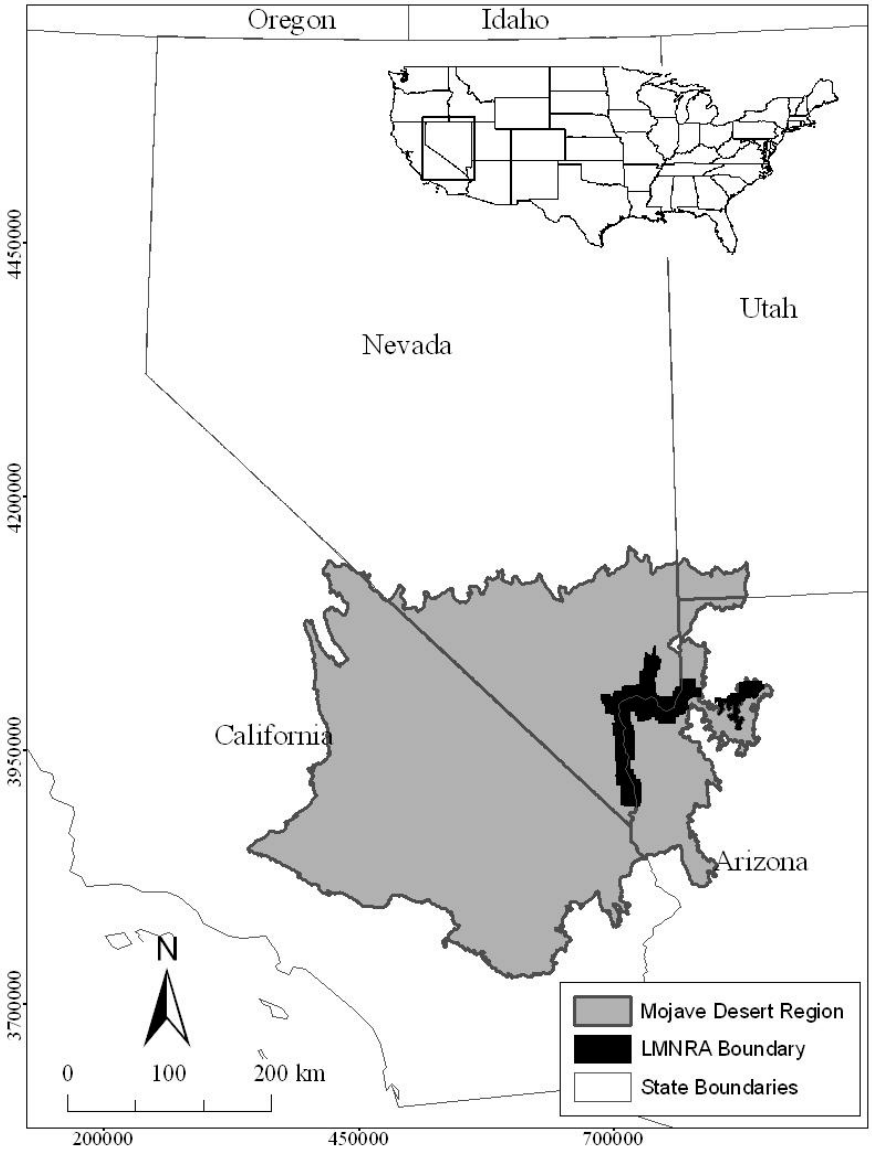


Figure 7 The extent of the Mojave Desert, USA (grey) across the southwest United States and Lake Mead National Recreation Area (black). The Mojave Desert Region includes areas in southern California, Nevada, and Utah and northwestern Arizona. UTM NAD 83 Zone 11N.

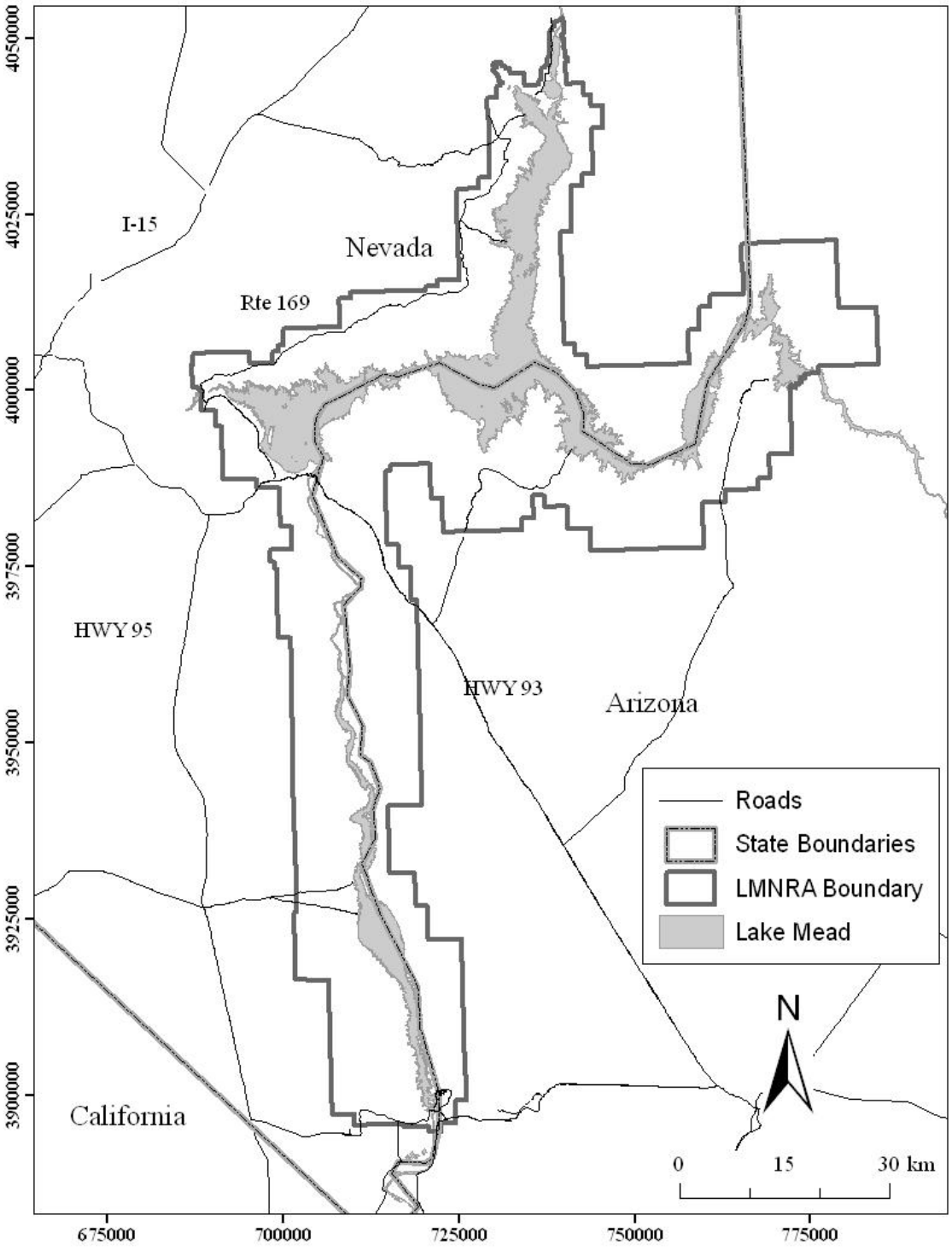


Figure 8 The extent of Lake Mead National Recreation Area (outlined), located within the eastern Mojave Desert, USA, in the southwestern United States along the Colorado and Virgin River basins. UTM NAD 83, Zone 11N.

Climate

All of the projects included within this synthesis occur within a region which receives most of its precipitation (70%) as fall/winter (September-April) rainfall with the remainder as summer (July-August) as monsoonal rainfall [Western Regional Climate Center (WRCC), Reno, NV, USA, 2010; Figure 9]. The mean summer daytime temperatures may exceed 37°C and are often paired with extremely low relative humidity of less than 25%. In some years there are several weeks of increased humidity and precipitation associated with monsoonal influence from the south (Gorelow and Skrbac 2005). Winter months are mild, with afternoon temperatures averaging around 15°C. The average percentage of possible days with sunshine is 85%, creating a highly exposed environment. The Mojave Desert also experiences strong wind events throughout the year with the highest average wind storm events occurring from March through June (Gorelow and Skrbac 2005). Located at an elevation of 768 m, the Boulder City, southern Nevada, weather station has recorded the following averages: daily high July temperature of 39°C, daily low January temperature of 4°C, and 14 cm yr^{-1} of precipitation (1931-2004 records; WRCC 2010). On average, 73% of annual precipitation is received during the September through April growing season for winter annual plants, with peak blooms typically occurring in March-May depending on adequate timing and amounts of rainfall beginning the previous September (Beatley 1974).

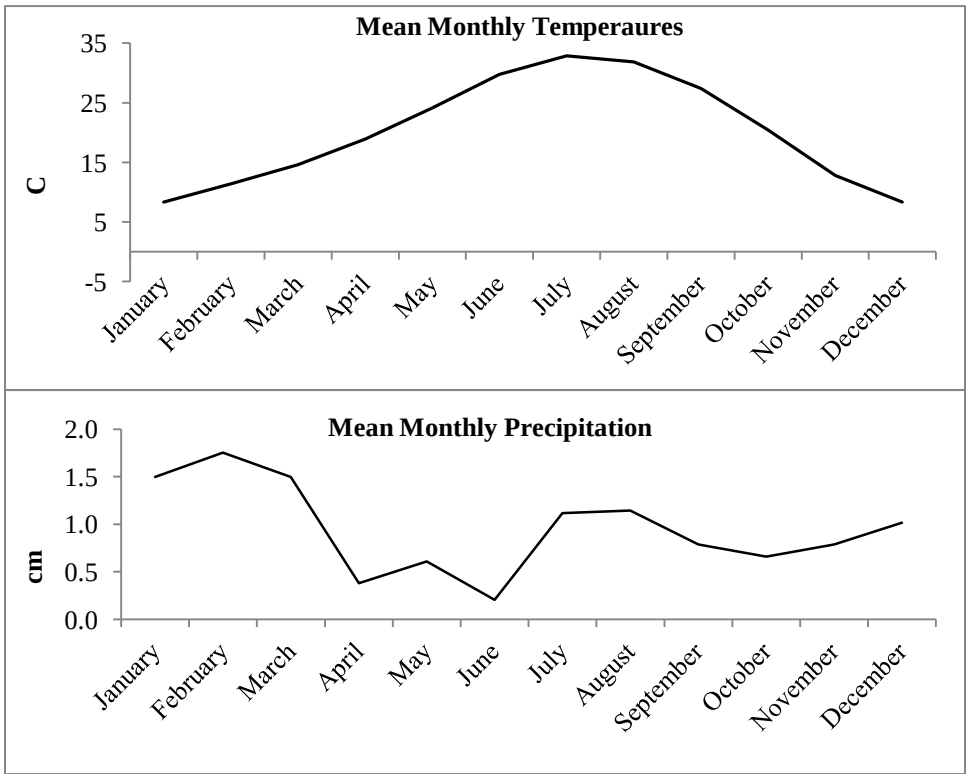


Figure 9 Mean monthly mean temperatures (°C; top) and precipitation (cm; bottom) for the Las Vegas region, southwest USA, complied from data collected from 1931-2001.

PROJECTS SELECTED FOR SYNTHESIS

Data from several projects conducted between the years 2007-2009 were surveyed to include in developing a profile for gypsum origin soils and soil communities associated with gypsum. The three project datasets which were compiled included vegetation, soil, and seed bank data (Table 1). Datasets were combined where appropriate to extend the sampling region and obtain a more comprehensive picture of the vegetation and soil profiles for differing soil-vegetation interactions within and around LMNRA and to identify specific characteristics, if any, of vegetation and soil environments. The LTV and Northshore Rd reference site studies occurred within the same time period. The Northshore Rd reference sites were evaluated alone; however, the inclusion of the LTV sites broadened the elevation and geographical profiles for identifying and defining gypsum soil areas specifically and for evaluating their vegetation and soil properties. The Northshore pre-reconstruction sites above-ground density and presence-absence data of perennial plant species were combined with the equivalent Northshore Rd reference site data, assuming that perennial plant species composition is slow to change over time. These two datasets occur within the same areas of impact along and in the path of destruction of the new Northshore Rd route. The seed bank samples results from the Pre-Reconstruction of Northshore Road study concentrated on a specific region in question and are analyzed independently.

Table 1 Project datasets included and compiled for defining gypsum vegetation and soil communities in Lake Mead National Recreation Area, eastern Mojave Desert.

Project Title	Years Conducted	Seed Bank (method)	Above ground vegetation			Soil Properties		
			density	richness	cover	physical	chemical	biological
Pre-Reconstruction Seed Bank Analysis of Northshore Road	*2007*	x (emergence)	x					
Northshore Rd Vegetation and Soil Reference Sites	*2009*		x	x	x	x	x	x
Long-Term Vegetation Sites	*2008-2009*			x	x	x	x	

PROJECT 1 *Pre-Reconstruction Seed Bank Analysis of Northshore Road*



Assessment of native above ground plant community and seed bank prior to Northshore Rd realignment in Lake Mead National Recreation Area

Contributed by E. Cayenne Engel
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Univeristy of Nevada, Las Vegas

Project Purpose

The purpose of this study was to examine the above ground vegetation and soil seed bank that would be present in topsoil during the construction process that would facilitate the recovery of the above ground vegetation post-construction. As part of the road reconstruction and alignment in LMNRA, resource management require the top lay of soil (topsoil) to be salvaged and stockpiled within close proximity to the site of origin. Topsoil salvage retains the soil seed bank to assist with reestablishment of the vegetation community and retains native soil biota During soil salvage, deeper soil fractions may be including during the mechanical removal process, diluting soil seed banks during reapplication. Guo et al. (1998) reported that the 0-5 cm soil surface depth contained 97% of seeds in Mojave Desert seed banks. Scoles-Sciulla and Defalco (2009) found that the germinable soil seed bank in areas along Northshore Rd in LMNRA was diluted by 14% after 4 months retained in a stockpile then reapplied. Reclaiming soils for amelioration of disturbance has mixed effects: reclaiming soils and reapplication may scar or break seeds and enhance germination, while piling may increase mortality due to germination during seed burial or fungal infestation. However, evaluation of soil seed banks still provide information relating to the potential germinable soil seed bank post disturbance.

Project Description

Construction included major road revisions including slight to significant road shifts, new routes and new bridges at Echo Wash, Valley of Fire Wash, and the Overton Beach Rd/St. Thomas Rd intersections with Northshore Rd (Table 2; Figure 10) as described in the FHWA Northshore Project. These road segments are located in soils that included gypsum as the soil parent material and formerly undisturbed gypsiferous soil habitats including areas with established desert pavement and highly developed biocrust communities in LMNRA (Table 3). To quantify the persistent soil seed bank prior to the Northshore Rd realignment in LMNRA, soil seed bank samples were

obtained in September 2007 with the goal of collecting samples after seeds for the year have germinated likely in spring or the previous winter), but before the fall precipitation, with the idea that those emerging species are part of the persistent soil seed bank. Twenty-three non-permanent, randomly placed 10 m × 10 m (0.01 ha) plots were established along the 2007 FHWA Northshore Project proposed route (Table 4; Figure 11). Plots were distributed across three main site corridors along Northshore Rd where construction sites had been identified by FHWA.

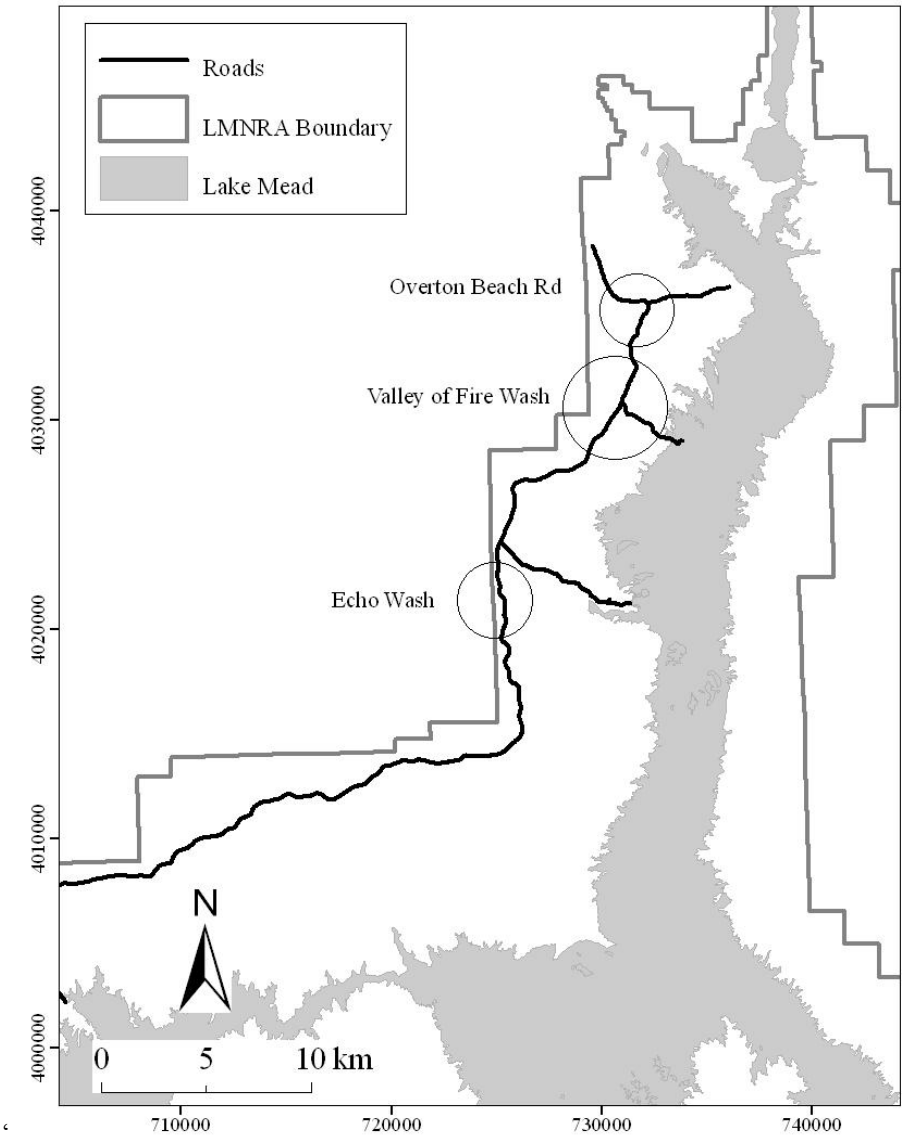


Figure 10 Study site locations along Northshore Rd (circled) in Lake Mead National Recreation Area, Mojave Desert, USA that were identified as slated for realignment in 2007 for the 2008 Rehabilitate Northshore Rd Project by the Federal Highway Administration. UTM NAD 83 Zone 11.

Table 2 Location and description of four regions of major construction along Northshore Rd in Lake Mead National Recreation Area, eastern Mojave Desert for the Rehabilitate Northshore Rd Project. Listed is the approximate southernmost latitude and the northernmost latitude (in UTM NAD 83 Zone 11) along Northshore Rd of construction start and end of each segment, along with the estimated length of road (or roadway) that was disturbed ("length new road") and the length of the original road that was obliterated ("length road obliteration").

Location	Work proposed	S. Lat, N. Lat	Length new road (m), length road obliteration (m)
Echo Wash	New bridge, slight road realignment	4020938, 4021407	422, 446
Valley of Fire Wash	New bridge, significant road realignment (curve elimination)	4031759, 4032975	1236, 1324
Overton Beach Road	Realignment, curve adjustment	4035438, 4035664	470, 556
St. Thomas Road	Realignment, establishment of new route	4035788, 4036129	357, 278

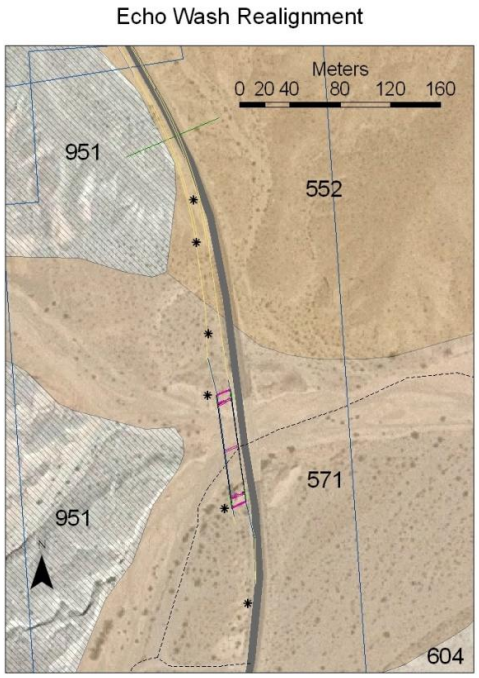
Table 3 Soil and plant associations for the four regions of Lake Mead National Recreation area that were slated for road realignment for the Rehabilitate Northshore Rd Project. Data are from the soil survey of Clark County area, Nevada, Lake Mead National Recreation Area, special report, by Douglas Merkler, National Resources Conservation Service and Leon J. Lato, National Resources Conservation Service. Realignment locations are organized south to north (top to bottom) along Northshore Rd. UTM NAD 83 Zone 11.

Realignment Location	Soil Series	Gypsum content (%)	Dominant Native Perennial Plant Species
Echo Wash	571 (Carrizo, Riverbend) 552 (Cheme, Dry Huevi, Huevi) 951 (Drygyp, Guardian, Baseline)	0 0 40-90	*Ambrosia dumosa* *Bebbia juncea* *Larrea tridentata*
Valley of Fire Wash	552 (Cheme, Dry Huevi, Huevi) 603 (Huevi) 950 (Drygyp) 965 (Azsand, Mesabase, Rositas)	0 0 40-90 0	*Ambrosia dumosa* *Larrea tridentata* *Suaeda moquinii* *Krameria* spp.
Overton Beach Road	930 (Cololag, Badland) 950 (Drygyp)	0 40-90	*Ambrosia dumosa* *Atriplex confertifolia* *Ephedra nevadensis* *Eriogonum inflatum* *Pleuraphis rigida* *Psorothamnus fremontii*
St. Thomas Road	950 (Drygyp)	40-90	*Ambrosia dumosa* *Pleuraphis rigida*

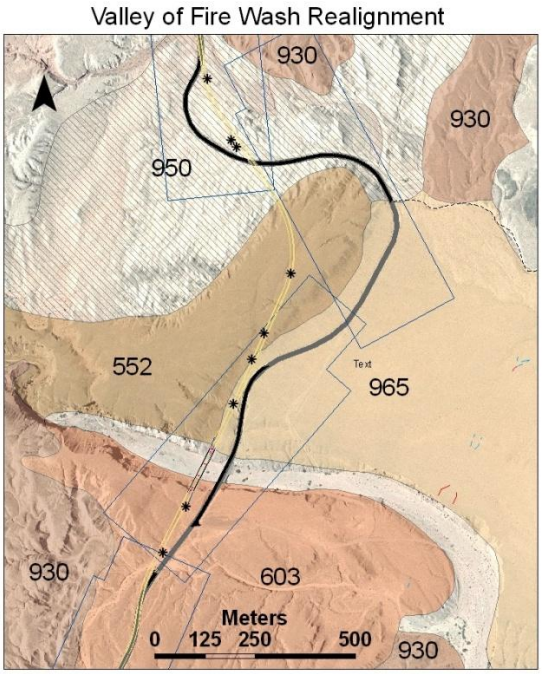
Table 4 General locations and UTMs (NAD 83 Zone 11) of assessment sites for the native above ground plant community in the proposed path of destruction along Northshore Rd in Lake Mead National Recreation Area, eastern Mojave Desert; with general location of road segments labeled by nearby landmark: Echo Wash, Valley of Fire (VOF) Wash, the Overton Beach Rd intersection with Northshore Rd, and the St Thomas intersection with Northshore Rd.

Site ID	General Location along Northshore Rd	UTM-X	UTM-Y
1	VOF Wash South	731403	4031890
2	VOF Wash South	731346	4031776
3	VOF Wash Mid	731597	4032321
4	VOF Wash Mid	731567	4032255
5	VOF Wash Mid	731521	4032145
6	Overton Beach Rd	731521	4032145
7	Overton Beach Rd	731903	4035673
8	Overton Beach Rd	731995	4035674
9	Overton Beach Rd	732078	4035659
10	VOF Wash North	731516	4032801
11	VOF Wash North	731457	4032955
12	VOF Wash North	731529	4032784
13	VOF Wash Mid	731664	4032470
14	Echo Wash South	725418	4021104
15	Echo Wash South	725437	4021028
16	Echo Wash North	725405	4021194
17	Echo Wash North	725406	4021243
18	Echo Wash North	725396	4021316
19	Echo Wash North	725394	4021349
20	Echo Wash South	725433	4021075
21	St. Thomas	730765	4035844
22	St. Thomas	730759	4036073
23	St. Thomas	730747	4035966

a)



b)



c)

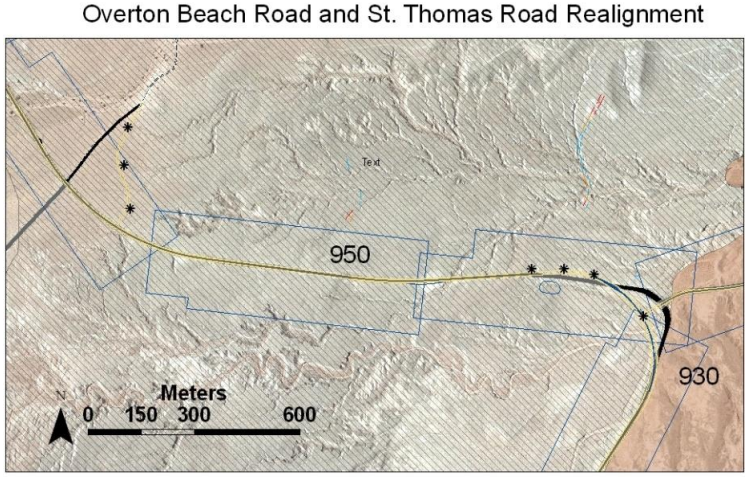


Figure 11 Engineering realignment along with historic path of Northshore Rd at the intersection of Northshore Rd with a) Echo Wash, b) Valley of Fire Wash, and c) Overton Beach Rd. and St Thomas Rd, with associated mapping units in Lake Mead National Recreation Area, Mojave Desert. Yellow outlines represent the new road path, as proposed in 2007. Grey lines represent Northshore Rd prior to construction. Black likes were drawn by the engineers as regions of the current road which will be obliterated. New bridges at Echo Wash and Valley of Fire Wash are represented by blue lines with pink bars. Black asterisks indicate the sites from which plant community information was collected. Soil association descriptions for the three number codes on the map are located in table 2. Regions shaded with hashed lines represent soil types with some gypsum content. UTM NAD 83 Zone 11.

PROJECT 2 *Northshore Rd Vegetation and Soil Reference Sites*



Assessment of native above ground plant and soil communities in undisturbed habitats along Northshore Rd, Lake Mead National Recreation Area,

Contributed by Lindsay P. Chiquoine
(Research Assistant),
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Project Purpose

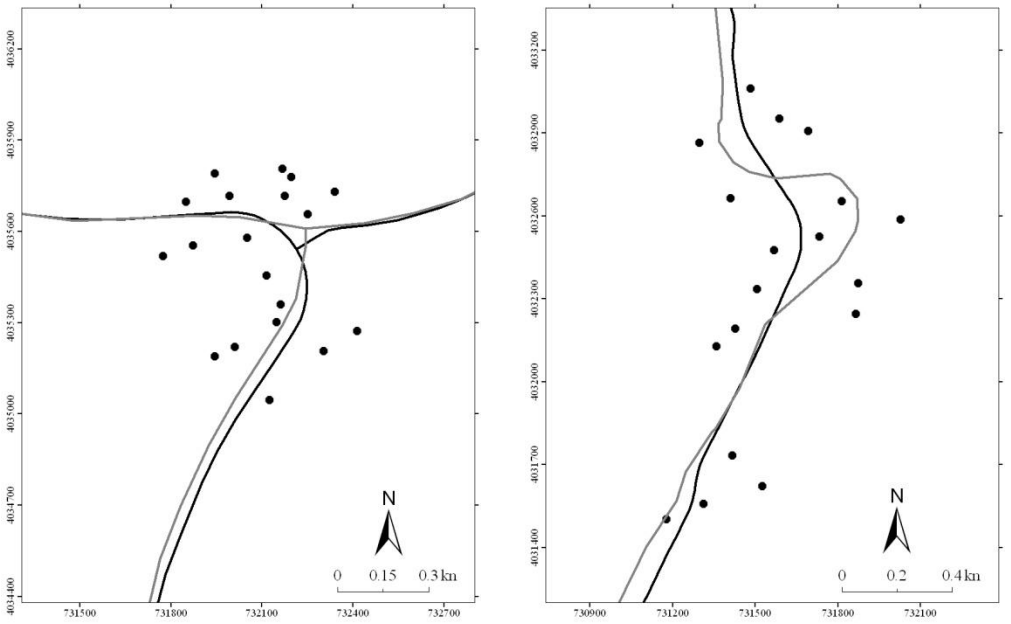
The second phase of the Northshore Rd Project concentrated disturbance in gypsiferous soil habitats, which differs in species assemblages and soil environments compared to non-gypsum parent materials. The stretches of undisturbed lands along the Northshore Rd corridor are mostly composed of hyperthermic and shallow Typic Petrogypsids, Durinodic Haplocalcids, Typic Calciargids, and Typic Haplodurids. These gypsum-derived soils have greater amounts of sulfur, calcium carbonates and higher silt content and are often paired or adjacent to soils with high carbonates. These areas also tend to have a lower vegetation cover and higher biocrust cover and species diversity. Gypsiferous soils in LMNRA support rare plants, such as the Las Vegas bearpoppy (*Arctomecon californica*) and southwestern ringstem (*Anulocaulis leiosolenus).* These communities are not well defined. Surveys of native vegetation and soil habitats provide information on the characteristic native assemblages and soil environment in undisturbed or relatively undisturbed areas, which assists with evaluating impacts from disturbance and developing active restoration goals such as species selection and treatment.

Project Description

In 2009, fifty-five permanent undisturbed 30 m × 30 m (0.09 ha) reference sites were established randomly within the same soil mapping units as the Northshore Rd realignment and within a 200-m proximity of Northshore Rd (Table 5). Each site contains a nested 10 m × 10 m (0.01 ha) subplot at the southwestern corner which contained 1 m × 1 m subplots centered at 0.5, 5, and 9.5 m along the southern and northern boundaries. Road segments affected by the Northshore Project included segments along Northshore Rd at Echo Wash, Valley of Fire (VOF) Wash and Fire Wash, and at the intersection with Overton Beach Rd, which coincide with the same areas as the pre-reconstruction Northshore Rd sites from 2007 (Figures 10 & 12). Within the nested site design areal percent cover was estimated for each perennial plant species. From within each site, soil analysis samples were taken.

a) Northshore Rd and Overton Beach Rd

b) Northshore Rd and Fire Wash Rd



c) Northshore Rd and EchoWash Rd

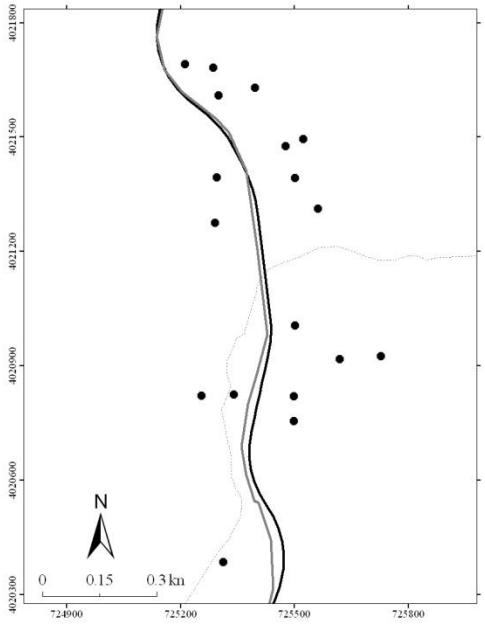


Figure 12 The new path of Northshore Rd. (in black) juxtaposed with the historic Northshore Rd. route (in grey) at the intersections with a) Overton Beach Rd., b) Fire Wash Rd. (AR106) and Valley of Fire Wash, and c) Echo Wash, Echo Wash Rd and Bitter Springs Rd in Lake Mead National Recreation Area, Mojave Desert. UTM NAD 83 Zone 11.

Table 5 Vegetation and soil reference sites within Lake Mead National Recreation Area, Mojave Desert, within 200-m of Northshore Rd and within proximity of the Rehabilitate Northshore Road Project sites at the intersections with, from south to north, Echo Wash, Valley of Fire (VOF) Wash, and Overton Beach Rd (Overton). UTM NAD 83 Zone 11.

Site ID	General Location	UTM-X	UTM-Y	Site ID	General Location	UTM-X	UTM-Y
1	Echo Wash	725477	4021476	29	Overton	732169	4035805
2	Echo Wash	725396	4021629	30	Overton	731994	4035716
3	Echo Wash	725255	4020821	31	Overton	731775	4035518
4	Echo Wash	725301	4021608	32	Overton	732304	4035206
5	Echo Wash	725619	4020917	33	Overton	732197	4035778
6	Echo Wash	725291	4021275	34	Overton	732251	4035655
7	Echo Wash	725296	4021393	35	Overton	731946	4035188
8	Echo Wash	725501	4021005	36	Overton	731874	4035553
9	Echo Wash	725313	4020384	37	Overton	732175	4035715
10	Echo Wash	725501	4021392	38	VOF Wash	731588	4032950
11	Echo Wash	725524	4021494	39	VOF Wash	731416	4031732
12	Echo Wash	725499	4020754	40	VOF Wash	731410	4032662
13	Echo Wash	725562	4021311	41	VOF Wash	731484	4033059
14	Echo Wash	725498	4020819	42	VOF Wash	731693	4032905
15	Echo Wash	725728	4020925	43	VOF Wash	731427	4032191
16	Echo Wash	725213	4021691	44	VOF Wash	731177	4031500
17	Echo Wash	725287	4021682	45	VOF Wash	731526	4031621
18	Echo Wash	725341	4020824	46	VOF Wash	731298	4032863
19	Overton	732116	4035455	47	VOF Wash	731815	4032652
20	Overton	732415	4035272	48	VOF Wash	731866	4032244
21	Overton	732149	4035300	49	VOF Wash	731569	4032474
22	Overton	732341	4035730	50	VOF Wash	731506	4032334
23	Overton	732162	4035359	51	VOF Wash	731312	4031557
24	Overton	732051	4035579	52	VOF Wash	732028	4032586
25	Overton	731850	4035697	53	VOF Wash	731733	4032523
26	Overton	732011	4035219	54	VOF Wash	731874	4032354
27	Overton	731945	4035789	55	VOF Wash	731360	4032126
28	Overton	732126	4035045				

PROJECT 3 *Long-Term Vegetation Sites*

Project Purpose

Permanent landscape survey sites across the region provide vegetation and soil data that can be used to document current conditions, contribute to rare species inventories and status of invasive plant populations, monitor growth and changes over time, and evaluate the impacts of environmental changes, such as those related to climate change or a large disturbance event (Abella et al. 2012a; 2012b).

Project Description

The long-term vegetation (LTV) sites established in the eastern Mojave around LMNRA are a part of a larger vegetation and inventory project. The LTV plots included in this study included 126 30 m × 30 m sites randomly identified in the in southern Nevada and in the northwestern corner of Arizona, within a 755,000 ha (1.9 million ac) area (Figure 13). A 449,000-ha portion of this region includes LMNRA including areas around the recreation area and Lake Mohave, and a 306,000 ha area surrounding the recreation area, which is managed by Bureau of Land Management (BLM). Each site contains a nested 10 m × 10 m (0.01 ha) subplot at the southwestern corner which contained 1 m × 1 m subplots centered at 0.5, 5, and 9.5m along the southern and northern boundaries of the $100m^2$ subplot. Within the nested site design areal percent cover was estimated for each perennial plant species. From within each site, soil analysis samples were taken.

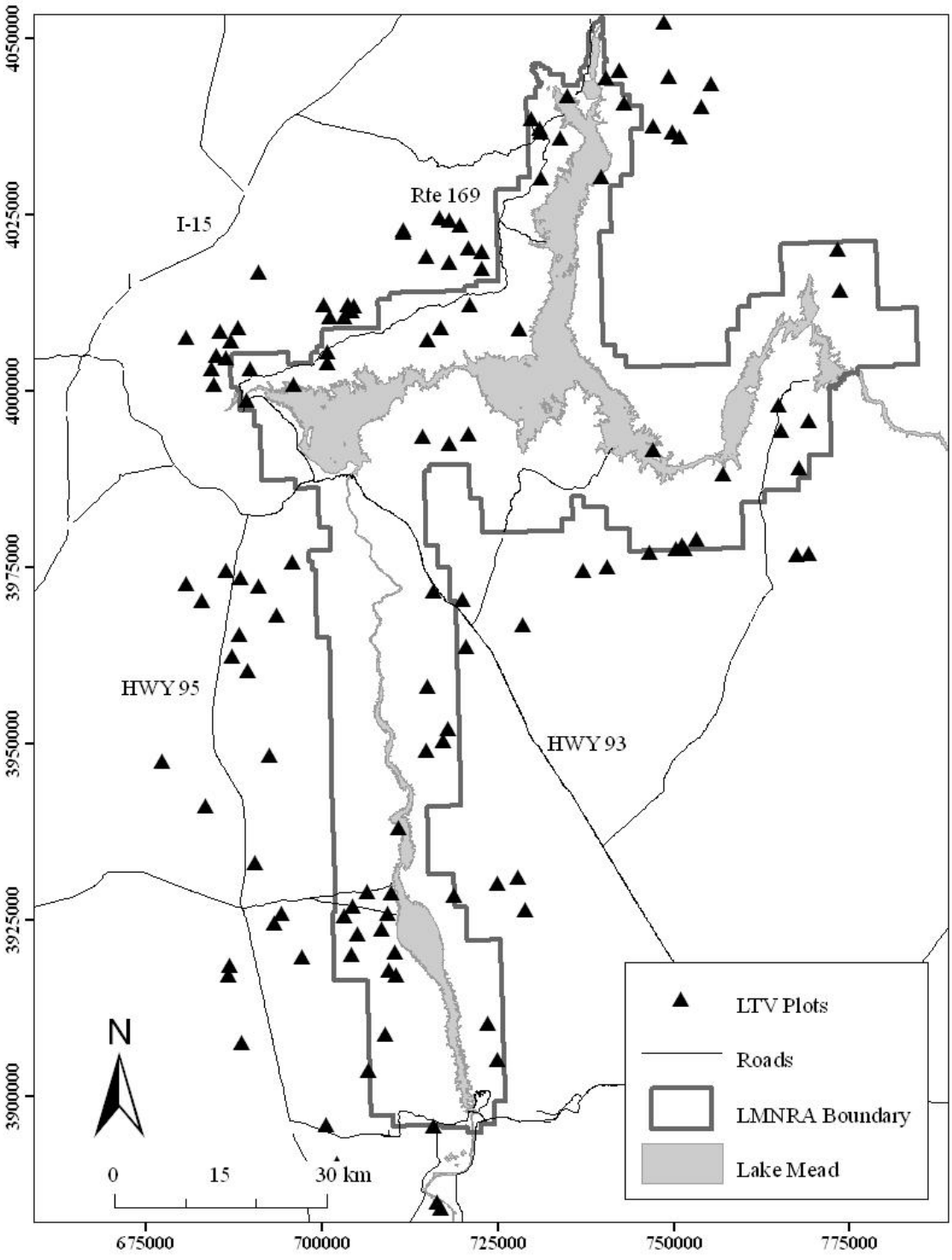


Figure 13 Location of the 126 long-term vegetation sites in and around Lake Mead National Recreation Area, eastern Mojave Desert. UTM NAD 83 Zone 11 and 12.

METHODS

A hierarchical approach was used initially to establish a system for clustering sites based on the soil environment, currently published information (e.g. Lato 2006; Abella et al. 2012a) and information easily accessed through government or public databases (e.g. Natural Resource Conservation Service, NPS, Google Earth). Where research sites occur, areas are identified using GIS software and mapping within soil and vegetation regions. Using site, soil, and vegetation information as site identifiers provides an initial metric for analyses of site and landscape data collected. Additional statistical programs and tools provide analytical, qualitative and quantitative data to either verify existing site descriptions or delineate new metrics for classifying a soil-vegetation profile.

Data Collection and Analyses

Site and Soil

At each site the 55 0.09-ha Northshore Rd reference site and 126 0.09-ha LTV sites, southwest corners of the sites, location was recorded (Universal Transverse Mercator [UTM] coordinates, using a global positioning system). Elevation (measured with a Global Positioning System [GPS] unit), slope aspect (compass) and slope gradient (clinometers) were recorded across the entire site. The Clark County, NV (Lato 2006) and Central Mohave County, AZ (Strait 2006) soil surveys were used to identify soils that were mapped following standard U. S. Natural Resource Conservation Service (NRCS) protocols (Soil Survey Division 1993) in an order 3 survey, with a minimum mapping unit of 4 ha, for Clark County, NV, and an order 2 to 3 survey, minimum mapping unit of 16 ha for Mohave County, AZ. For all three studies, soil associations, soil great groups, soil subgroups, and parent material were identified. As described in Abella et al. (2012), LTV site (n=126) soils were sampled where pedons were fully described and specific soil type was identified per LTV site. Additionally, sites are categorized in low (149-490 m), mid (491-776 m), and high (777-1222 m) elevation categories following Abella et al. (2012).

Soil samples from the 126 LTV and 55 Northshore Rd reference sites were sampled within the same 2008-2009 season and the same sample methods and laboratory tests and methods were used to estimate soil variables. Two samples obtained from the SW and NE corners were composited for a 400-cm^3 total sample/plot. All soil samples were obtained from the surface 0–5 cm depth to provide a consistent depth across sites while remaining within typical depths of A horizons at the sites (Cochran and Richardson 2003). Soil samples were air dried, sieved through a 2-mm sieve, and analyzed for texture (hydrometer method following Tan (2005)); pH (1:3 soil:water); available P (Olsen sodium-bicarbonate extraction); total C, N, and S (dry combustion, CNS analyzer); $CaCO_3$ (manometer method, Burt); organic C (subtraction of inorganic C from total C); NO_3, SO_4, and Cl (ion chromatography); and the water-soluble concentrations of Ca, B, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, and Zn (1:3 soil:water extracts, inductively coupled plasma mass spectroscopy) following Burt (2004).

Bulk density was collected using the same methods as soil analysis samples. Bulk density was estimated by sieving soil samples through a 2-mm sieve and oven drying samples at 105°C for 24 hours. Bulk

density of the <2-mm fraction was calculated with the volume (estimated by water displacement) of coarse fragments ≥ 2 mm included (>2mm wt; Burt 2004). All nutrient concentrations were converted to volumetric contents at g/m^2 at 5cm depth using bulk density. Correlations were examined with Pearson product- moment correlation coefficients to determine if percent soil variable results were correlated with calculated volumes (using bulk density analysis results; g/m^2 at 5 cm depth). Calculated percent values of total N, total C, total S, $CaCO_3$, inorganic and organic C, P, ions NO_3, SO_4, Cl, Ca, B, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, and Zn were all highly correlated with calculated volumes for g/m^2 at 5 cm depth; and calculated volumes were used in soil analyses.

Principal components analysis (PCA) was used to identify significant site and soil variables that influence potential site dissimilaries and hierarchical (soil) grouping for Northshore Rd reference sites alone and LTV and Northshore Rd reference sites in a combined dataset. PCA was run in PC-ORD (MJM Software Design 2006) as a cross-products matrix correlation with calculated scores for variables as a distance-based biplot with randomization tests. Both site (elevation, slope gradient, transformed aspect following Beers et al. 1966) and soil [all calculated volumes (in g/m^2) of total N, S, C, $CaCO_3$, inorganic and organic C, Olsen P, and ions, and texture consisting of percent clay, silts, and sand, pH, and electrolytic conductivity (EC μS/cm)] variables were included. This provided a summary of site and soil properties associated with different levels of a soil organizational hierarchy, while also identifying potential factors that may more greatly influence site grouping.

For a second round of analyses highly correlated soil parameters were removed with a single soil parameter representing the correlated set (e.g. total C was highly correlated with inorganic C and $CaCO_3$) to remove any potential of redundancy or unequal representation of highly correlated gradients (Peck 2010). For both Northshore Rd reference sites alone and LTV and Northshore Rd reference sites combined, to verify significant site and/or soil variables which influences site placement in PCA analysis, stepwise multiple regression analysis models were tested using the software SAS 9.1 (SAS Institute 2002-2008, Cary, NC) with PCA coordinates (PCA scores).

For both Northshore Rd reference sites independently and for LTV and Northshore Rd reference site combined dataset, site and soil variables were analyzed by individual analyses of variance (ANOVA) to compare differences of soil properties between categories within each grouping structure to identify significant differences between categories and also delineate which soil hierarchical structure best defines gypsum-derived soils specifically and may be used in a predictive model. Additionally, elevation categories were included with whichever hierarchical structure best delineated gypsum specifically for the LTV and Northshore Rd reference plot dataset, and statistical analyses were applied within this grouping structure in similar models already described.

Vegetation

Within both the 55 0.09-ha Northshore Rd reference site and 126 0.09-ha LTV sites mean cover for perennial plant species was estimated across the entire site within the nested design using cover class categories from Peet et al. (1998): 1 = trace (assigned

0.1), 2 = 0 - 1%, 3 = 1 - 2%, 4 = 2 - 5%, 5 = 5 - 10%, 6 = 10 - 25%, 7 = 25 - 50 %, 8 = 50 - 75%, 9 = 75 - 95% and 10 = > 95%. The center point for each cover class was used for estimating means per species. Perennial plant cover was estimated within smaller subplots and within larger site if a species was not present within smaller sites. Mean cover per species, per growth form, and within established soil hierarchies was calculated. For the Northshore Rd reference sites and the Northshore Rd pre-reconstruction sites, the total density/ha was calculated per species, growth form, and within soil hierarchical groups.

For the Northshore Rd reference sites a 55 site × 45 species matrix representing all plant species detected at all reference sites was created. Nonmetric multidimensional scaling (NMS) conducted in PC-ORD (MJM Software Design, Gleneden Beach, Oregon, 2006), with correlation distance measure, 2 axes with 250 real runs and with 20 iterations to evaluate stability and randomized tests, was used for the Northshore Rd reference sites to identify the strongest structure of site ordination based on species presence-absence data. Initially, NMS was run several times on autopilot slow and thorough setting to determine the maximum number of axes. Presence–absence data was used over relativized cover data to focus more on plant fidelity since some species had a high range of cover across plots. Species and soil vector overlays were examined and compared with statistical tests.

A matrix was complied with the 126 LTV and 55 Northshore Rd reference sites combine (total 181 sites) × 131 species representing all plant species detected at all sites. To compare species composition among sites, NMS was conducted in PC-ORD (MJM Software Design 2006), with correlation distance measure, 2 axes with 250 real runs and with 20 iterations to evaluate stability and randomized tests, was used for the Northshore Rd reference sites and LTV sites combine to identify the strongest structure of site ordination based on species presence-absence data. Initially, NMS was run several times on autopilot slow and thorough setting to determine the maximum number of axes. Presence–absence data was used over relativized cover data to focus more on plant fidelity since some species had a high range of cover across plots. Species and soil vector overlays were examined and compared with statistical tests. A comprehensive analysis of the hierarchy of the LTV sites can be found in Abella et al. (2012a).

To determine specifically how community structure differed among soil types, indicator species analysis (ISA) was used (Dufrene & Legendre 1997) in PC-ORD (MJM Software Design 2006) on both the Northshore Rd reference site dataset and the Northshore Rd reference and LTV sites combine. ISA (Dufrêne and Legendre 1997) is a statistical tools used for hierarchical community analysis and is used for identifying species that indicate fidelity among hierarchically classified communities, such as those defined by vegetation, site, or soil groups or parameters. It combines the relative dominance (based on presence for this analysis; Bakker 2008) and frequency (number of sites occupied) of a species within a group to produce an indicator value that ranges from zero (no fidelity to a group) to 100 (maximum fidelity). Statistical significance, the probability of obtaining a given indicator value (IV) due to chance alone, was determined by a Monte Carlo test (1000 permutations), as implemented in PC-ORD (MJM Software Design 2006). A 'strong indicator' of a particular soil type was defined as one with an IV of 0.25-0.50, a

'very strong indicator' as one with an IV of 0.51-0.75, and an 'excellent indicator' as one with an IV (greater than or equal to) 0.76. For the reference sites dataset, a reduced species list of 33 species using presence-absence was used since species with only one or two occurrences never yield an indicator value stronger than expected by chance (McCune and Grace 2002) and non-native annual species presence differs year to year. For the reference sites and LTV combined dataset, a reduced species list of 83 species using presence-absence was due to the same limiting factors of ISA listed above.

Using stepwise multiple regression (SAS Institute 2002-2008, Cary, NC), presence-absence species data were used as explanatory variables for the NMS coordinates for the Northshore Rd reference sites alone and the LTV and Northshore Rd sites combine to identify which species best explain site ($P \leq 0.001$ and r^2 contribution of ≥ 0.05 in model) placement along axes and to identify if they reflect both NMS ordinations and the indicator species analyses. For the Northshore Rd reference sites, all species were included in analysis model. For the LTV and Northshore Rd reference sites the total species used in the regression analyses were reduced by those individual species with the greatest significant influence on NMS ordination ($r^2 \geq 0.20$) and/or were significant in indicator species analyses. To identify any correlations between plant species presence and to identify correlations between total species cover and perennial plant species richness with site and soil variables, Pearson product-moment correlation coefficients was used. Additionally, site and soil variables were used as explanatory variables for NMS coordinates in multiple regression analysis to delineate potential variables which most influence species distribution ($P \leq 0.001$ and r^2 contribution ≥ 0.05 in model).

The Northshore Rd reference sites and the Northshore Rd pre-reconstruction sites above ground perennial plant 100-m^2 sites were compiled to provide an estimated perennial plant density/ha along the Northshore Rd construction corridor by relevant hierarchical site groups found to be most beneficial for direct applicability with currently accessible habitat descriptions (i.e. general soil parent material and elevation).

Seed Bank

Seed bank samples were conducted from September 2007 – March, 2008. Seed bank samples from the Northshore Rd pre-reconstruction sites in September 2007 from within (up to) five microsites within each of 20 sites along the new Northshore Rd corridor. The five microsites included *Larrea tridentata, Ambrosia dumosa, Psorothamnus fremontii, Ephedra* spp., and interspaces (defined as $\geq$ 1 m from the nearest perennial plant). Soil was collected in September with the goal of collecting samples after seeds for the year have germinated (likely in spring or the previous winter), but before the fall monsoons, with the idea that those seeds we find in the soil are part of the persistent soil seed bank. Not all microsites were present in each site due to differences in plant species composition across sites. Three seed bank samples were collected per microsite totaling 400 cm^3. Seed bank samples were delivered to the LMNRA nursery facility the same day of collection and the sample was placed in pots on top of a (Black Gold cactus mix, Sun Gro Horticulture Distribution, Inc., Bellevue, WA, USA) in 4-L, 15-cm diameter pot for each microsite type at each site. A watering system was constructed and fitted to a greenhouse bench in the northeast corner of

the Lake Mead nursery outdoors so that soils with seed bank samples would experience natural climatological factors during the grow out period (Figure 14). Benches were outfitted with shade cloth to reduce heat stress and try to maintain higher soil moisture levels. Pots were watered daily, and plants counted then removed once identified. The number of forbs and grasses were counted.





Figure 14 Outside setup of seed bank assay for the *Pre-Reconstruction of Northshore Rd* assessment of native above ground plant community and seed bank in path of destruction at the Lake Mead National Recreation Area nursery facilities.

RESULTS

Soils

Northshore Rd Corridor

Sites crossed a wide range of soil types in the eastern Mojave. Northshore Rd reference sites and the Northshore Rd pre-reconstruction sites were located within 6 soil subgroups in 5 great groups, which included 4 soil rock origin material types and 4 general parent material categories. Northshore Rd pre-reconstruction seed bank sites are within areas that are now within the new pathway of Northshore Rd. Two soil associations are dominated by soil types containing Gypsids, and three associations are dominated by soil types with Calcids. One soil type with mixed alluvium parent material is dominated by Orthents. All soil properties include the top 0-5 cm depth soil surface. Reported soil constituents are calculated to g/m^2 at 0-5 cm depth. For the Northshore Rd sites, EC was highly positively correlated with SO_4, Ca, Ni, and Fe; and total C was highly positively correlated with $CaCO_3$ and inorganic C, however along a different axis. Additionally, % silt was highly negatively correlated with % sand.

Northshore Rd reference site PCA results show that 45% of the variance, explained by a 2 axis solution, was characterized by Ni (r^2 = 0.83), Ca (r^2 = 0.80), SO_4 (r^2 = 0.77), and EC (r^2 = 0.75) along axis one, and Cu (r^2 = 0.66) and total N (r^2 = 0.62) along axis two. Grouped by three levels of hierarchy within soil taxonomy, soil variable overlay, with a $r^2 \geq 0.60$ cutoff, show EC, SO_4, Ca, Fe, and Ni were correlated with Gypsids sites at all three soil taxonomic levels, and total C, $CaCO_3$, and inorganic C were correlated with igneous-metamorphic or mixed alluvium sites at the parent material level (Figures 15-17). Other soil types appear to loosely cluster and are not distinguished by any soil or vegetation variables at a soil great group or subgroup level. Soil variable clusters reflect correlated soil variables. All soil taxonomic levels reflect similar information showing a correlation between soil properties and gypsum-derived soils, which were evaluated with additional statistical analyses. Multiple regression models using PCA scores from analysis of Northshore Rd reference sites resulted in Ni (partial r^2 = 0.83; F = 257.83, P<0.0001) and inorganic C (partial r^2 = 0.12, F = 85.59, P<0.0001) most defining the difference between sites along axis one, with a total r^2 model of 0.94 (P<0.001); and Cu (partial r^2 = 0.68, F = 101.51, P<0.0001), % silt (partial r^2 = 0.17, F = 52.22, P<0.0001), and Mg (partial r^2 = 0.05, F= 20.04, P<0.0001), with a total model $r^2 \geq 0.88$ (P<0.0001) most defining the difference between sites along axis two. These data indicate possible soil variables which best describe the gypsum soil profile.

Graphed soil PCA scores with vegetation vector overlay, with $r^2 \geq 0.30$, show that *Atriplex confertifolia* and *Pleuraphis rigida* were mostly correlated with Gypsids sites (Figures 18-20). The species *Astragalus preussii*, *Isocoma acradenia*, and *Suaeda moquinii* all cluster towards Gypsids, although in a multiple regression analysis, only the *Astragalus* species was significant in explaining PCA scores. Multiple regression model using PCA scores with plant species presence-absence as explanatory variables resulted in the *Atriplex confertifolia* (partial r^2 = 0.57; F = 66.31,

P<0.0001) and *Atriplex canescens* (partial r^2 = 0.12; F = 18.66, *P*<0.0001) as the most significant species explaining PCA axis 1 scores, with a full model $r^2 \geq 0.68$ (*P*<0.0001), and *Astragalus preussii* (partial r^2 = 0.17; F = 10.21, *P*<0.0001) and *Pleuraphis rigida* (partial r^2 = 0.11; F = 7.54, *P*<0.0001) as the most significant species explaining PCA axis 2 scores, with a full model $r^2 \geq 0.28$ (*P*<0.0001).

Individual ANOVAs for soil great groups showed that EC, $CaCO_3$, and inorganic C influenced the most differences between categories, and that the great group category Petrogypsids in particular was different from the other four soil great groups (Table 6). Soil variables which did not show significant difference between soil great groups included, total N, organic C, NO_3, Olsen P, Na, B, Co, Cu, Mo, % Clay, silt and sand. Individual ANOVAs based on soil subgroup categories resulted in Typic Petrogypsids with the most significant differences with other soil subgroups compared to other comparisons (Table 7). Typic Petrogypsids had the most differences with *Typic Haplodurids*. Soil variables that did not show significance between soil subgroups included total N, Organic C, NO_3, Olsen P, B, Co, Cu, Mo, % Clay. Again within individual ANOVA results, gypsum was found to have the most differences from the other parent material categories, particularly in total C and $CaCO_3$ which were highly correlated (Table 8). ANOVA results present similar information to the PCA analysis displaying the differences between site soil parent materials (Figure 21 & 22). Soil variables which did not show significance between soil parent material included total N, Organic C, NO_3, Olsen P, B, Cd, Cu, Mn, Mo, and % Clay, which is mostly consistent with the above soil taxonomic hierarchy. Gypsum had the most significant differences with mixed alluvium soils. The general parent material also only has one other difference between other non-gypsum categories between mixed alluvium and sedimentary (sandstone). Table 9-12 presents the means with standard error and ranges of soil properties which were significant for comparing gypsum to other parent material categories for soils within the Northshore Rd corridor within LMNRA.

LTV and Northshore Rd Reference Sites

LTV and Northshore Rd reference sites together ranged across 23 soil subgroups within 16 great groups and were within 9 rock origin material types, or four general parent material classifications. Most soils were within Calcids and Gypsids suborders. Similar correlations occurred as with the Northshore Rd reference site dataset alone: EC was highly correlated with Ni, SO_4, and Ca, but not as highly correlated as just within Northshore Rd reference sites; total C was highly correlated with $CaCO_3$ and inorganic C; % sand and % silt were also highly negatively correlated; and bulk density was highly correlated with > 2mm wt.

PCA results showed that 37% of the variance between sites, explained by a 2 axis solution, was characterized by the soil parameters Ni ($r^2 = 0.83$), Ca ($r^2 = 0.78$) and SO_4 ($r^2 = 0.78$) along axis one and total C ($r^2 = 0.93$), $CaCO_3$ ($r^2 = 0.89$), and inorganic C ($r^2 = 0.89$) along axis 2. Soil variable vector overlay, with a $r^2 \geq 0.60$ cutoff, show a similar pattern influencing site clustering as the Northshore Rd reference sites, with EC, Ni, SO_4, Ca, and Mg correlated with Gypsids sites and total C, $CaCO_3$, and inorganic C correlated with Calcids sites (igneous-metamorphic) and Orthents sites (mixed alluvial) sites (Figures 23-27). Significant PCA soil variables overlay predominantly sites with gypsum derived soils (Petrogypsids and Haplogypsids), which include EC, Ni, SO_4, Ca, Mg and Fe (not shown at current orientation; Figure 23 & 26). Total C, $CaCO_3$, and inorganic C overlay mostly Haplodurids great group sites, which are composed to mixed alluvium parent material (Figures 23 & 25).

Multiple regression using PCA scores from analysis of LTV and Northshore Rd reference sites resulted in Ni g/m^2 at 5 cm depth (partial $r^2 = 0.83$, $F = 894.46$, $P<0.0001$), bulk density (partial $r^2 = 0.07$, $F = 126.59$, $P>0.0001$), and B g/m^2 at 5 cm depth (partial $r^2 = 0.05$, $F = 224.84$, $P>0.0001$) most defining the difference between sites along axis one, with a total model $r^2 = 0.96$ ($P<0.0001$); and total C g/m^2 at 5 cm depth (partial $r^2 = 0.93$, $F = 2404.75$, $P>0.0001$) most defining the difference between sites along axis two in ordinal space, with a total model $r^2 = 0.93$ ($P<0.0001$).

Individual ANOVA results for LTV and Northshore Rd reference sites grouped by great groups showed that Petrogypsids sites had the greatest number of significant soil variable differences with Torriorthents sites, which contained parent materials of igneous-metamorphic (consisting of granite, limestone and sandstone), mixed alluvium, and sedimentary (limestone) origin, and with Haplargids sites, which were either igneous-metamorphic (generally or granite) or mixed alluvium derived soils. Haplogypsids sites had the greatest number of significant differences with Petrocalcids, which were mostly of limestone origin. However, in either case of delineating the gypsum-derived soils, there were a number of other significant differences with other groups which were commonly occurring (Table 13 &14). Individual ANOVAs show that Gypsids subgroups, particularly Typic Petrogypsids, had the most number of soil property differences with other subgroup categories compared to other subgroup comparisons (Table 15 & 16). EC, Total S, Ni, SO_4, Ca, occasionally Fe, Mg, and K,

bulk density and >2mm wt were significantly different between Typic Petrogypsids and many of the other soil subgroup categories. EC was significantly different between Leptic Haplogypsids and 11 other subgroup categories. Other variables that influenced several differences included Fe, Zn, NO_3 Cu and % Silt. For rock origin material types, gypsum also had more soil variables which were significantly different than other categories, including EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, and bulk density (Table 17 & 18). Soil texture appears to also be significant between different categories; for example basalt was different from several other categories due to % clay. Soil parent material categories are more generally defined groups, with gypsum showing distinct differences in soil properties from the other three soil parent material categories and few soil property differences between the remaining three categories (Table 19 & 20). EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, bulk density, and >2mm wt appear to delineate gypsum, while total C, CaCO3, and inorganic C delineate igneous-metamorphic parent material from mixed alluvium and sedimentary parent material (Figures 28 & 29). Percent clay and bulk density were the only differences between mixed alluvium and sedimentary parent material (Table 20). Broken up into elevation categories, gypsum soil at low elevations appear to be more greatly distinct from other soil parent materials and gypsum at high elevations (Table 21; Figure 27). For middle and higher elevation gypsum sites, EC was different in most instances with soils derived from other materials (Table 21). Most of the differences between other soil categories appear to be influenced by elevation and soil texture (Table 22; Figure 27).

Vegetation vector overlay, with $r^2 \geq 0.15$, show weaker associations with site clusters than the Northshore Rd reference sites alone, with several species overlaying gypsum-derived soils and only one species, *Krameria erecta*, correlating with Calcids, Psamments, Fluvents, and Orthents sites (Figures 30-34).

Table 6 Significant soil variables ($\alpha \leq 0.05$) between soil taxonomic great groups for Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Great Group 1	Great Group 2	Significant soil variables
Calciargids	Haplocalcids	Cl
Calciargids	Haplodurids	$CaCO_3$, Inorganic C, Cl
Calciargids	Torriorthents	Total C, CaCO3, Inorganic C
Haplocalcids	Haplodurids	Ni
Haplocalcids	Torriorthents	Total C, $CaCO_3$, Inorganic C, Cd
Haplodurids	Torriorthents	Cd
Petrogypsids	Calciargids	Total S, Ni, Cl
Petrogypsids	Haplocalcids	pH, EC, Total S, Fe, SO_4, Ca, Ni, Zn, Inorganic C, Organic C, K, >2mm wt
Petrogypsids	Haplodurids	pH, EC, Total S, SO_4, Ca, Ni, Fe, K, Mg, Mn, Zn, Total C, $CaCO_3$, Inorganic C, Bulk density, >2mm wt
Petrogypsids	Torriorthents	EC, Total S, SO_4, Ca, Ni, Fe, Total C, $CaCO_3$, Inorganic C, Ni, Cd, >2mm wt

Table 7 Significant soil variables ($\alpha \leq 0.05$) between soil taxonomic subgroups for Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Soil Subgroup 1	Soil Subgroup 2	Significant soil variables
Durinodic Haplocalcids	Typic Haplocalcids	Na, % Silt, % Sand, Bulk Density, >2mm wt
Durinodic Haplocalcids	Typic Torriorthents	Cd
Typic Calciargids	Typic Torriorthents	Total C, CaCO3, Inorganic C, >2mm wt
Typic Calciargids	Durinodic Haplocalcids	Cl, >2mm wt
Typic Calciargids	Typic Haplocalcids	Na, % Silt, % Sand
Typic Haplodurids	Typic Torriorthents	Cd
Typic Haplodurids	Typic Haplocalcids	CaCO3, Inorganic C, % Silt, % Sand, Bulk Density, >2mm wt
Typic Petrogypsids	Typic Haplodurids	pH, EC, Total S, Ni, SO4, Ca, Fe, K, Mn, Zn, Total C, CaCO3, Inorganic C, Bulk Density, >2mm wt
Typic Petrogypsids	Durinodic Haplocalcids	pH, EC, Total S, Ni, SO4, Ca, Fe, Mg, Zn, Total C, Bulk Density, >2mm wt
Typic Petrogypsids	Typic Torriorthents	EC, Total S, Ni, SO4, Ca, Fe, Total C, CaCO3, Inorganic C, Cd, 2>mm wt
Typic Petrogypsids	Typic Haplocalcids	Total S, Ni, Fe, Zn, Na, % Silt, % Sand
Typic Petrogypsids	Typic Calciargids	Cl
Typic Torriorthents	Typic Haplocalcids	Total C, CaCO3, Inorganic C, Na, >2mm (rock) wt

Table 8 Significant soil variables ($\alpha \leq 0.05$) between soil general parent material categories for Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Parent Material 1	Parent Material 2	Significant soil variables
gypsum	igneous-metamorphic	Total S, Ni, Cl
gypsum	mixed alluvium	pH, EC, Total S, Ni, SO4, Ca, Fe, Zn, K, Mg, Co Total C, CaCO3, Inorganic C, Bulk density, >2mm wt
gypsum	sedimentary (sandstone)	Total S, Ni, Fe, Zn, Na, % Clay, % Sand
igneous-metamorphic	mixed alluvium	Cl, >2mm wt
igneous-metamorphic	sedimentary (sandstone)	Na, % Clay, % Sand
mixed alluvium	sedimentary (sandstone)	Na, Total C, CaCO3, Inorganic C, % Clay, % Sand, Bulk density, >2mm wt

Table 9 Mean with standard error (SE) and range of non-mineral soil properties for soil parent materials for soil types along the Northshore Rd corridor in Lake Mead National Recreation Area, Mojave Desert. Gypsum soil properties are highlighted in bold text.

Soil Variable	Units		**gypsum**	igneous-metamorphic	mixed alluvium	sedimentary	Across all groups
Total C	g/m^2	Mean	**930.19**	1089.24	2160.87	635.95	1504.593
		SE	**658.13**	209.78	1093.36	358.78	1065.697
		Min	**173.13**	850.11	606.71	400.99	173.130
		Max	**2905.07**	1242.27	3505.12	1048.93	3505.125
$CaCO_3$	g/m^2	Mean	**5782.14**	7150.55	15380.61	2545.23	10217.681
		SE	**4784.26**	1213.55	8045.88	768.25	8023.656
		Min	**600.10**	6178.34	3261.08	1790.25	600.098
		Max	**22171.42**	8510.62	26121.53	3326.11	26121.527

Table 10 Mean with standard error (SE) and range of significant physical soil properties for soil parent materials for soil types along the Northshore Rd corridor in Lake Mead National Recreation Area, Mojave Desert. Gypsum soil properties are highlighted in bold text. '*' soil variables correlated with gypsum-rich soils. Gypsum soil properties are highlighted in bold text.

Soil Variable	Units		**gypsum**	igneous-metamorphic	mixed alluvium	sedimentary	Across all groups
pH	-	Mean	**7.34**	7.57	7.69	7.48	7.528
		SE	**0.17**	0.03	0.25	0.23	0.267
		Min	**7.08**	7.53	7.19	7.29	7.079
		Max	**7.78**	7.60	8.34	7.73	8.339
EC*	µS/cm	Mean	**1381.80**	786.03	499.79	663.20	893.156
		SE	**493.44**	510.27	505.19	789.81	655.648
		Min	**211.80**	220.10	177.20	190.80	177.200
		Max	**1930.00**	1211.00	1763.00	1575.00	1930.000
Inorganic C	g/m^2	Mean	**693.86**	858.07	1845.67	305.43	1226.122
		SE	**574.11**	145.63	965.51	92.19	962.839
		Min	**72.01**	741.40	391.33	214.83	72.012
		Max	**2660.57**	1021.27	3134.58	399.13	3134.583
Sand	%	Mean	**74.74**	67.12	72.69	90.97	74.237
		SE	**9.65**	5.94	6.29	1.28	8.787
		Min	**45.70**	62.13	61.79	89.49	45.697
		Max	**91.11**	73.69	84.67	91.77	91.775
Silt	%	Mean	**25.01**	32.19	26.80	8.87	25.367
		SE	**9.53**	5.82	6.39	1.14	8.717
		Min	**8.86**	25.87	15.31	8.19	8.194
		Max	**53.82**	37.33	37.81	10.19	53.820
Bulk density	g/m^2 0-5cm depth	Mean	**1.27**	1.24	1.08	1.42	1.186
		SE	**0.20**	0.08	0.15	0.07	0.198
		Min	**0.77**	1.15	0.62	1.34	0.622
		Max	**1.62**	1.30	1.33	1.48	1.615
>2mm wt		Mean	**10.63**	15.30	37.31	14.45	23.708
		SE	**11.19**	12.37	10.93	3.47	16.827
		Min	**0.00**	1.69	14.31	11.07	0.000
		Max	**39.35**	25.88	63.50	18.00	63.497

Table 11 Mean with standard error (SE) and range of significant soil macronutrients for soil parent materials for soil types along the Northshore Rd corridor in Lake Mead National Recreation Area, Mojave Desert. Gypsum soil properties are highlighted in bold text. '*' soil variables correlated with gypsum-rich soils. Gypsum soil properties are highlighted in bold text.

Soil Variable	Units		**gypsum**	igneous-metamorphic	mixed alluvium	sedimentary	Across all groups
Total S*	g/m^2	Mean	**1124.28**	236.19	37.56	14.02	501.557
		SE	**733.19**	218.18	74.93	7.54	713.669
		Min	**7.05**	15.49	3.03	7.46	3.029
		Max	**2143.74**	451.75	302.33	22.25	2143.738
SO_4*	g/m^2	Mean	**438.42**	148.25	86.94	189.32	242.850
		SE	**219.30**	127.09	153.99	317.32	252.089
		Min	**6.89**	7.02	0.86	5.12	0.862
		Max	**854.93**	253.39	508.82	555.72	854.930
Ca*	g/m^2	Mean	**211.10**	87.66	47.17	92.94	120.425
		SE	**99.54**	71.08	71.69	137.31	116.138
		Min	**2.74**	9.15	1.80	7.82	1.803
		Max	**396.93**	147.62	230.33	251.34	396.934
K*	g/m^2	Mean	**1.741**	1.652	0.887	0.666	1.274
		SE	**1.101**	1.033	0.375	0.215	0.891
		Min	**0.486**	0.842	0.251	0.520	0.251
		Max	**4.623**	2.816	1.650	0.913	4.623
Mg*	g/m^2	Mean	**1.262**	0.813	0.509	0.250	0.826
		SE	**0.888**	0.547	0.518	0.049	0.777
		Min	**0.380**	0.234	0.099	0.220	0.099
		Max	**3.988**	1.320	2.523	0.307	3.988

Table 12 Mean with standard error (SE) and range of significant soil micronutrients for soil parent materials for soil types along the Northshore Rd corridor in Lake Mead National Recreation Area, Mojave Desert. Gypsum soil properties are highlighted in bold text. '*' soil variables correlated with gypsum-rich soils. Gypsum soil properties are highlighted in bold text.

Soil Variable	Units		**gypsum**	igneous-metamorphic	mixed alluvium	sedimentary	Across all groups
Cl	g/m^2	Mean	**0.66**	5.485	0.612	0.358	0.883
		SE	**1.10**	9.158	2.101	0.099	2.626
		Min	**0.13**	0.158	0.089	0.295	0.089
		Max	**5.40**	16.059	10.899	0.472	16.059
Fe*	$\mu g/m^2$	Mean	**227.17**	81.13	58.72	27.20	128.669
		SE	**116.71**	64.04	76.88	3.10	124.997
		Min	**12.55**	14.98	13.35	23.64	12.549
		Max	**461.69**	142.82	319.69	29.30	461.687
Na	g/m^2	Mean	**0.694**	0.456	0.493	3.960	0.764
		SE	**0.832**	0.029	0.253	6.195	1.531
		Min	**0.185**	0.423	0.220	0.331	0.185
		Max	**3.734**	0.476	1.266	11.112	11.112
Ni*	$\mu g/m^2$	Mean	**1.73**	0.65	0.41	0.12	0.960
		SE	**0.70**	0.47	0.54	0.02	0.887
		Min	**0.17**	0.11	0.07	0.10	0.073
		Max	**3.08**	0.99	1.84	0.13	3.077
Pb	$\mu g/m^2$	Mean	**0.005**	0.004	0.015	0.030	0.011
		SE	**0.008**	0.005	0.016	0.020	0.014
		Min	**0.000**	0.001	0.001	0.010	0.000
		Max	**0.032**	0.011	0.051	0.050	0.051
Zn*	$\mu g/m^2$	Mean	**0.450**	0.351	0.189	0.123	0.303
		SE	**0.177**	0.285	0.152	0.032	0.209
		Min	**0.185**	0.068	0.036	0.086	0.036
		Max	**0.887**	0.638	0.734	0.143	0.887

Table 13 Significant soil variables ($\alpha \leq 0.05$) between Gypsids soil taxonomic great groups and non-Gypsids soil great groups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Great Group 1	Great Group 2	Soil Variables
Argigypsids	Petroargids	EC, Bulk density
Argigypsids	Torrifluvents	pH, EC, Total S, SO_4, Ca, K, Mg, Co, Fe, Ni, Zn, % Clay, Bulk density, >2mm wt
Calcigypsids	Petroargids	EC, Total S, Ni, SO_4, Ca, Fe
Calcigypsids	Torrifluvents	>2mm wt
Haplogypsids	Argidurids	Zn
Haplogypsids	Calciargids	EC, Total S, Ni, SO4, Ca
Haplogypsids	Haplargids	NO_3, Cu
Haplogypsids	Haplocalcids	Zn
Haplogypsids	Haplocambids	% Clay
Haplogypsids	Haplodurids	Cu
Haplogypsids	Petroargids	Cu
Haplogypsids	Petrocalcids	EC, Total S, Ni, SO_4, Ca, K, Mg, Fe, % Clay, Bulk density, >2mm wt
Haplogypsids	Torrifluvents	EC, NO_3, Cu
Haplogypsids	Torriorthents	Total S, Ca, Zn
Haplogypsids	Torripsamments	EC, Total S, SO_4, Ca, Ni
Petrogypsids	Argidurids	Zn
Petrogypsids	**Argigypsids**	EC, Ni
Petrogypsids	Calciargids	Fe, Zn
Petrogypsids	**Calcigypsids**	% Sand
Petrogypsids	Haplargids	pH, EC, Total S, Ni, SO_4, Ca, K, Mg, Co, Fe, Zn, Mo, % Clay, Bulk density, >2mm wt
Petrogypsids	Haplocalcids	NO_3, Cu
Petrogypsids	Haplocambids	Zn
Petrogypsids	Haplodurids	EC, Ni
Petrogypsids	**Haplogypsids**	Fe, Zn
Petrogypsids	Natrargids	EC, Total S, Ni, SO_4, Ca, Fe, Bulk density, >2mm wt
Petrogypsids	Petroargids	NO_3, Cu
Petrogypsids	Petrocalcids	EC, Ni
Petrogypsids	Torrifluvents	pH, Total S, Ni, Ca
Petrogypsids	Torriorthents	pH, EC, Total S, SO_4, Ca, Mg, Fe, Ni, % Clay, % Sand, Bulk density, >2mm wt
Petrogypsids	Torripsamments	NO_3, Cu, >2mm wt

Table 14 Significant soil variables ($\alpha \leq 0.05$) between non-Gypsids soil taxonomic great groups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Great Group 1	Great Group 2	Soil Variables
Argidurids	Petroargids	>2mm Wt
Argidurids	Torrifluvents	Fe, Zn
Calciargids	Haplocalcids	EC
Calciargids	Petroargids	Fe, Zn
Calciargids	Torrifluvents	NO_3, Cu
Calciargids	Torriorthents	NO_3
Haplargids	Petroargids	NO_3, Cu
Haplargids	Torrifluvents	Zn
Haplargids	Torripsamments	% Sand
Haplocalcids	Petroargids	Bulk Density, >2mm Wt
Haplocalcids	Petrocalcids	Fe, Zn
Haplocalcids	Torrifluvents	Zn
Haplocalcids	Torripsamments	EC, Total S, NO_3, SO_4, Ca, Cu, Fe, Ni
Haplocambids	Petroargids	Zn
Haplocambids	Torrifluvents	EC, Ni
Haplodurids	Petroargids	Total S, Ni
Haplodurids	Torrifluvents	Total S, SO_4, Ca, Fe, Ni, % Clay, Bulk density, >2mm wt
Haplodurids	Torriorthents	Fe, Zn
Haplodurids	Torripsamments	pH, EC, Total S, SO_4, Ca, Mg, Co, Fe, Ni, B, K, Zn, % Clay, Bulk density, >2mm wt
Natrargids	Petroargids	EC, Ni
Natrargids	Torrifluvents	EC, Ni
Petroargids	Petrocalcids	NO_3, Cu
Petroargids	Torrifluvents	EC
Petroargids	Torriorthents	NO_3, Fe
Petrocalcids	Torrifluvents	pH, Zn
Petrocalcids	Torriorthents	Fe, Zn
Torrifluvents	Torriorthents	NO_3, Cu
Torrifluvents	Torripsamments	NO_3
Torriorthents	Torripsamments	Zn, >2mm Wt

Table 15 Significant soil variables ($\alpha \leq 0.05$) between Gypsids soil taxonomic subgroups and non-Gypsids soil subgroups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Subgroup 1	Subgroup 2	Soil Variable
Typic Petrogypsids	Calcic Petrocalcids	EC, Total S, Ni, SO_4, Ca, Fe, % Clay, Bulk density, >2mm wt
Typic Petrogypsids	Cambidic Haplodurids	EC, Total S, Ni, SO_4, Ca
Typic Petrogypsids	Duric Petroargids	Zn
Typic Petrogypsids	Durinodic Calciargids	SO_4
Typic Petrogypsids	Durinodic Haplocalcids	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, Bulk density, >2mm wt
Typic Petrogypsids	Leptic Haplogypsids	Total S, Ni, SO_4, Ca, Fe, K, % Clay, Bulk density, >2mm wt
Typic Petrogypsids	Lithic Haplargids	% Clay
Typic Petrogypsids	Lithic Torriorthents	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co,% Clay, Bulk density, >2mm wt
Typic Petrogypsids	Typic Argidurids	EC, Total S, Ni, SO_4, Ca
Typic Petrogypsids	**Typic Argigpysids**	% Clay
Typic Petrogypsids	Typic Calciargids	EC, Total S, Ni, SO_4, Ca, Fe
Typic Petrogypsids	**Typic Calcigypsids**	Ni, % Clay
Typic Petrogypsids	Typic Haplargids	EC, Total S, Ni, SO_4, Ca, Fe, >2mm wt
Typic Petrogypsids	Typic Haplocalcids	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, % Clay, % Silt, Bulk density, >2mm wt
Typic Petrogypsids	Typic Haplocambids	EC, Ni, SO_4, Ca, Fe, Bulk density
Typic Petrogypsids	Typic Haplodurids	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Zn, Co, Bulk density
Typic Petrogypsids	Typic Natrargids	pH, Ni
Typic Petrogypsids	Typic Petrocalcids	pH, EC, Total S, Ni, SO_4, Ca, Fe, % Clay, % Silt, Bulk density, >2mm wt
Typic Petrogypsids	Typic Torrifluvents	Total S, Ni, SO_4, Ca, NO_3, Cu
Typic Petrogypsids	Typic Torriorthents	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, % Clay, % Silt, Bulk density
Typic Petrogypsids	Typic Torripsamments	EC, Total S, Ni, SO_4, Ca,
Typic Petrogypsids	Ustic Haplargids	EC, Total S, Ni, SO_4, Ca, NO_3, % Clay
Leptic Haplogypsids	Typic Torrifluvents	NO_3, Cu
Leptic Haplogypsids	Typic Torriorthents	EC, Ni
Leptic Haplogypsids	Typic Torripsamments	EC

Table 15 *continued* Significant soil variables ($\alpha \leq 0.05$) between Gypsids soil taxonomic subgroups and non-Gypsids soil subgroups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Gypsum-derived soils are highlighted in bold text.

Subgroup 1	Subgroup 2	Soil Variable
Typic Argigypsids	Duric Petroargids	Zn
Leptic Haplogypsids	Calcic Petrocalcids	EC
Leptic Haplogypsids	Cambidic Haplodurids	EC
Leptic Haplogypsids	Duric Petroargids	Zn
Leptic Haplogypsids	Durinodic Haplocalcids	EC
Leptic Haplogypsids	Lithic Torriorthents	EC, Ni, >2mm wt
Leptic Haplogypsids	Typic Calciargids	EC, Bulk density
Leptic Haplogypsids	Typic Haplargids	EC
Leptic Haplogypsids	Typic Haplocalcids	EC, Ni
Leptic Haplogypsids	Typic Haplocambids	EC
Leptic Haplogypsids	Typic Haplodurids	EC, Ni
Leptic Haplogypsids	Typic Petrocalcids	EC
Typic Calcigypsids	Duric Petroargids	Zn

Table 16 Significant soil variables ($\alpha \leq 0.05$) between non-Gypsids soil taxonomic subgroups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Subgroup 1	Subgroup 2	Soil Variable
Calcic Petrocalcids	Duric Petroargids	Fe, Zn
Calcic Petrocalcids	Typic Torrifluvents	NO_3, Cu
Durinodic Haplocalcids	Lithic Torriorthents	% Clay, Bulk density, >2mm wt
Durinodic Haplocalcids	Typic Calciargids	>2mm wt
Durinodic Haplocalcids	Typic Haplocalcids	% Silt
Durinodic Haplocalcids	Typic Petrocalcids	% Clay
Durinodic Haplocalcids	Typic Torrifluvents	NO_3, Cu
Durinodic Haplocalcids	Typic Torriorthents	% Silt
Durinodic Haplocalcids	Ustic Haplargids	NO_3
Typic Haplocalcids	Typic Haplodurids	% Silt
Typic Haplocalcids	Typic Petrocalcids	% Silt, % Sand
Typic Haplocalcids	Typic Torrifluvents	NO_3, Cu
Typic Haplocalcids	Ustic Haplargids	NO_3
Typic Petrocalcids	Typic Torrifluvents	NO_3, Cu
Typic Petrocalcids	Typic Torriorthents	% Silt, % Sand
Typic Petrocalcids	Typic Torripsamments	% Sand
Cambidic Haplodurids	Duric Petroargids	Zn
Cambidic Haplodurids	Typic Torrifluvents	NO_3
Typic Haplodurids	Typic Torrifluvents	NO_3, Cu
Typic Haplodurids	Typic Torriorthents	% Silt, % Sand
Typic Haplodurids	Typic Torripsamments	Zn
Typic Haplocambids	Typic Torrifluvents	NO_3, Cu
Typic Haplocambids	Typic Torripsamments	>2mm wt

Table 16 *continued* Significant soil variables ($\alpha \leq 0.05$) between non-Gypsids soil taxonomic subgroups for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Subgroup 1	Subgroup 2	Soil Variable
Duric Petroargids	Durinodic Haplocalcids	Fe, Zn
Duric Petroargids	Lithic Torriorthents	Fe, Zn
Duric Petroargids	Typic Argidurids	Zn
Duric Petroargids	Typic Calciargids	Zn
Duric Petroargids	Typic Haplargids	Fe, Zn
Duric Petroargids	Typic Haplocalcids	Fe, Zn
Duric Petroargids	Typic Haplocambids	Zn
Duric Petroargids	Typic Haplodurids	Fe, Zn
Duric Petroargids	Typic Natrargids	pH, Zn
Duric Petroargids	Typic Petrocalcids	Zn
Duric Petroargids	Typic Torriorthents	Fe, Zn
Duric Petroargids	Ustic Haplargids	Zn
Lithic Haplargids	Typic Torrifluvents	NO_3
Lithic Torriorthents	Typic Calciargids	Bulk density, >2mm wt
Lithic Torriorthents	Typic Haplocalcids	% Sand, Bulk density, >2mm wt
Lithic Torriorthents	Typic Haplodurids	Bulk density, >2mm wt
Lithic Torriorthents	Typic Torrifluvents	NO3, Cu, >2mm wt
Lithic Torriorthents	Typic Torriorthents	% Sand, Bulk density, >2mm wt
Lithic Torriorthents	Typic Torripsamments	Zn, >2mm wt
Typic Argidurids	Typic Torrifluvents	NO_3, Cu
Typic Argigpsids	Typic Torrifluvents	NO_3, Cu
Typic Calciargids	Typic Haplocalcids	>2mm wt
Typic Calciargids	Typic Torrifluvents	NO_3, Cu
Typic Calciargids	Typic Torriorthents	>2mm wt
Typic Haplargids	Typic Torrifluvents	NO_3, Cu
Ustic Haplargids	Typic Haplocambids	NO_3
Typic Natrargids	Typic Torrifluvents	NO_3
Typic Natrargids	Typic Torriorthents	>2mm wt

Table 17 Significant soil variables ($\alpha \leq 0.05$) between gypsum rock origin type and other rock origin types for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Rock Origin 1	Rock Origin 2	Variable
gypsum	basalt	EC, Total S, Ni, SO_4, Ca, Fe, % Clay
gypsum	granite	EC, Total S, Ni, SO_4, Ca, Fe, Mg, % Clay, Bulk density, >2mm wt
gypsum	granite	EC, Total S, Ni, SO_4, Ca, Fe, Mg, % Clay, Bulk density, >2mm wt
gypsum	igneous-metamorphic	EC, Total S, Ni, SO_4, Ca, Fe, Mg, Cu, % Clay, Bulk density, >2mm wt
gypsum	limestone	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co,% Clay, Bulk density, >2mm wt
gypsum	limestone-sandstone	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, Mo, % Clay, Bulk density, >2mm wt
gypsum	mixed alluvium	pH, EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, Zn, Mo, B, >2mm wt
gypsum	sandstone	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, >2mm wt
gypsum	sedimentary	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Mn >2mm wt

Table 18 Significant soil variables ($\alpha \leq 0.05$) between non-gypsum rock origin types for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Rock Origin 1	Rock Origin 2	Soil Variable
granite	limestone	% Clay
igneous-metamorphic	limestone	pH
mixed alluvium	limestone	% Clay
igneous-metamorphic	limestone-sandstone	pH, Total N
basalt	mixed alluvium	% Clay
igneous-metamorphic	mixed alluvium	% Clay
limestone	mixed alluvium	% Sand, Bulk density
limestone-sandstone	mixed alluvium	% Clay
basalt	sandstone	% Clay
granite	sandstone	% Sand
igneous-metamorphic	sandstone	% Sand
limestone	sandstone	% Clay, % Sand
basalt	sedimentary	% Clay
granite	sedimentary	Mn
limestone	sedimentary	pH, Mn, % Clay
limestone-sandstone	sedimentary	pH, Mn
mixed alluvium	sedimentary	Mn
sandstone	sedimentary	Mn

Table 19 Significant soil variables ($\alpha \leq 0.05$) between gypsum parent material categories and other soil parent material categories for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Parent Material 1	Parent Material 2	Soil variable
gypsum	igneous-metamorphic	pH, EC, Ni, Total S, Total N, SO_4, Ca, K, Mg, B, Co, Cu, Fe, Mo, % Clay, Bulk density, >2mm wt
gypsum	mixed alluvium	pH, EC, Ni, Total S, SO_4, Ca, K, Mg, B, Co, Fe, Zn, Mo, % Clay, % Silt, Bulk density, >2mm wt
gypsum	sedimentary	pH, EC, Ni, Total S, SO_4, Ca, K, Mg, B, Co, Fe, Mo, % Clay, Bulk density, >2mm wt

Table 20 Significant soil variables ($\alpha \leq 0.05$) between non-gypsum soil parent material categories for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth.

Parent Material 1	Parent Material 2	Soil variable
igneous-metamorphic	mixed alluvium	Total C, $CaCO_3$, inorganic C, % Clay, % Sand
igneous-metamorphic	sedimentary	pH, Total N, Total C, $CaCO_3$, inorganic C
mixed alluvium	sedimentary	% Clay, Bulk density

Table 21 Significant soil variables ($\alpha \leq 0.05$) between gypsum soil parent material categories and other parent material categories with sites separated into elevation categories for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Elevation categories (Elv): 1 = 149 - 490 m; 2 = 491 - 776 m; and 3 = 777 – 1222 m.

Elv x Parent Material 1	Elv x Parent Material 2	Soil Variable
Elv1 gypsum	Elv1 igneous-metamorphic	EC, Total S, Ni, SO_4, Ca, Fe, Mg, % Clay, >2mm wt
Elv1 gypsum	Elv1 mixed alluvium	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, B, Co, Mo, Bulk density, >2mm wt
Elv1 gypsum	Elv1 sedimentary	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, Mo, % Clay, Bulk density, >2mm wt
Elv1 gypsum	Elv2 gypsum	Total S, Ni, SO_4, Mg, Ca, Fe, % Clay, Bulk density
Elv1 gypsum	Elv2 igneous-metamorphic	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, Co, % Clay, Bulk density, >2mm wt
Elv1 gypsum	Elv2 mixed alluvium	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, B, Co, Mo, % Silt, Bulk density, >2mm wt
Elv1 gypsum	Elv2 sedimentary	EC, Total S, Ni, SO_4, Ca, Fe, Mg, K, B, Co, Mo, % Clay, Bulk density, >2mm wt
Elv1 gypsum	Elv3 igneous-metamorphic	EC, Total S, Ni, SO_4, Ca, Fe, Mg, % Clay, >2mm wt
Elv1 gypsum	Elv3 mixed alluvium	EC, Total S, Ni, SO_4, Ca, Fe, Mg, % Clay, Bulk density, >2mm wt
Elv1 gypsum	Elv3 sedimentary	EC, Total S, Ni, SO, Ca, Fe, Mg, % Clay, Bulk density, >2mm wt
Elv2 gypsum	Elv1 mixed alluvium	EC
Elv2 gypsum	Elv2 igneous-metamorphic	EC
Elv2 gypsum	Elv2 mixed alluvium	EC, Ni, % Silt, % Sand
Elv2 gypsum	Elv2 sedimentary	EC
Elv2 gypsum	Elv3 igneous-metamorphic	EC
Elv2 gypsum	Elv3 mixed alluvium	EC
Elv2 gypsum	Elv3 sedimentary	EC
Elv3 gypsum	Elv1 mixed alluvium	EC, Total C
Elv3 gypsum	Elv2 igneous-metamorphic	EC
Elv3 gypsum	Elv2 mixed alluvium	EC, Ni
Elv3 gypsum	Elv2 sedimentary	EC
Elv3 gypsum	Elv3 igneous-metamorphic	EC
Elv3 gypsum	Elv3 mixed alluvium	EC

Table 22 Significant soil variables ($\alpha \leq 0.05$) between igneous-metamorphic, mixed alluvium, and sedimentary soil parent material categories with sites separated into elevation categories for LTV and Northshore Rd reference sites, eastern Mojave Desert. All soil variables were calculated to g/m^2 at 0-5 cm depth or obtained from soil sample collected at 0-5 cm depth. Elevation categories (Elv): 1 = 149 - 490 m; 2 = 491 - 776 m; and 3 = 777 – 1222 m.

Elv x Parent Material 1	Elv x Parent Material 2	Soil Variable
Elv1 mixed alluvium	Elv1 sedimentary	Na, % Clay
Elv1 mixed alluvium	Elv2 igneous-metamorphic	CaCO3, Inorganic C, % Clay
Elv1 mixed alluvium	Elv2 mixed alluvium	% Clay
Elv1 mixed alluvium	Elv2 sedimentary	% Clay, Bulk density
Elv1 mixed alluvium	Elv3 igneous-metamorphic	Total C, CaCO3, Inorganic C
Elv1 mixed alluvium	Elv3 igneous-metamorphic	% Clay
Elv1 mixed alluvium	Elv3 sedimentary	% Clay
Elv1 sedimentary	Elv2 mixed alluvium	Na
Elv1 sedimentary	Elv2 sedimentary	Na
Elv2 igneous-metamorphic	Elv2 mixed alluvium	% Sand
Elv2 mixed alluvium	Elv2 sedimentary	% Sand

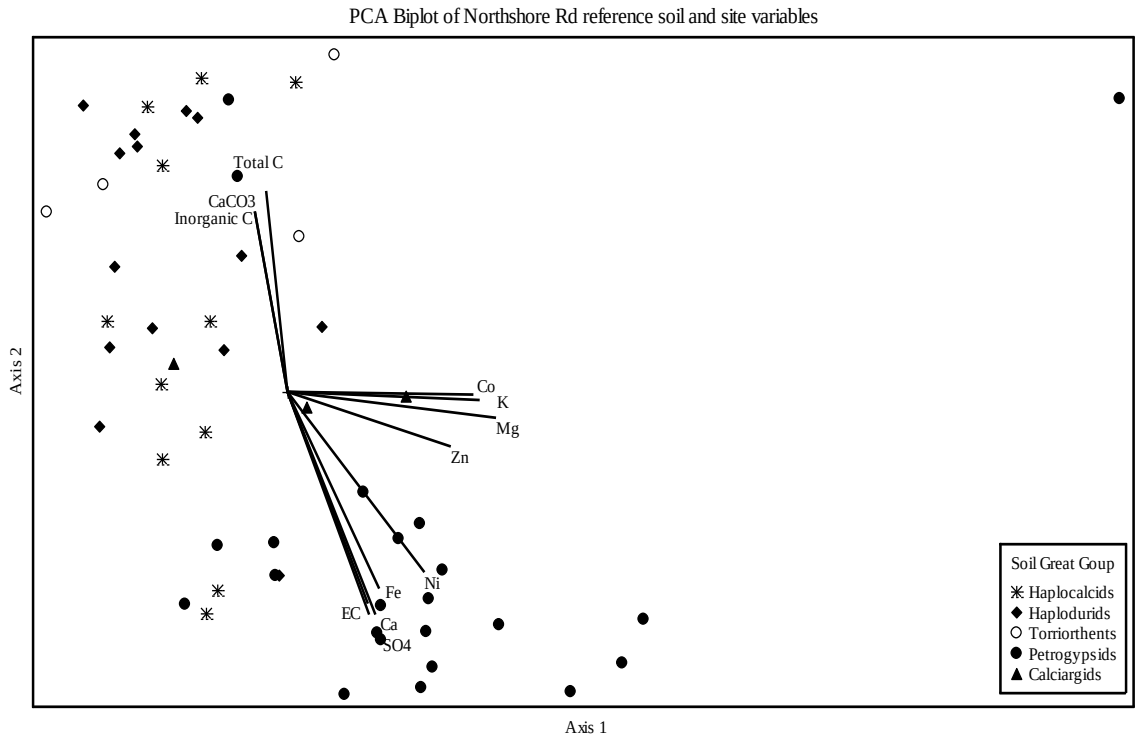


Figure 15 Principle component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by soil taxonomic great groups; with soil variable vector overlay with a cutoff $r^2 \geq 0.60$.

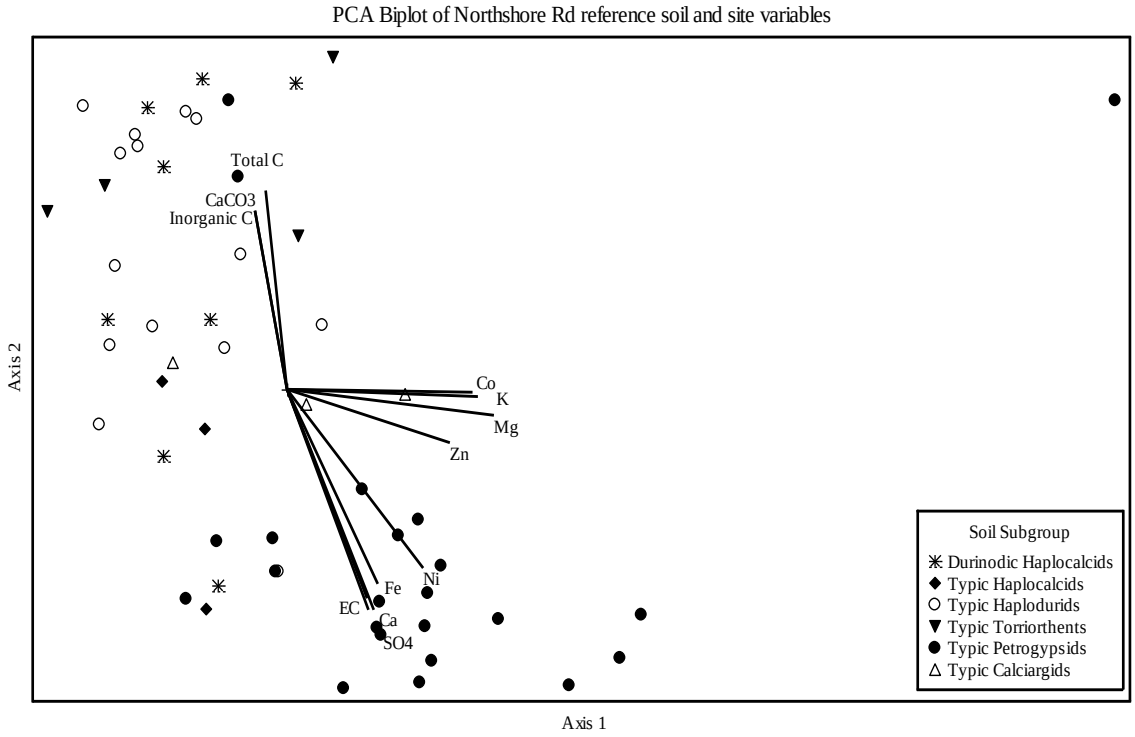


Figure 16 Principle component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by soil taxonomic subgroups; with soil variable vector overlay with a cutoff $r^2 \geq 0.60$.

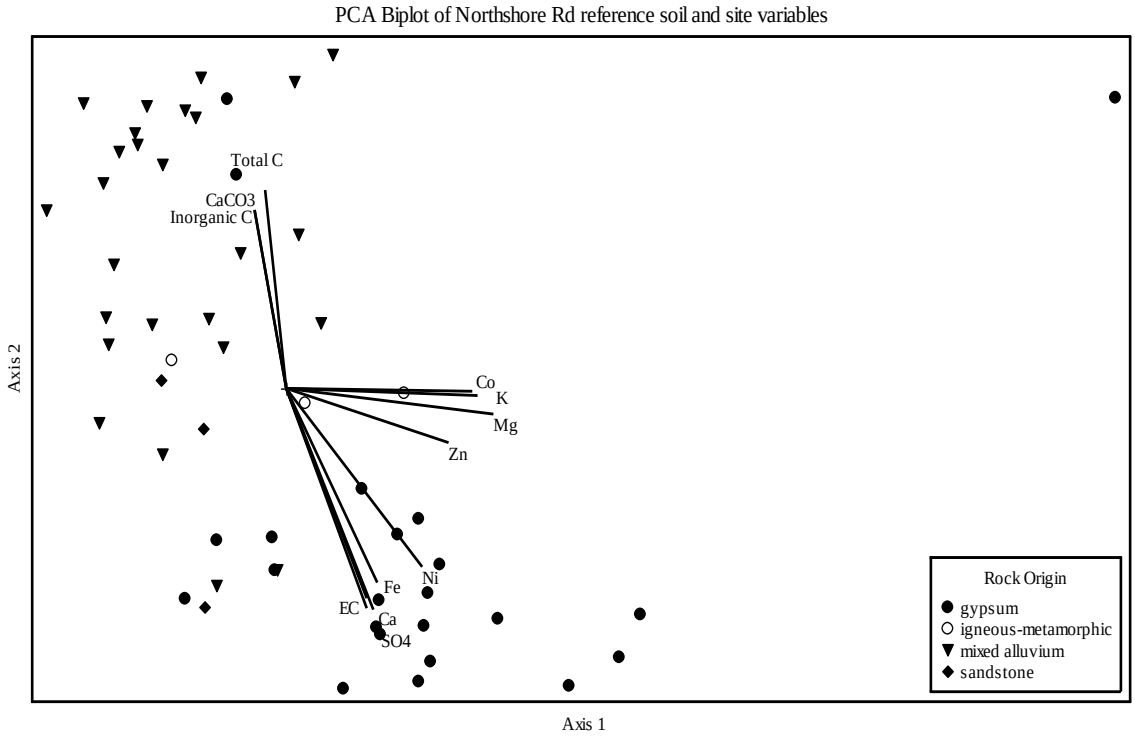


Figure 17 Principle component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by general soil parent material categories; with soil variable vector overlay with a cutoff $r^2 \geq 0.60$.

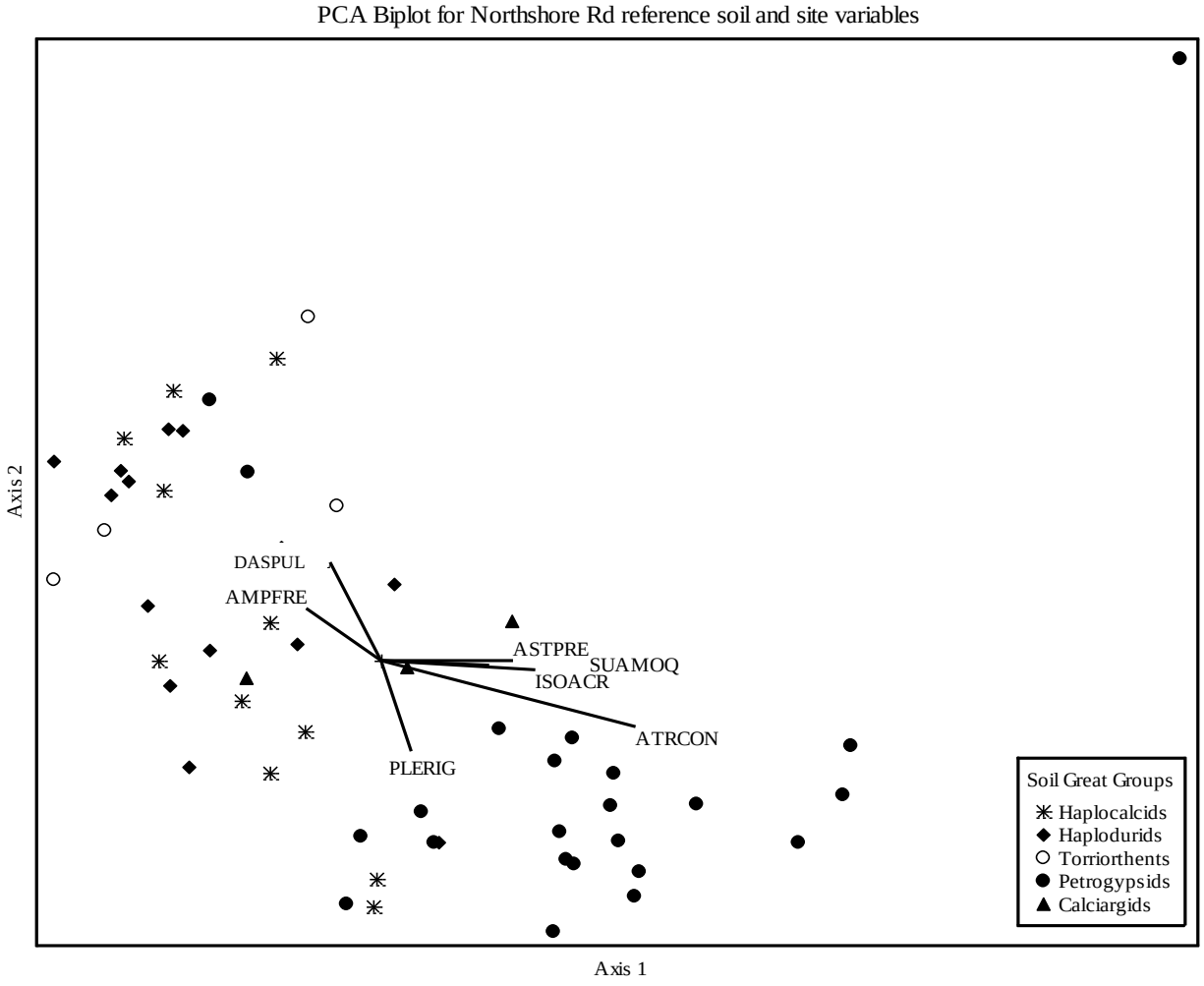


Figure 18 Principal component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by soil taxonomic great groups; with vegetation variable vector overlay with a cutoff $r^2 \geq 0.30$, showing significant perennial plant species (presence), including AMPFRE (*Amphippappus fremontii*), ASTPRE (*Astragalus preussii*), ATRCON (*Atriplex confertifolia*), DASPUL (*Dasyochloa pulchella*, formerly *Erioneuron pulchellum*), ISOACR (*Isocoma acradenia*), PLERIG (*Pleuraphis rigida*), and SUAMOQ (*Suaeda moquinii*).

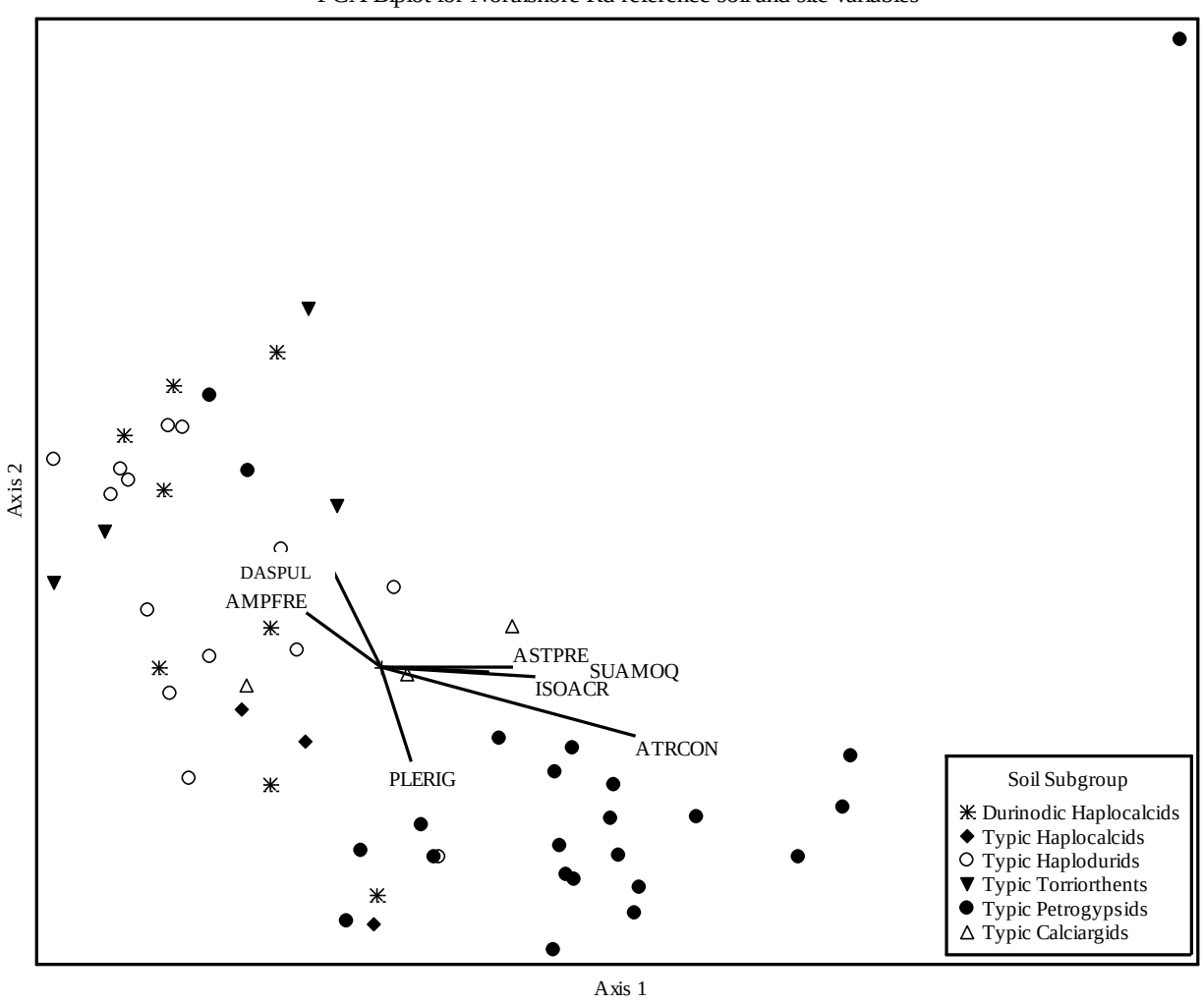


Figure 19 Principle component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by soil taxonomic subgroups; with vegetation variable vector overlay with a cutoff $r^2 \geq 0.30$, showing significant perennial plant species (presence), including AMPFRE (*Amphippappus fremontii*), ASTPRE (*Astragalus preussii*), ATRCON (*Atriplex confertifolia*), DASPUL (*Dasyochloa pulchella*, formerly *Erioneuron pulchellum*), ISOACR (*Isocoma acradenia*), PLERIG (*Pleuraphis rigida*), and SUAMOQ (*Suaeda moquinii*).

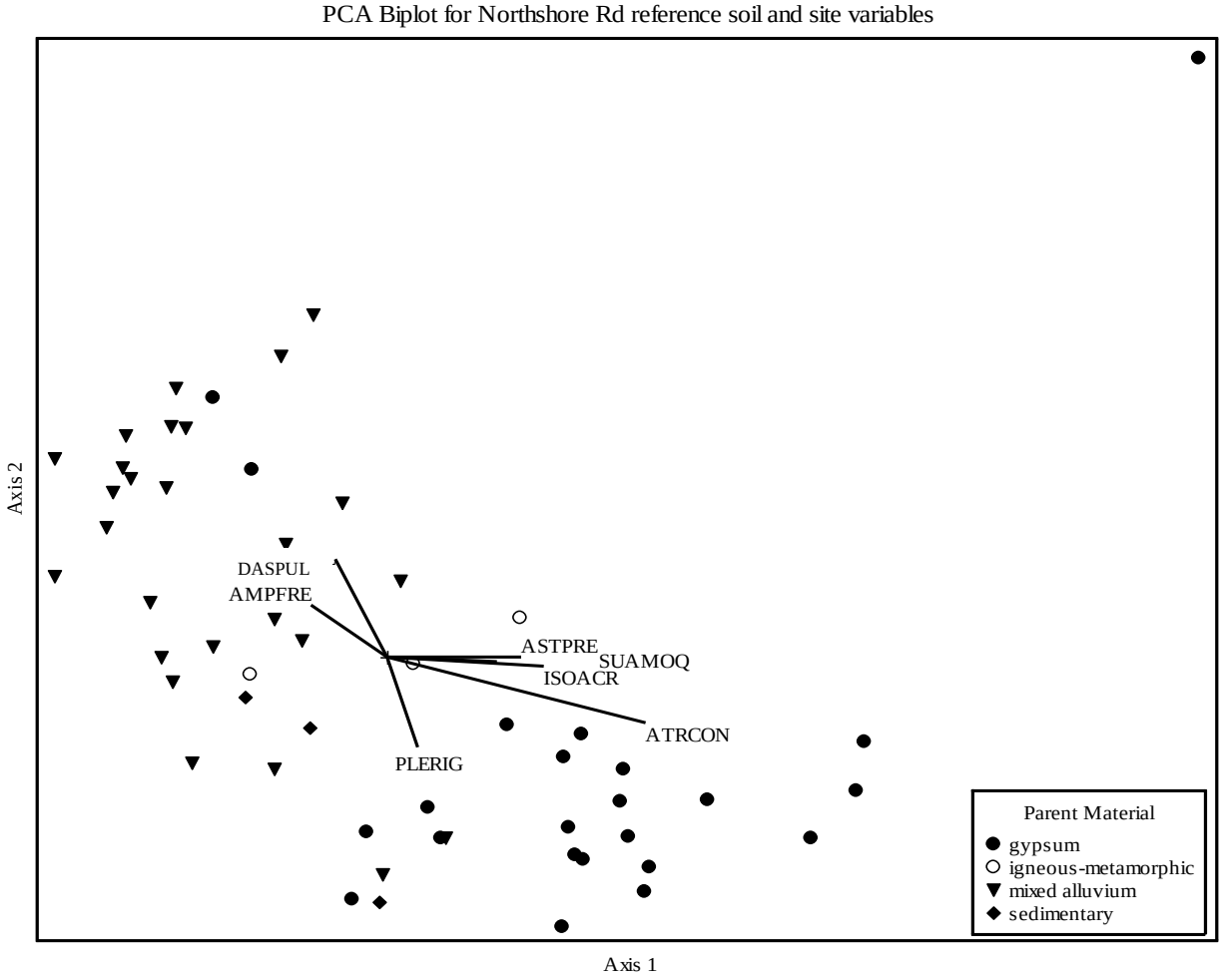


Figure 20 Principle component analysis biplot for the Northshore Rd reference sites, Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, grouped by general soil parent material categories; with vegetation variable vector overlay with a cutoff $r^2 \geq 0.30$, showing significant perennial plant species (presence), including AMPFRE (*Amphippappus fremontii*), ASTPRE (*Astragalus preussii*), ATRCON (*Atriplex confertifolia*), DASPUL (*Dasyochloa pulchella*, formerly *Erioneuron pulchellum*), ISOACR (*Isocoma acradenia*), PLERIG (*Pleuraphis rigida*), and SUAMOQ (*Suaeda moquinii*).

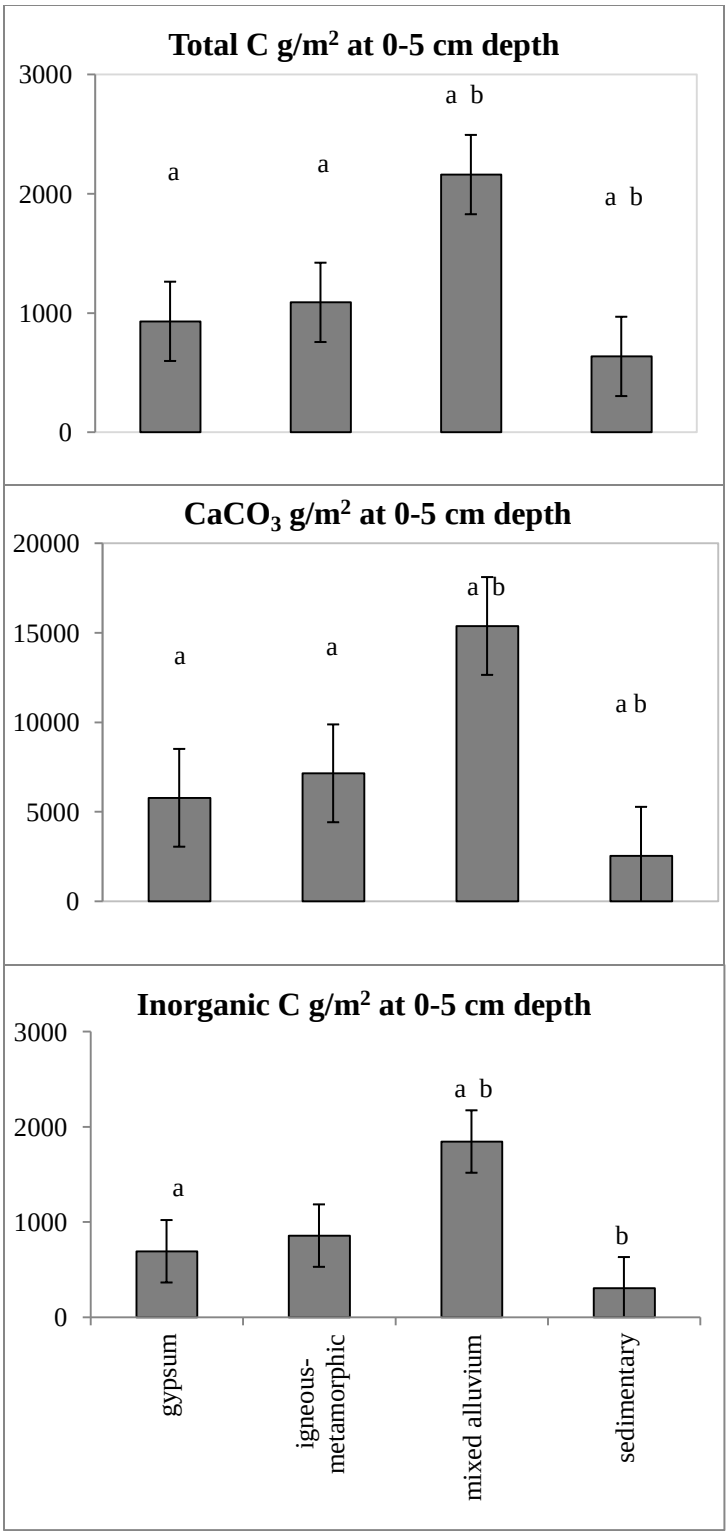


Figure 21 Means and standard error for the soil variables, total C, $CaCO_3$, and inorganic C in g/m^2 at 0-5 cm soil depth, with significant differences between gypsum parent material and igneous-metamorphic, mixed alluvium, and sedimentary parent material categories for based on analyses of soils collected from the Northshore Rd references sites, Lake Mead National Recreation Area, Mojave Desert. Significant differences between parent material categories at $\alpha \leq 0.05$ are shown by letters.

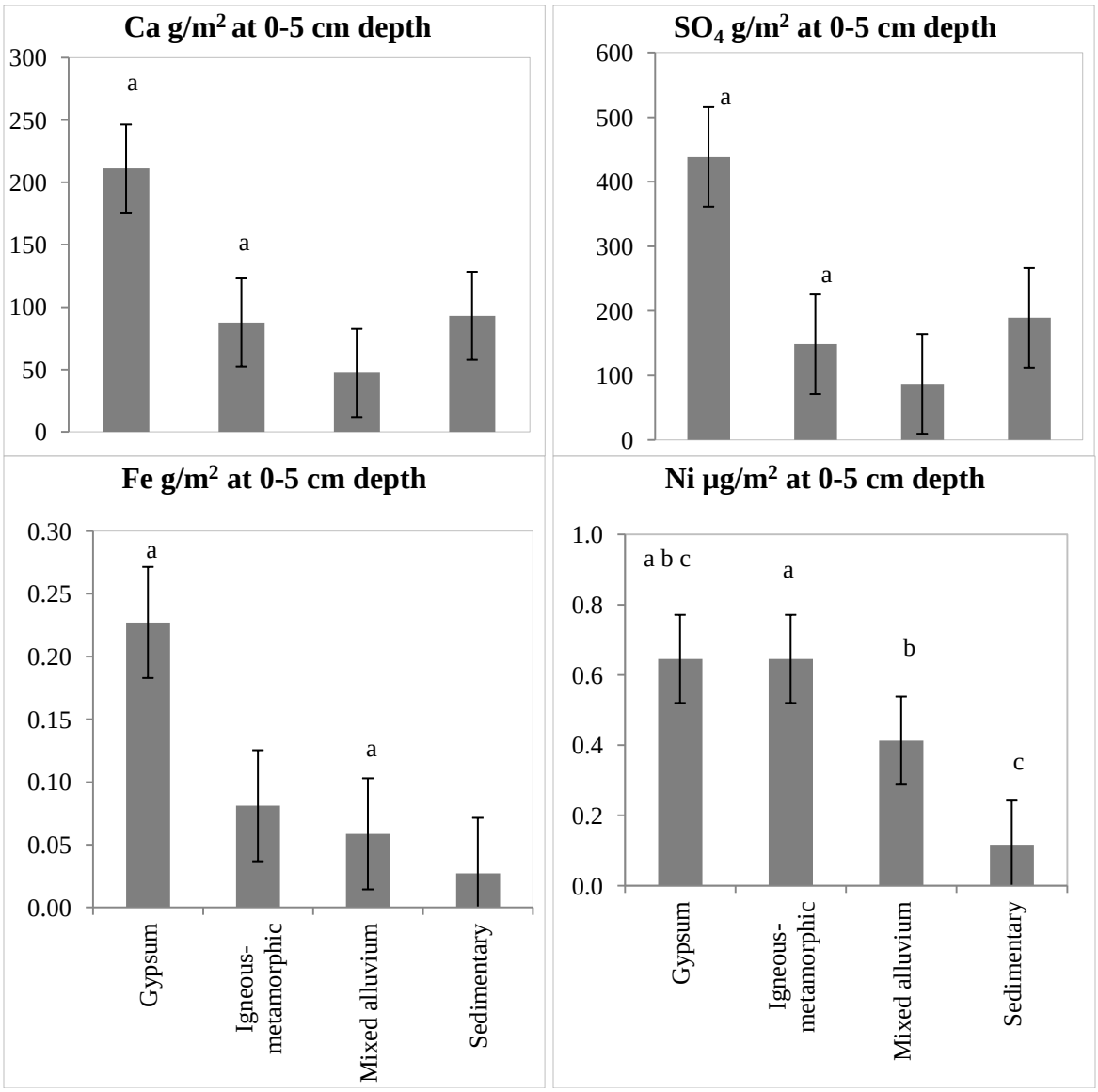


Figure 22 Means and standard error for the soil variables, Ca, SO_4, and Fe in g/m^2 at 0-5 cm soil depth and Ni in $\mu g/m^2$ at 0-5 cm soil depth, with significant differences between gypsum parent material and mixed alluvium parent material categories based on analyses of soils collected from the Northshore Rd references sites, Lake Mead National Recreation Area, Mojave Desert. Significant differences between parent material categories at $\alpha \leq 0.05$ are shown by letters.

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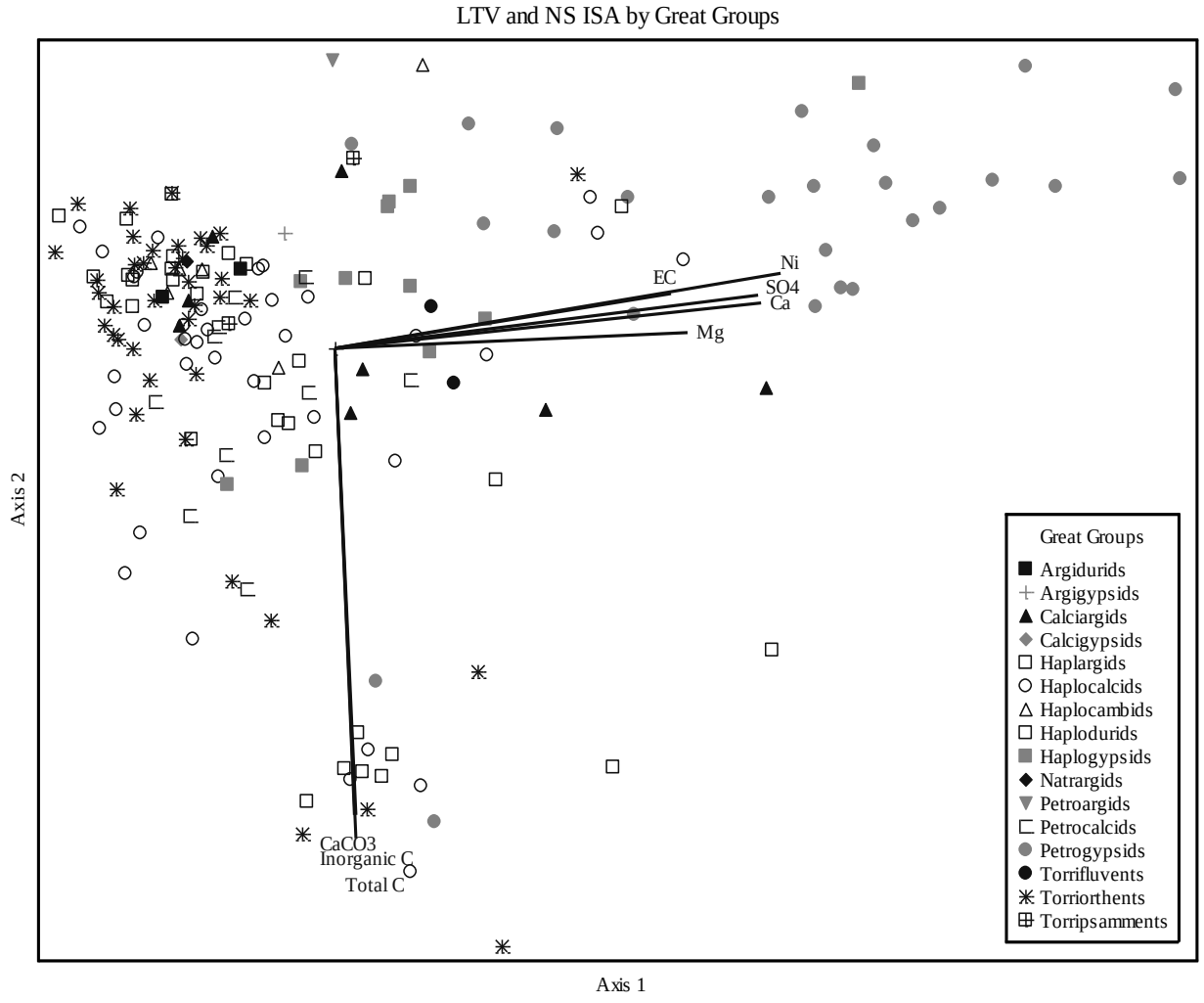


Figure 23 Principle component analysis biplot for the LTV and Northshore Rd reference sites, within and around Lake Mead National Recreation Area, eastern Mojave Desert, using site and soil variables, grouped by taxonomic soil great groups; with a soil variable vector overlay cutoff $r^2 \geq 0.60$.

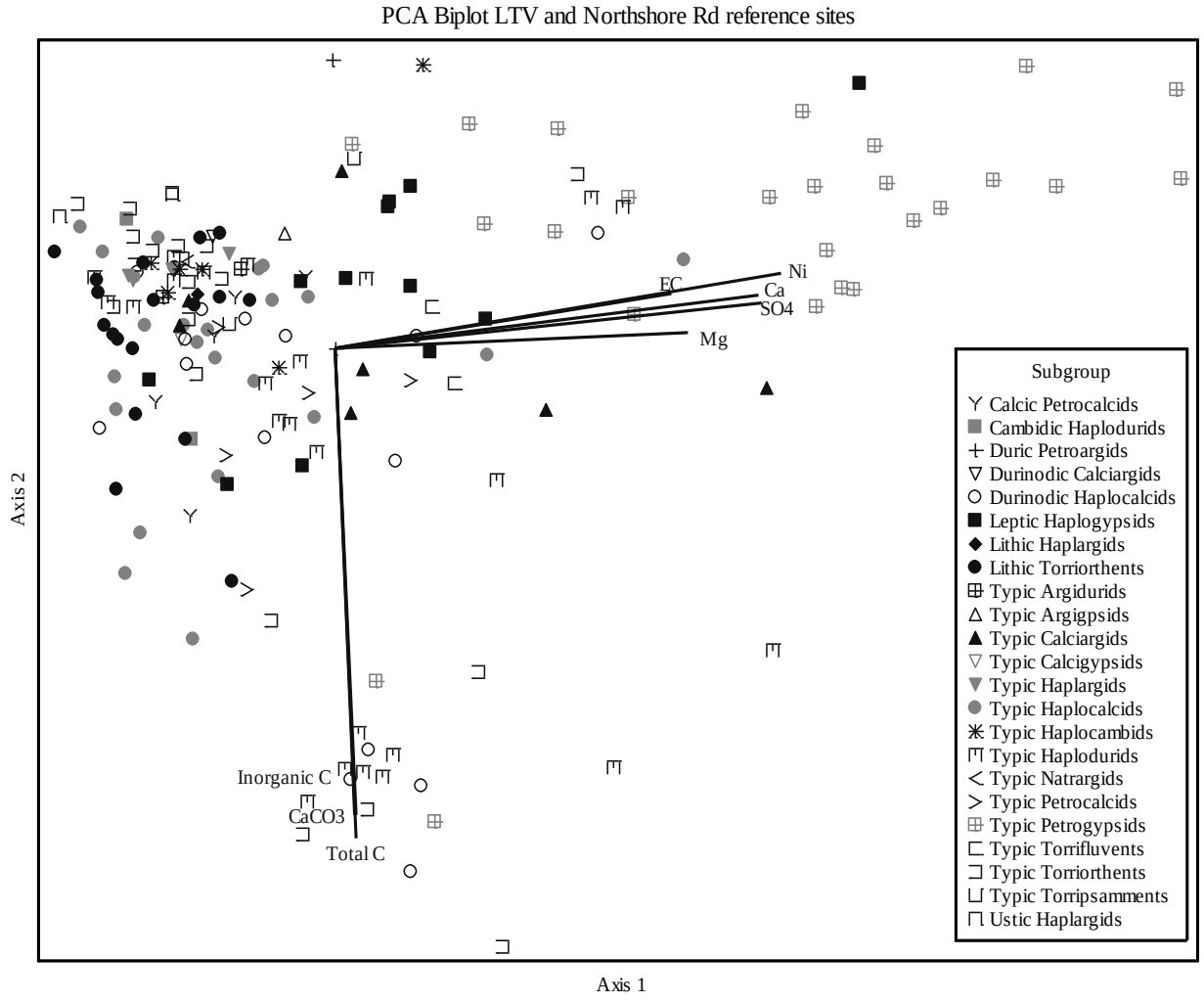


Figure 24 Principle component analysis biplot for the LTV and Northshore Rd reference sites, within and around Lake Mead National Recreation Area, eastern Mojave Desert, using site and soil variables, grouped by soil taxonomic subgroups; with soil variable vector overlay cutoff $r^2 \geq 0.60$.

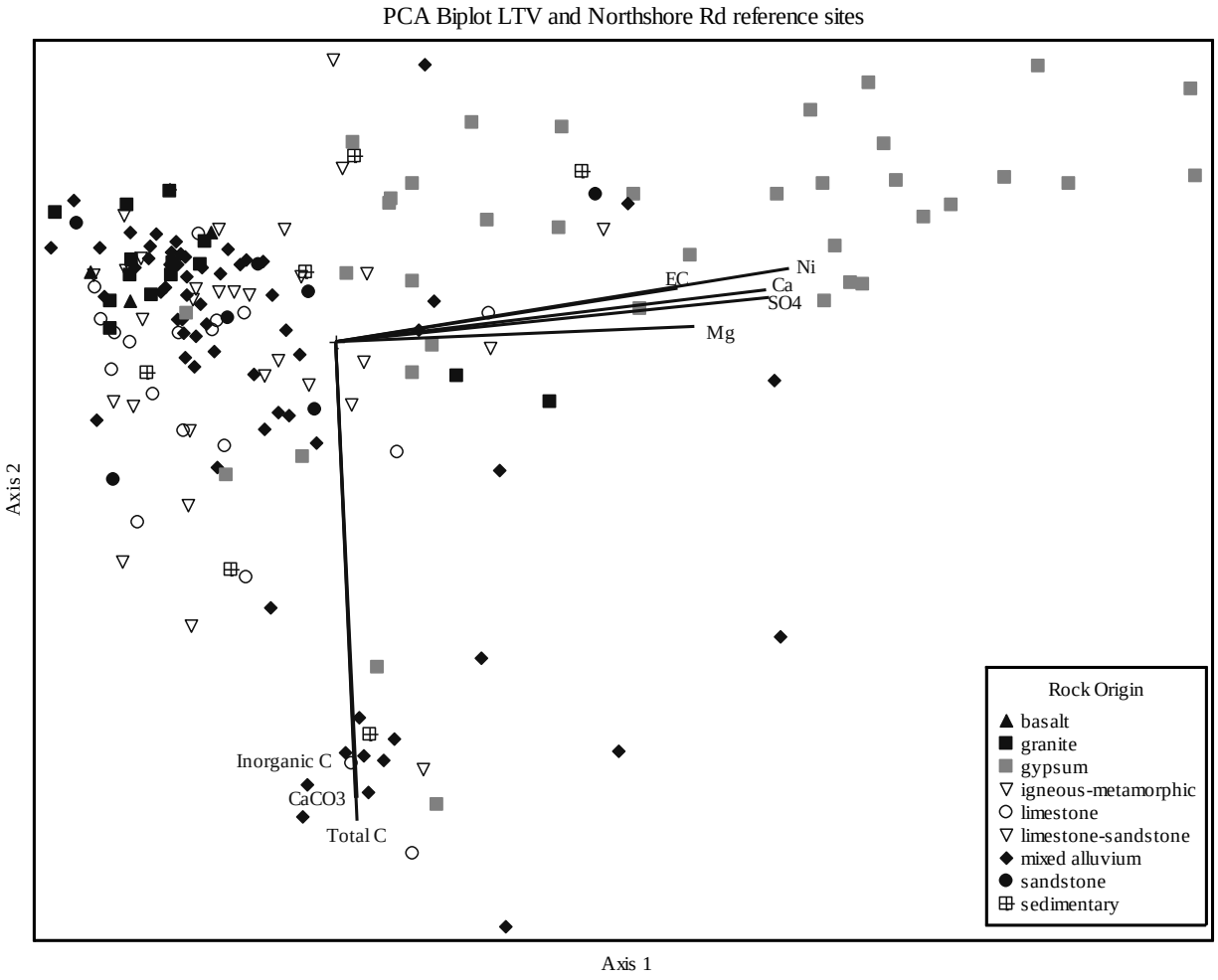


Figure 25 Principle component analysis biplot for the LTV and Northshore Rd reference sites, within and around Lake Mead National Recreation Area, eastern Mojave Desert, using site and soil variables, grouped by soil rock origin material type; with soil variable vector overlay cutoff $r^2 \geq 0.60$.

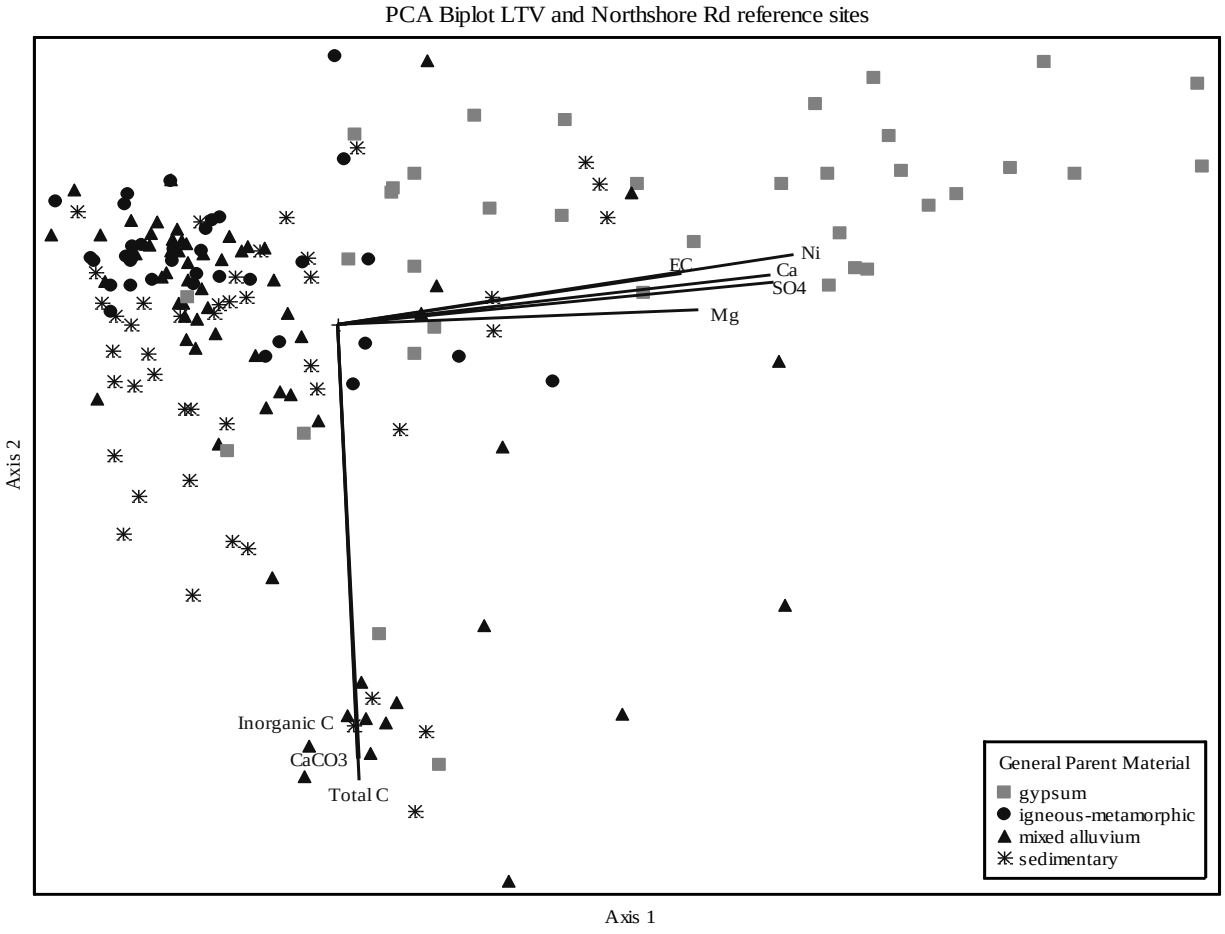


Figure 26 Principle component analysis biplot for the LTV and Northshore Rd reference sites, within and around Lake Mead National Recreation Area, eastern Mojave Desert, using site and soil variables, grouped by general soil parent material categories; with soil variable vector overlay cutoff $r^2 \geq 0.60$.

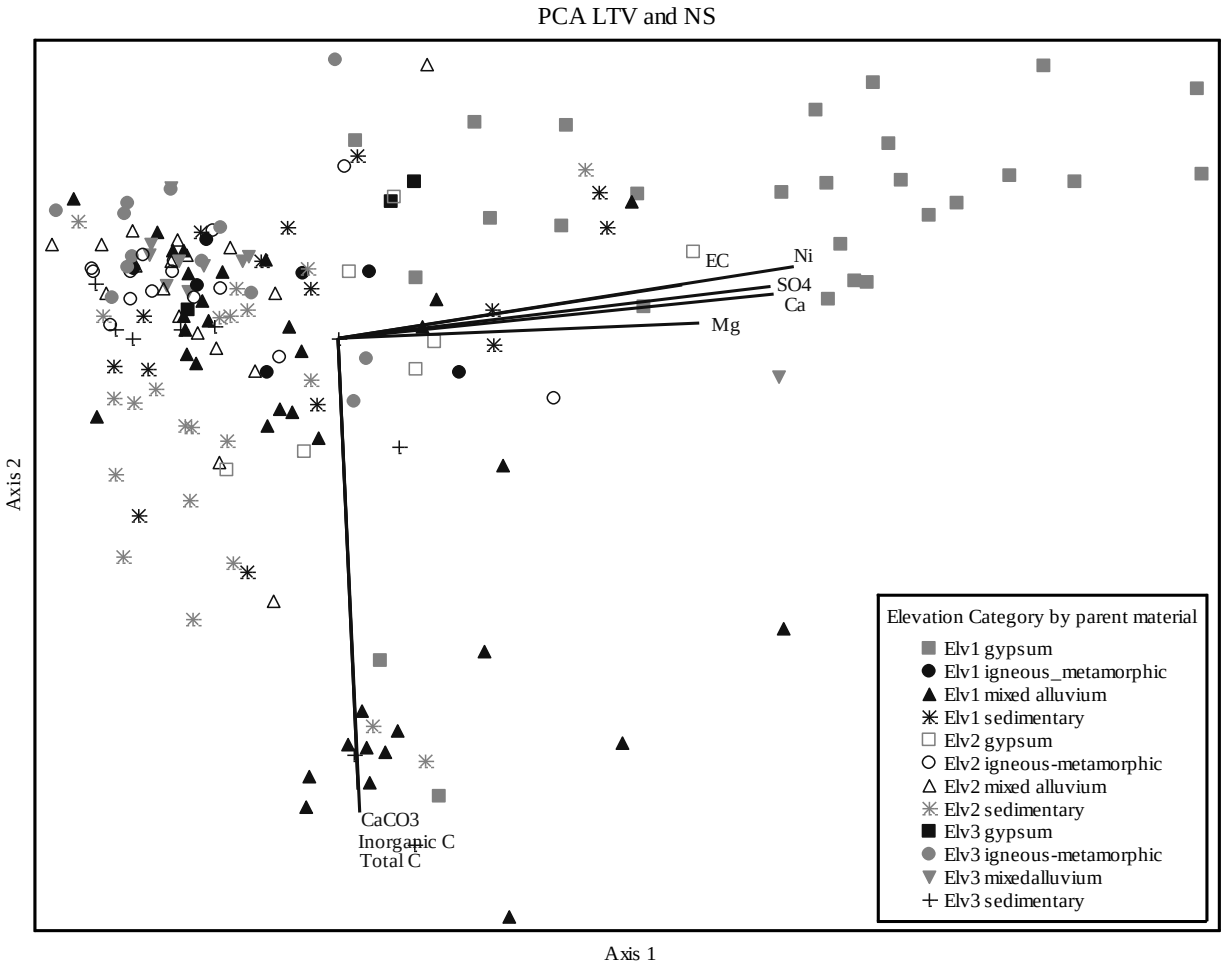


Figure 27 Principle component analysis biplot for the LTV and Northshore Rd reference sites, within and around Lake Mead National Recreation Area, eastern Mojave Desert, using site and soil variables, grouped by elevation categories (1 = 149-490 m; 2 = 491-776 m; and 3 = 777-1222 m) and general soil parent material categories; with soil variable vector overlay cutoff $r^2 \geq 0.60$.

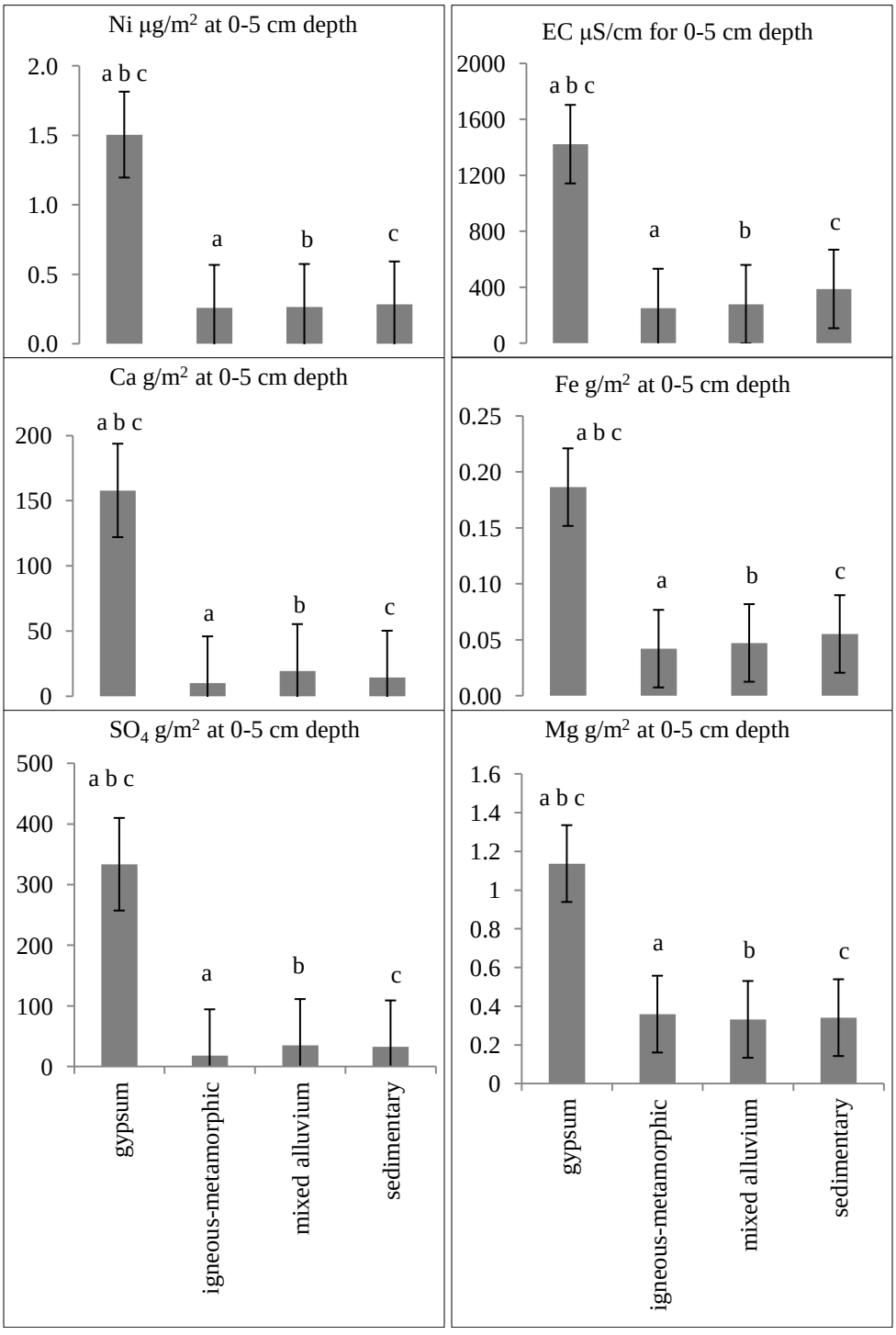


Figure 28 Means and standard error for the soil variables, electroconductivity (EC) µS/cm from 0-5 cm soil depth, Ni µg/m^2 at 0-5 cm soil depth, and Ca, SO_4, Fe, and Mg g/m^2 at 0-5 cm soil depth, with significant differences between gypsum, igneous-metamorphic, mixed alluvium, and sedimentary parent material categories, using soil data from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, Mojave Desert. Significant differences between parent material categories at $\alpha \leq 0.05$ are shown by letters.

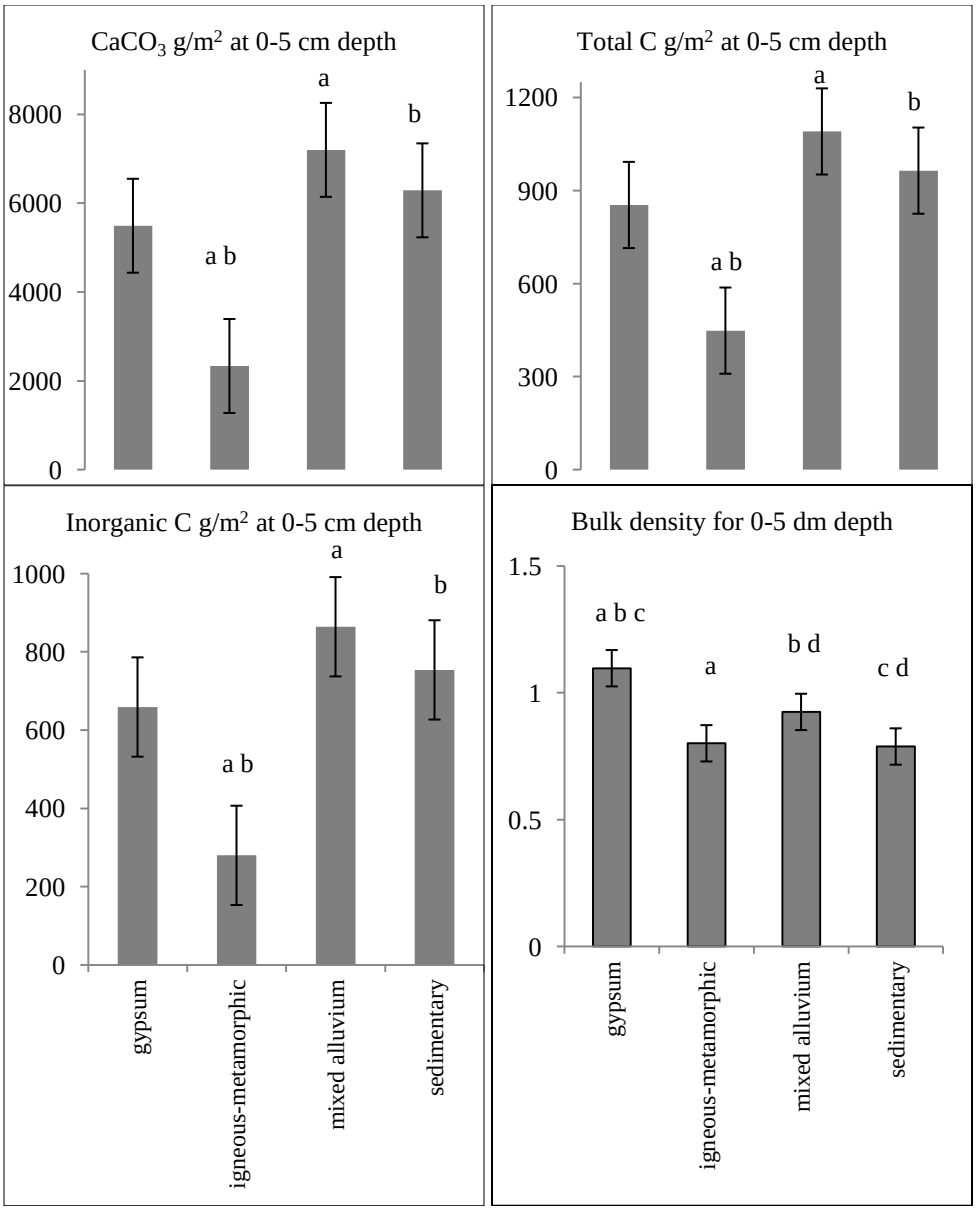


Figure 29 Means and standard error for the soil variables, total C, $CaCO_3$, and inorganic C g/m^2 at 0-5 cm soil depth and bulk density from 0-5 cm soil depth, with significant differences between gypsum, igneous-metamorphic, mixed alluvium, and sedimentary parent material categories, using soil data from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, Mojave Desert. Significant differences between parent material categories at $\alpha \leq 0.05$ are shown by letters.

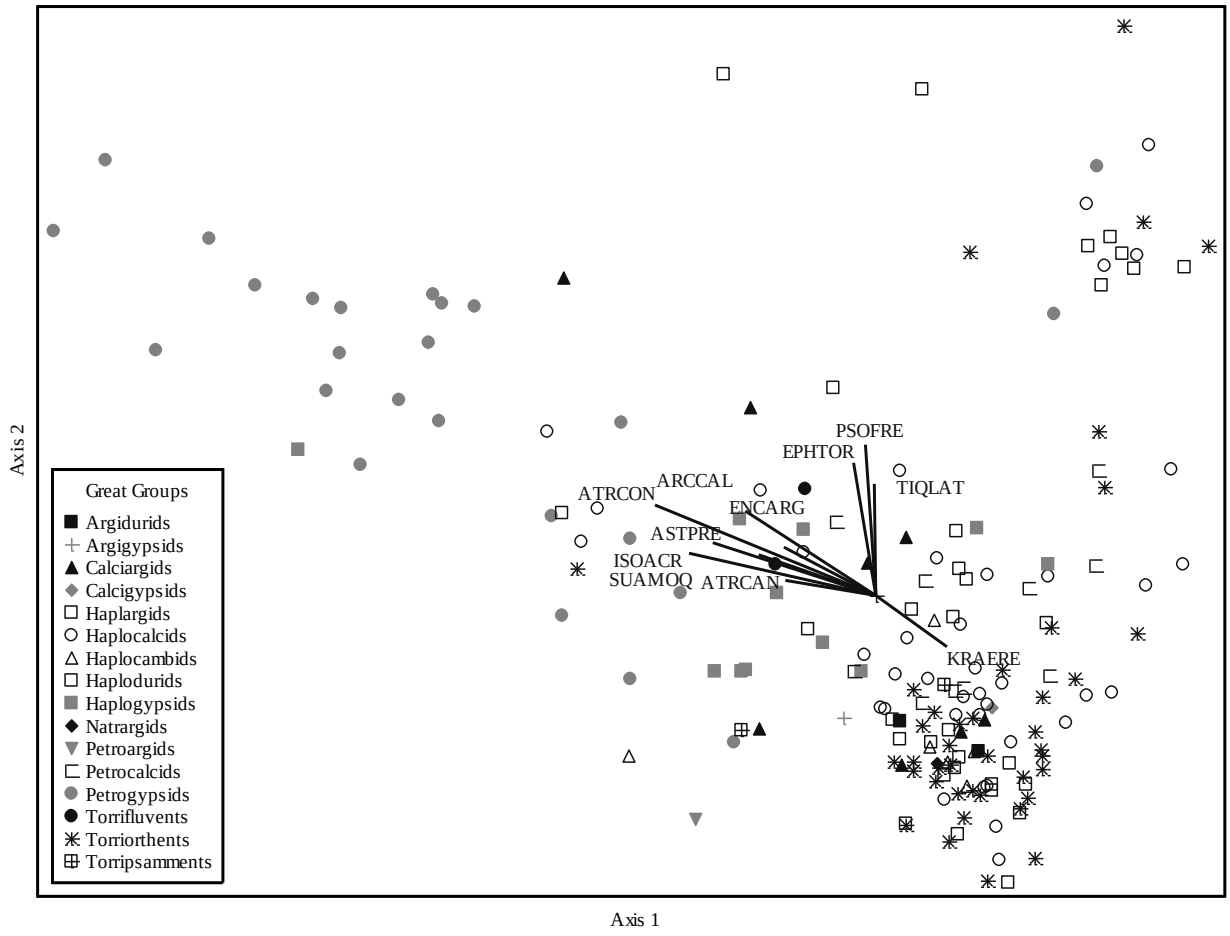


Figure 30 Principle component analysis biplot for the LTV and Northshore Rd reference sites, in and around Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, with sites grouped by soil taxonomic great groups, with vegetation vector overlay cutoff $r^2 \geq 0.15$, showing significant perennial plant species (presence), including ARCCAL (*Arctomecon californica*), ASTPRE (*Astragalus preussii*), ATRCAN (*Atriplex canescens*), ATRCON (*Atriplex confertifolia*), ENCARG (*Enceliopsis argophylla*), EPHTOR (*Ephedra torreyana*), ISOACR (*Isocoma acradenia*), KRAERE (*Krameria erecta*), PSOFRE (*Psorothamnus fremontii*), SUAMOQ (*Suaeda moquinii*), and TIQLAT (*Tiquilia latior*).

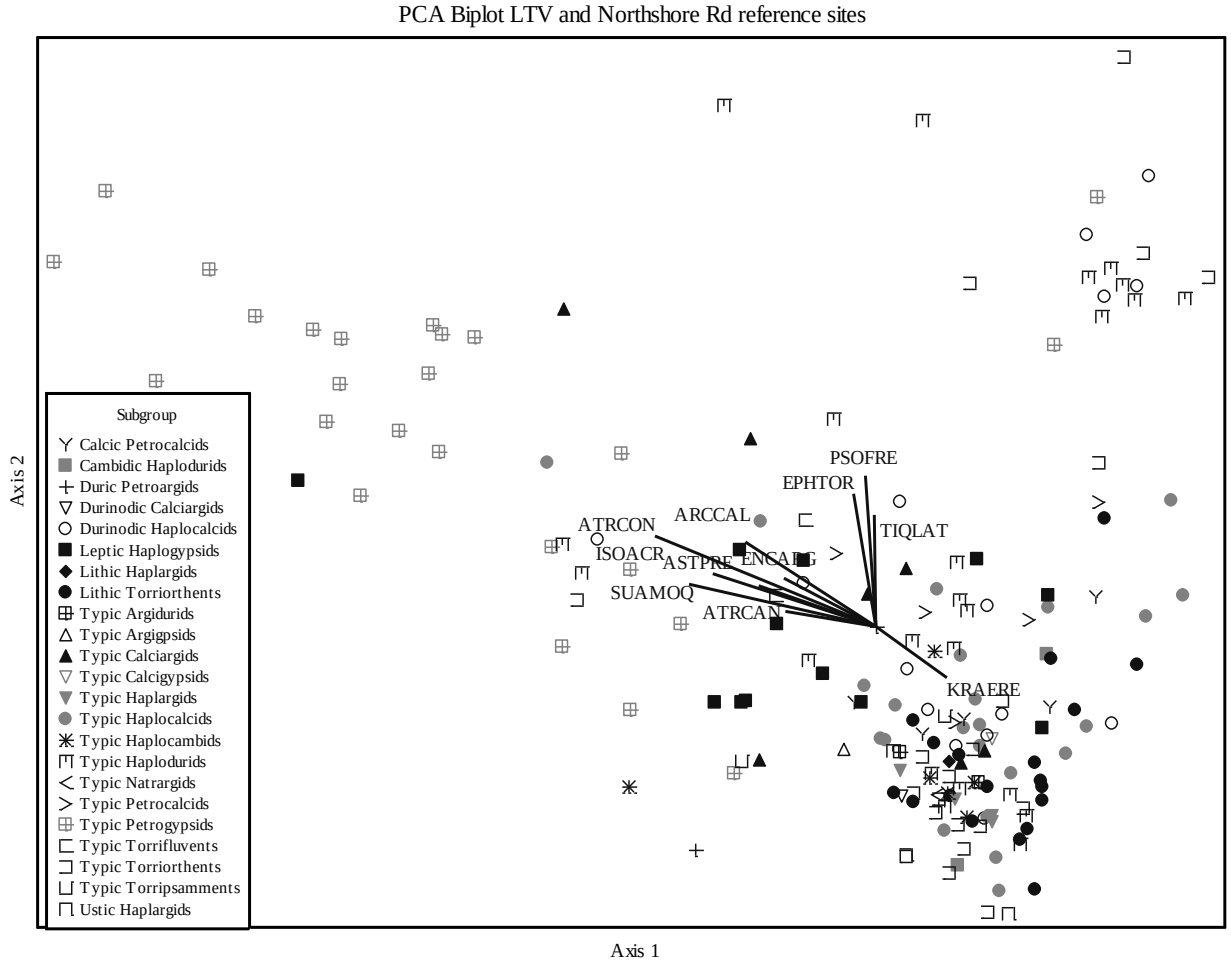


Figure 31 Principle component analysis biplot for the LTV and Northshore Rd reference sites, in and around Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, with sites grouped by soil taxonomic subgroup, with vector overlay cutoff $r^2 \geq 0.15$, showing significant perennial plant species (presence), including ARCCAL (*Arctomecon californica*), ASTPRE (*Astragalus preussii*), ATRCAN (*Atriplex canescens*), ATRCON (*Atriplex confertifolia*), ENCARG (*Enceliopsis argophylla*), EPHTOR (*Ephedra torreyana*), ISOACR (*Isocoma acradenia*), KRAERE (*Krameria erecta*), PSOFRE (*Psorothamnus fremontii*), SUAMOQ (*Suaeda moquinii*), and TIQLAT (*Tiquilia latior*).

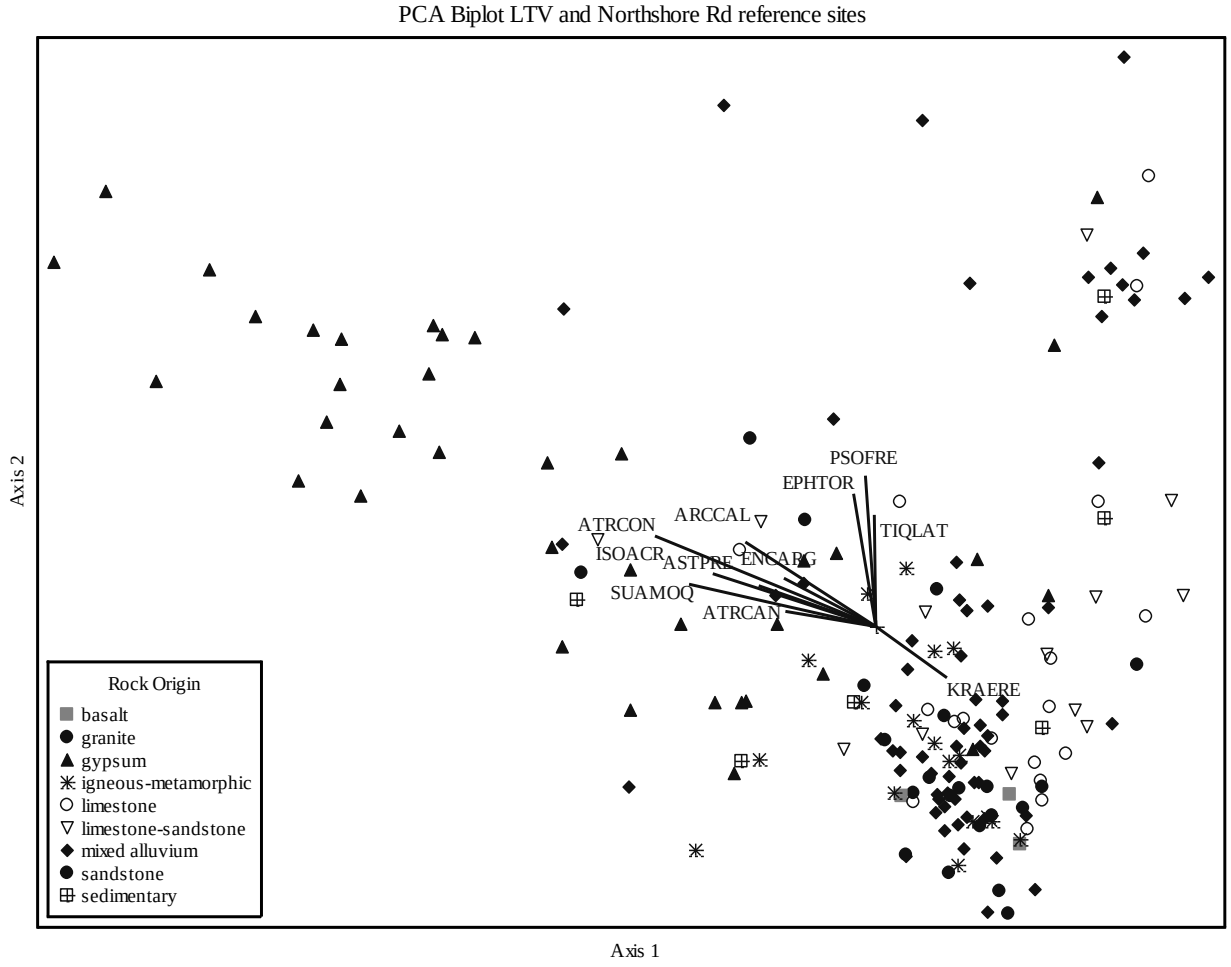


Figure 32 Principle component analysis biplot for the LTV and Northshore Rd reference sites, in and around Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, with sites grouped by soil rock origin material types, with vegetation vector overlay cutoff $r^2 \geq 0.15$, showing significant perennial plant species (presence), including ARCCAL (*Arctomecon californica*), ASTPRE (*Astragalus preussii*), ATRCAN (*Atriplex canescens*), ATRCON (*Atriplex confertifolia*), ENCARG (*Enceliopsis argophylla*), EPHTOR (*Ephedra torreyana*), ISOACR (*Isocoma acradenia*), KRAERE (*Krameria erecta*), PSOFRE (*Psorothamnus fremontii*), SUAMOQ (*Suaeda moquinii*), and TIQLAT (*Tiquilia latior*).

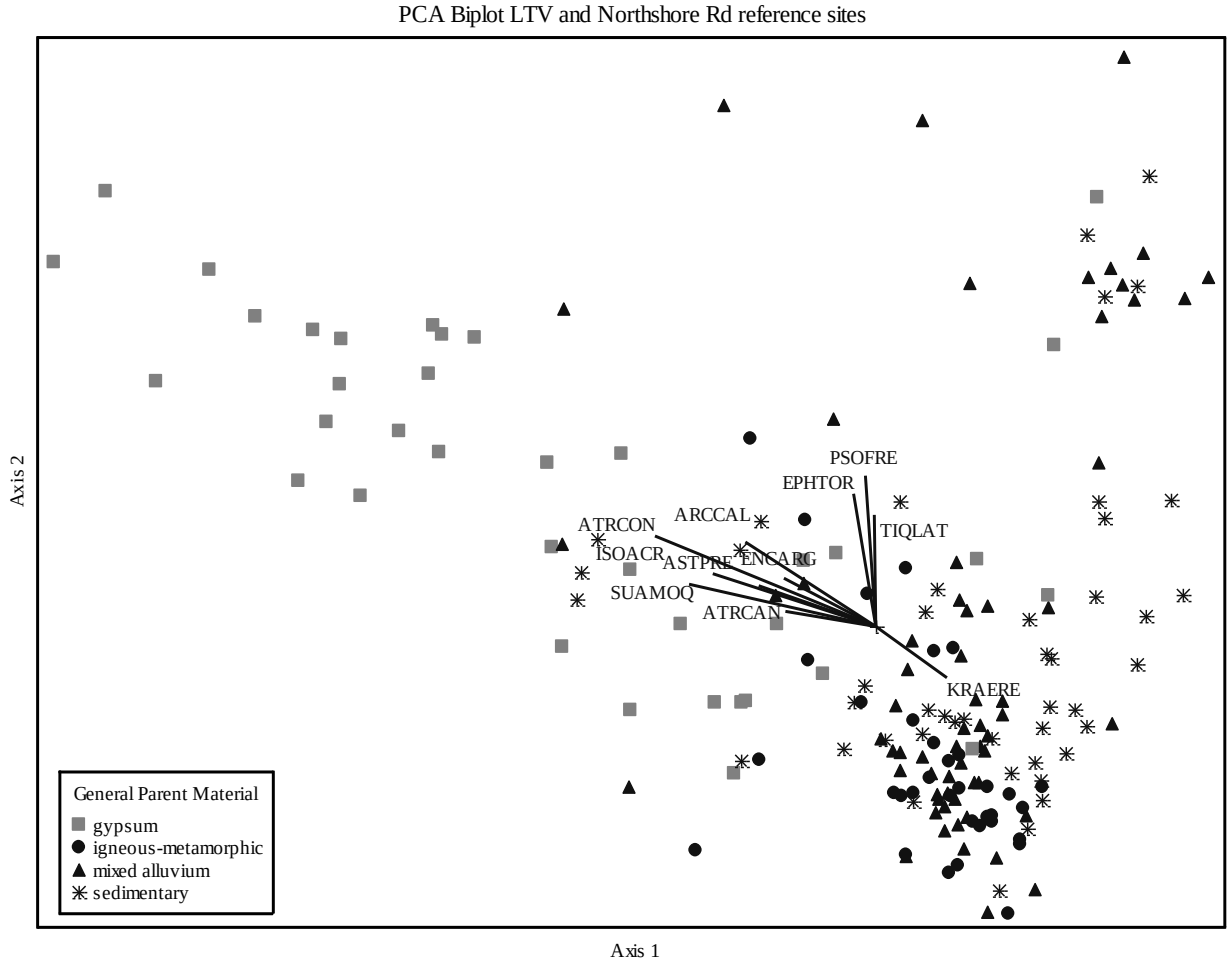


Figure 33 Principle component analysis biplot for the LTV and Northshore Rd reference sites, in and around Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, with sites grouped by general parent material categories, with vegetation vector overlay cutoff $r^2 \geq 0.15$, showing significant perennial plant species (presence), including ARCCAL (*Arctomecon californica*), ASTPRE (*Astragalus preussii*), ATRCAN (*Atriplex canescens*), ATRCON (*Atriplex confertifolia*), ENCARG (*Enceliopsis argophylla*), EPHTOR (*Ephedra torreyana*), ISOACR (*Isocoma acradenia*), KRAERE (*Krameria erecta*), PSOFRE (*Psorothamnus fremontii*), SUAMOQ (*Suaeda moquinii*), and TIQLAT (*Tiquilia latior*).

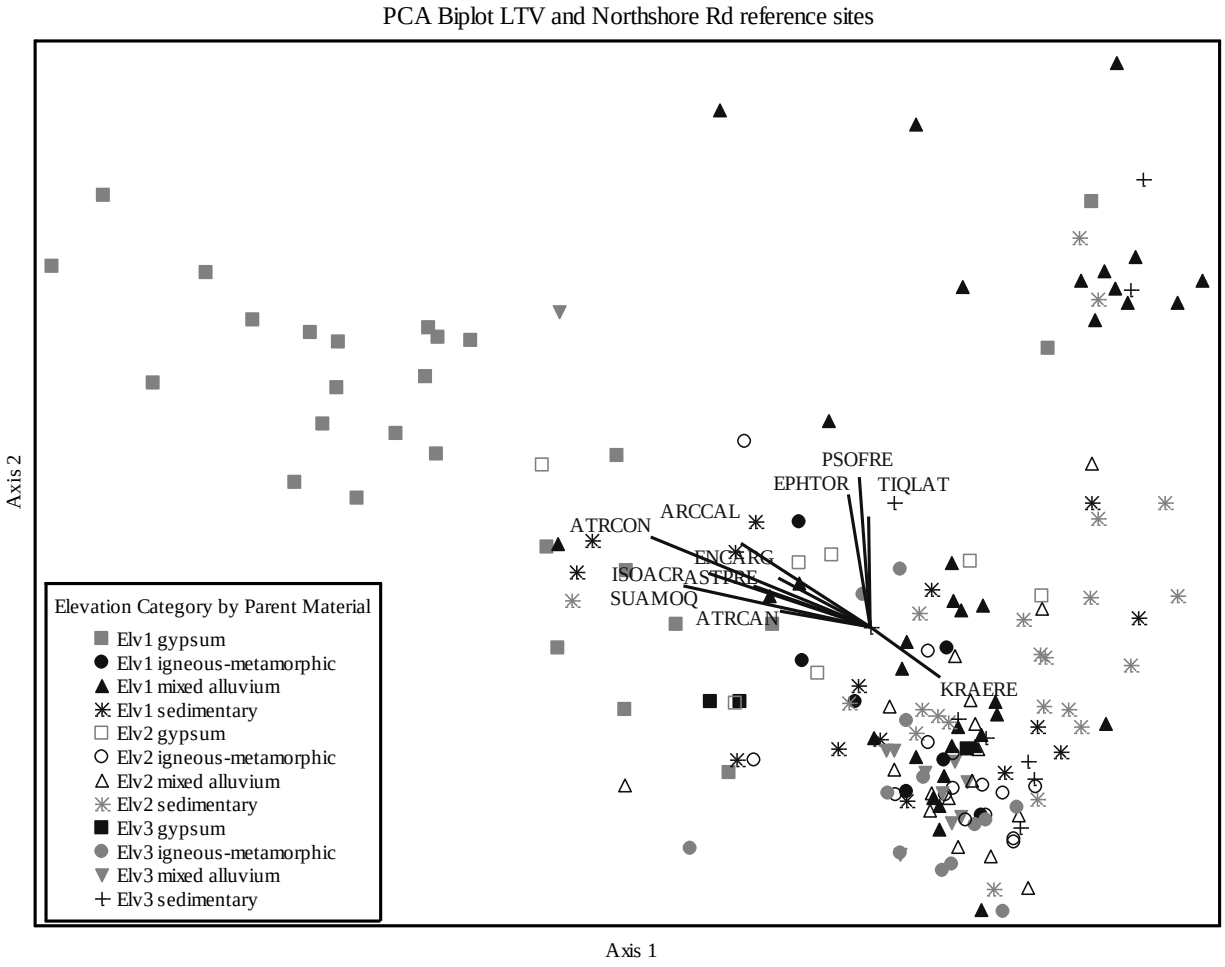


Figure 34 Principle component analysis biplot for the LTV and Northshore Rd reference sites, in and around Lake Mead National Recreation Area, Mojave Desert, using site and soil variables, with sites grouped by elevation categories and by general parent material categories, with vegetation vector overlay cutoff $r^2 \geq 0.15$, showing significant perennial plant species (presence), including ARCCAL (*Arctomecon californica*), ASTPRE (*Astragalus preussii*), ATRCAN (*Atriplex canescens*), ATRCON (*Atriplex confertifolia*), ENCARG (*Enceliopsis argophylla*), EPHTOR (*Ephedra torreyana*), ISOACR (*Isocoma acradenia*), KRAERE (*Krameria erecta*), PSOFRE (*Psorothamnus fremontii*), SUAMOQ (*Suaeda moquinii*), and TIQLAT (*Tiquilia latior*). Elevation categories: 1 = 149 - 490 m; 2 = 491- 776 m; and 3 = 777 – 1222 m.

Vegetation

Northshore Rd Corridor

Cover, Richness, and Density

Across all the Northshore Rd reference sites and the Northshore Rd pre-reconstruction sites, the overall mean cover was only 4%, consisting of a total of 37 species, 11 forbs, 2 grasses, and 24 shrubs, with a mean species richness of 10 species per 0.09/ha. Including the Northshore Rd pre-construction sites, the mean species density/ha was 246 individuals, 46 forbs, 8 grasses, and 193 shrubs. *Eriogonum inflatum* had the greatest forb density/ha, with only a mean cover of 0.04%. *Stephanomeria pauciflora* had the greatest forb cover, although just below 1% with only a mean density/ha of 3 individuals. The rare species *Arctomecon californica* had a very low mean cover of 0.006% with 1 individual averaging for every 4 ha, although we know this species tends to occur in more dense populations (see Section 2). *Pleuraphis rigida* was the only perennial grass found at the 0.01 ha resolution in density plots with a mean of 8 individuals/ha, however it only had a mean cover of 0.15%. *Dasyochloa pulchella* (formerly *Erioneuron pulchellum*, common name low woollygrass), was the only other perennial grass species observed in the Northshore Rd-specific sites, with a mean cover of 0.004%. *Ambrosia dumosa*, a common Mojave Desert species, had a mean cover of less than 1% and the highest occurrence of 82 individuals/ha. Another common Mojave Desert shrub, *Larrea tridentata* had a mean cover of 0.64% and 24 individuals/ha.

Depending on the resolution at which site soils are classified, perennial plant species cover, richness, and abundance will be more or less specific. Attachments included with this document in Excel files provides full the full dataset and summary of mean cover, richness and individuals/ha. Tables 23-37 present species richness/0.09ha, percent cover, and density/ha estimates per species and growth habit (forb, grass, shrub) for soil groups at different soil hierarchy levels. Only one of the soil great groups contained more than one subgroup; the Haplocalcids sites consisted of either Durinodic Haplocalcids or Typic Haplocalcids sites, which had a significant difference in species cover, species richness, and individuals/ha (Tables 30 & 31). Sites grouped by general parent material showed that sedimentary had the highest cover and individuals/ha estimates (Table 37). In all parent material categories, shrubs dominated the species identified, the cover, and the density/ha (Table 38). Gypsum had the greatest diversity of species identified with 33 species followed by mixed alluvium with 29 species; however sites within both these soils categories had the lowest overall cover, gypsum with 3.8% cover and mixed alluvium with 3.4% cover (Table 38). The grass-forb presence was greatest in gypsum-derived soils, although species within both these growth habits were consistently very low in cover.

Nonmetric multidimensional Scaling and Multiple Regression

NMS ordination of the Northshore Rd reference sites by species presence-absence data displayed site grouping mostly of Gypsids, with Calcids sites loosely clustering between Gypsids and Durids (Figures 35-37). Gypsum-derived soil sites clustered together and with perennial plant species presence vector overlay *Arctomecon*

californica, *Atriplex confertifolia*, and *Pleuraphis rigida*, with *Psorothamnus fremontii* appear to divide the Gypsids sites from other soil group sites. Typic Haplodurids were the only Durids occurring in the Northshore Rd dataset and were correlated with *Amphipappus fremontii* and *Larrea Tridentata*. Durids site-clustering was split between the two Haplocalcids subgroups (Typic and Durinodic Haplocalcids) (Figures 35 & 36). Torriorthents also were loosely clustered, although there were only three sites representing this soil group (Figure 35 & 36). Sites grouped in general parent material categories show a split between mixed alluvial and gypsum sites with *Pleuraphis rigida* and *Psorothamnus fremontii* between groups (Figure 37).

Ordination with soil vector overlay revealed gypsum-derived soils were correlated with the correlated variables EC, total S, Ni, SO_4, Ca, and Fe (Figures 38-40). Total C, $CaCO_3$, and inorganic C were correlated with mixed alluvium soils derived from different soil great groups (Figures 38-40). Ordination results with soil vector overlay were analogous to multiple regression results using NMS axis scores as predicted variables with soil variables as explanatory variables. Multiple regression showed that $CaCO_3$ (partial $r^2 \geq 0.30$, $P<0.00001$) and Cd (partial $r^2 \geq 0.06$, $P<0.00001$), with a full model $r^2 \geq 0.36$, had the strongest effect on site position and clustering along axis one, which reflects the difference between gypsum and non-gypsum derived soil sites. Total S (partial $r^2 \geq 0.33$, $P<0.00001$) and Zn (partial $r^2 \geq 0.08$, $P<0.0099$), with a full model $r^2 \geq 0.41$, had the greatest influence on site placement and clustering of the gypsum-derived soil sites along axis two.

Indicator Species Analysis

ISA for sites grouped by soil great groups resulted in a total of 9 indicator species, 3 species for the Calciargids, 1 species for Halplodurids, 2 species for the Torriorthents, and 3 species for Petrogypsids. The Petrogypsids sites has three strong indicator species, *Atriplex canescens*, *Atriplex confertifolia*, and *Isocoma acradenia*, with a significance of $\alpha \leq 0.10$, and which coincide with NMS results (Table 39). *Suaeda moquinii* and *Sphaeralcea ambigua* were strong indicator species for Calciargids sites, with a significance of $\alpha \leq 0.05$ (Table 39). *Dalea mollissima* and *Hymenoclea salsola* were an excellent indicator species and a very strong indicator species, respectively, with a significance of $\alpha \leq 0.05$ for the Torriorthents sites (Table 39). Subgroups had fewer indicator species, which included *Atriplex confertifolia* and *Isocoma acradenia* as strong indicator species for Typic Petrogypsids sites, again with a significance of $\alpha \leq 0.10$ (Table 40). Indicator values for common species across different levels of site-soil hierarchy either remained the same or reduced slightly with the addition of subgroup categories. Parent material gypsum category sites also had the same three species as indicator species for gypsum-derived soil, all of which were strong indicators with a significance of $\alpha \leq 0.10$ (Table 41). Only sandstone (or sedimentary) had indicator species, with *Krameria erecta* as a very strong indicator species with a significance of $\alpha \leq 0.05$ and *Opuntia acanthocarpa* as a strong indicator species, with a significance of $\alpha \leq 0.10$ (Table 41).

LTV and Northshore Rd Reference Sites

Cover, Richness, and Density

The overall total estimated mean cover in LTV and Northshore Rd reference sites across all soil types and elevation categories for all native perennial plants and non-native plants was 10.68%, with increasing mean cover as elevation increased (Table 42), and with the proportion of native vegetative cover at 99%. Growth habit distribution included 85 shrub species or 64.9% of total species [2 non-native shrubs included athel tamerisk (*Tamarix aphylla* (L.) Karst.) and saltcedar (*Tamarix ramosissima* Ledeb.)] with an overall mean percent cover of 9.9%, 37 forb species or 28.2% of total species with an overall mean percent cover of 0.40%, and 9 grass species or 6.9% of total species with an overall mean percent cover of 0.32%. Species richness and cover varied across elevation categories. In several instances there was only one site per soil great group and soil subgroups; therefore mean cover and richness were not calculated for these hierarchical levels. Elevation categories added an additional level of resolution for site specific vegetation models and also showed variability between species richness and cover per plant growth habit (Figures 41-46) and per individual species (Tables 43-54).

Nonmetric multidimensional Scaling and Multiple Regression

Ordination of vegetative species for the LTV and Northshore Rd reference sites reveal clusters of groups overlapping at different levels of soil taxonomic hierarchy or categorized by soil rock origin or general parent material, with gypsum-derived soils clustering. However there were no obvious correlations of gypsum-derived soils with vegetation (Figures 47-50). Species displayed with vector cutoff at $r^2 \geq 0.20$ with axes include *Coleogyne ramosissima, Eriogonum inflatum, Ephedra torreyana, Eriogonum fasciculatum, Krameria erecta, Larrea tridentata, Pluchea sericea, Prosopis pubescens, Psorothamnus fremontii,* and *Yucca schidigera,* with a stress maximum of 28.2 ($P = 0.002$). Several species correlated with elevation categories, including *Pluchea sericea* and *Prosopis pubescens* distinctly with elevation category 1, and *Atriplex confertifolia, Eriogonum inflatum, Ephedra torreyana,* S*phaeralcea ambigua,* and *Psorothamnus fremontii* mostly with elevation 1 but at approximate right angles to *Pluchea sericea* and *Prosopis pubescens* (Figure 51). Both *Psorothamnus fremontii* and *Pluchea sericea* appear to overlay on the edges of the gypsum soil sites within the elevation categories 1 and 3, while the gypsum sites within the elevation 2 category were correlated with *Larrea tridentata* (Figure 52).

The reduced species multiple regression showed that *Eriogonum inflatum* (partial $r^2 = 0.30$, $P<0.0001$), *Ephedra torreyana* (partial $r^2 = 0.16$, $P<0.0001$), *Larrea tridentata* (partial $r^2 = 0.10$, $P<0.0001$), *Psorothamnus fremontii* (partial $r^2 = 0.09$, $P<0.0001$) and *Ephedra viridis* (partial $r^2 = 0.05$, $P<0.0001$) had the strongest influence on NMS scores along axis 1, with a full model $r^2 \geq 0.70$, and *Eriogonum fasciculatum* (partial $r^2 = 0.42$, $P<0.0001$), *Ambrosia dumosa* (partial $r^2 = 0.17$, $P<0.0001$), *Krameria erecta* (partial $r^2 = 0.08$, $P<0.0001$) and *Ephedra viridis* (partial $r^2 = 0.07$, $P<0.0001$) had the strongest influence on NMS scores along axis 7, with a full model $r^2 \geq 0.74$.

NMS ordination revealed that the correlated soil variables, EC, total S, Ni, SO_4, Ca, Mg, and Fe were correlated with gypsum-derived

soils (Figures 53-56), particularly at lower elevation (Figure 57). NMS correlated soil vectors were similar to multiple regression results using NMS axis scores as predicted variables with soil variables as explanatory variables. Multiple regression showed that EC (partial $r^2 \geq 0.23$, $P<0.0001$), total C (partial $r^2 \geq 0.13$, $P<0.0001$), and elevation (partial $r^2 \geq 0.05$, $P<0.0004$), with a full model $r^2 \geq 0.0.40$ had the strongest effect on site position and clustering along axis one, Total N (partial $r^2 \geq 0.16$, $P<0.0001$) and >2mm wt (partial $r^2 \geq 0.17$, $P<0.0001$), with a full model $r^2 \geq 0.33$, had the greatest influence on site placement and clustering along axis two.

Indicator Species Analysis

Indicator species varied with the resolution of examination of species composition within soil taxonomic groups or categories and within elevation categories (Tables 55-59). There were two indicator species for Petrogypsids sites: *Arctomecon californica* (at $\alpha = 0.05$) and *Atriplex confertifolia* (at $\alpha = 0.10$) (Table 55). Analyzed using soil subgroups, Typic Petrogypsids only had one indicator species, *Arctomecon californica*, at $\alpha = 0.05$ (Table 56). For soil rock origin material types, gypsum-derived soils had a single indicator species *Atriplex confertifolia* at $\alpha = 0.05$ (Table 57). Analysis using general soil parent materials resulted in 7 species as indicator species, including *Ambrosia dumosa*, *Arctomecon californica*, *Atriplex canescens*, *Enceliopsis argophylla*, *Ephedra torreyana*, *Eriogonum inflatum*, and *Psorothamnus fremontii* (Table 58). *Atriplex canescens* was also found to be an indicator species for Typic Torrifluvents sites; however, there were only 2 sites within this subgroup. Including elevation categories with soil parent material categories reduced the overall species indicators per soil unit, resulting in only four species as indicator species for two different group combinations (Table 59). Three of these species occurred with gypsum-derived parent material soils in elevation category 1: *Atriplex confertifolia*, *Arctomecon californica*, and *Isocoma acradenia*. The only other indicator species identified was *Muhlenbergia porteri*, which was identified for mixed alluvium parent material sites in elevation 3 category. A full discussion on indicator species analysis for the LTV plots can be found in Abella et al. (2012a).

Table 23 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic great group Petrogypsids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Great Group	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Petrogypsids	31			3.80	246
	9	Forb		0.13	36
			Arctomecon californica	0.01	<1
			Astragalus preussii	0.01	4
			Delphinium parishii	<0.01	-
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.05	1
			Eriogonum inflatum	0.02	12
			Sphaeralcea ambigua	0.02	5
			Stephanomeria pauciflora	0.01	5
			Tiquilia latior	0.01	8
	2	Grass		0.22	15
			Dasyochloa pulchella	<0.01	-
			Pleuraphis rigida	0.22	15
	20	Shrub		3.45	196
			Acacia greggii	<0.01	<1
			Ambrosia dumosa	1.05	91
			Amphipappus fremontii	<0.01	<1
			Atriplex canescens	0.01	1
			Atriplex confertifolia	0.20	12
			Atriplex hymenelytra	<0.01	-
			Bebbia juncea	-	2
			Encelia virginensis	<0.01	-
			Ephedra nevadensis	0.01	1
			Ephedra torreyana	0.64	19
			Gutierrezia sarothrae	<0.01	-
			Hymenoclea salsola	0.21	6
			Isocoma acradenia	0.03	-
			Krameria grayi	0.01	6
			Larrea tridentata	0.35	14
			Lepidium fremontii	<0.01	-
			Lycium andersonii	<0.01	2
			Lycium cooperi	0.04	<1
			Opuntia acanthocarpa	-	<1
			Opuntia basilaris	<0.01	<1
			Psorothamnus fremontii	0.75	32
			Suaeda moquinii	0.14	9

Table 24 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic great group Calciargids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Great Group	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Calciargids	15			6.96	117
	4	Forb		0.20	23
			Dichelostemma capitatum	0.01	-
			Eriogonum inflatum	0.01	10
			Sphaeralcea ambigua	0.17	3
			Tiquilia latior	0.00	10
	1	Grass		0.19	-
			Pleuraphis rigida	0.19	-
	10	Shrub		6.58	93
			Ambrosia dumosa	0.10	17
			Amphipappus fremontii	0.15	-
			Atriplex confertifolia	0.08	-
			Ephedra nevadensis	0.31	-
			Ephedra torreyana	0.50	3
			Krameria grayi	0.75	10
			Larrea tridentata	4.33	23
			Opuntia basilaris	<0.01	-
			Psorothamnus fremontii	0.03	-
			Suaeda moquinii	0.32	40

Table 25 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic great group Haplocalcids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Great Group	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Haplocalcids	24			2.84	327
	8	Forb		0.24	75
			Arctomecon californica	0.01	-
			Baileya multiradiata	0.01	8
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.02	3
			Eriogonum inflatum	0.12	36
			Sphaeralcea ambigua	0.01	6
			Stephanomeria pauciflora	0.05	5
			Tiquilia latior	0.02	15
	2	Grass		0.03	-
			Dasyochloa pulchella	0.01	-
			Pleuraphis rigida	0.02	-
	14	Shrub		2.57	253
			Acacia greggii	0.02	-
			Ambrosia dumosa	0.99	126
			Amphipappus fremontii	0.04	6
			Atriplex confertifolia	<0.01	-
			Bebbia juncea	<0.01	-
			Encelia virginensis	0.02	2
			Ephedra nevadensis	<0.01	5
			Ephedra torreyana	0.29	23
			Krameria erecta	0.19	14
			Krameria grayi	0.16	15
			Larrea tridentata	0.62	43
			Opuntia acanthocarpa	<0.01	3
			Opuntia basilaris	0.03	<1
			Psorothamnus fremontii	0.20	15

Table 26 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic great group Haplodurids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Great Group	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Haplodurids	28			4.22	231
	8	Forb		0.14	53
			Arctomecon californica	0.01	-
			Baileya multiradiata	0.04	4
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	<0.01	-
			Eriogonum inflatum	0.03	27
			Sphaeralcea ambigua	0.01	6
			Stephanomeria pauciflora	0.01	<1
			Tiquilia latior	0.04	16
	2	Grass		0.13	5
			Dasyochloa pulchella	0.01	-
			Pleuraphis rigida	0.13	5
	18	Shrub		3.95	173
			Acacia greggii	<0.01	-
			Ambrosia dumosa	1.07	77
			Amphipappus fremontii	0.22	3
			Atriplex confertifolia	<0.01	-
			Bebbia juncea	<0.01	-
			Encelia virginensis	0.01	2
			Ephedra nevadensis	0.07	12
			Ephedra torreyana	0.43	18
			Ferocactus cylindraceus	<0.01	-
			Hymenoclea salsola	0.03	<1
			Krameria erecta	0.78	5
			Krameria grayi	0.07	11
			Larrea tridentata	0.50	29
			Lycium andersonii	<0.01	<1
			Opuntia acanthocarpa	<0.01	<1
			Opuntia basilaris	0.15	<1
			Psorothamnus fremontii	0.61	15
			Suaeda moquinii	<0.01	-

Table 27 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic great group Torriorthents for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Great Group	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Torriorthents	16			5.04	219
	4	Forb		0.35	30
			Dalea mollissimai	0.01	-
			Eriogonum inflatum	0.01	-
			Sphaeralcea ambigua	0.02	10
			Tiquilia latior	0.31	20
	1	Grass		<0.01	-
			Pleuraphis rigida	<0.01	-
	11	Shrub		4.69	189
			Acacia greggii	0.66	9
			Ambrosia dumosa	0.66	24
			Bebbia juncea	<0.01	39
			Ephedra nevadensis	0.55	3
			Ephedra torreyana	0.05	11
			Hymenoclea salsola	1.98	63
			Krameria grayi	<0.01	3
			Larrea tridentata	0.09	21
			Lepidium fremontii	<0.01	-
			Opuntia basilaris	<0.01	-
			Psorothamnus fremontii	0.69	16

Table 28 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Typic Petrogypsids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Typic Petrogypsids	31			3.80	246
	9	Forb		0.13	36
			Arctomecon californica	0.01	<1
			Astragalus preussii	0.01	4
			Delphinium parishii	<0.01	-
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.05	1
			Eriogonum inflatum	0.02	12
			Sphaeralcea ambigua	0.02	5
			Stephanomeria pauciflora	0.01	5
			Tiquilia latior	0.01	8
	2	Grass		0.22	15
			Dasyochloa pulchella	<0.01	-
			Pleuraphis rigida	0.22	15
	20	Shrub		3.45	196
			Acacia greggii	<0.01	<1
			Ambrosia dumosa	1.05	91
			Amphipappus fremontii	<0.01	<1
			Atriplex canescens	0.01	1
			Atriplex confertifolia	0.20	12
			Atriplex hymenelytra	<0.01	-
			Bebbia juncea	-	2
			Encelia virginensis	<0.01	-
			Ephedra nevadensis	0.01	1
			Ephedra torreyana	0.64	19
			Gutierrezia sarothrae	<0.01	-
			Hymenoclea salsola	0.21	6
			Isocoma acradenia	0.03	-
			Krameria grayi	0.01	6
			Larrea tridentata	0.35	14
			Lepidium fremontii	<0.01	-
			Lycium andersonii	<0.01	2
			Lycium cooperi	0.04	<1
			Opuntia acanthocarpa	-	<1
			Opuntia basilaris	<0.01	<1
			Psorothamnus fremontii	0.75	32
			Suaeda moquinii	0.14	9

Table 29 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Typic Calciargids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Typic Calciargids	15			6.96	117
	4	Forb		0.20	23
			Dichelostemma capitatum	0.01	-
			Eriogonum inflatum	0.01	10
			Sphaeralcea ambigua	0.17	3
			Tiquilia latior	0.00	10
	1	Grass		0.19	-
			Pleuraphis rigida	0.19	-
	10	Shrub		6.58	93
			Ambrosia dumosa	0.10	17
			Amphipappus fremontii	0.15	-
			Atriplex confertifolia	0.08	-
			Ephedra nevadensis	0.31	-
			Ephedra torreyana	0.50	3
			Krameria grayi	0.75	10
			Larrea tridentata	4.33	23
			Opuntia basilaris	<0.01	-
			Psorothamnus fremontii	0.03	-
			Suaeda moquinii	0.32	40

Table 30 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Durinodic Haplocalcids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Durinodic Haplocalcids	24			1.51	251.25
	8	Forb		0.29	96.25
			Arctomecon californica	0.01	-
			Baileya multiradiata	0.01	11.25
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.03	3.75
			Eriogonum inflatum	0.15	46.25
			Sphaeralcea ambigua	0.01	7.5
			Stephanomeria pauciflora	0.06	6.25
			Tiquilia latior	0.02	21.25
	2	Grass		0.01	<1
			Dasyochloa pulchella	0.01	-
			Pleuraphis rigida	<0.01	<1
	14	Shrub		1.21	155
			Acacia greggii	0.02	
			Ambrosia dumosa	0.15	33.75
			Amphipappus fremontii	0.05	8.75
			Atriplex confertifolia	<0.01	-
			Bebbia juncea	<0.01	-
			Encelia virginensis	0.02	2.5
			Ephedra nevadensis	<0.01	2.5
			Ephedra torreyana	0.07	22.5
			Krameria erecta	<0.01	7.5
			Krameria grayi	0.14	20
			Larrea tridentata	0.48	36.25
			Opuntia acanthocarpa	<0.01	2.5
			Opuntia basilaris	0.02	1.25
			Psorothamnus fremontii	0.25	17.5

Table 31 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Typic Haplocalcids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Typic Haplocalcids	12			5.43	795
	4	Forb		0.03	25
			Baileya multiradiata	<0.01	-
			Dichelostemma capitatum	<0.01	-
			Eriogonum inflatum	0.02	15
			Sphaeralcea ambigua	-	5
			Stephanomeria pauciflora	<0.01	5
	0	Grass		0.07	-
			Pleuraphis rigida	0.07	-
	8	Shrub		5.32	770
			Ambrosia dumosa	2.93	560
			Amphipappus fremontii	0.01	
			Ephedra nevedensis	-	15
			Ephedra torreyana	0.77	35
			Krameria erecta	0.63	45
			Krameria grayi	0.17	5
			Larrea tridentata	0.79	90
			Opuntia acanthocarpa	<0.01	5
			Opuntia basilaris	0.03	-
			Psorothamnus fremontii	-	15

Table 32 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Typic Haplodurids for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Typic Haplodurids	28			4.22	231
	8	Forb		0.14	53
			Arctomecon californica	0.01	-
			Baileya multiradiata	0.04	4
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	<0.01	-
			Eriogonum inflatum	0.03	27
			Sphaeralcea ambigua	0.01	6
			Stephanomeria pauciflora	0.01	<1
			Tiquilia latior	0.04	16
	2	Grass		0.13	5
			Dasyochloa pulchella	0.01	-
			Pleuraphis rigida	0.13	5
	18	Shrub		3.95	173
			Acacia greggii	<0.01	-
			Ambrosia dumosa	1.07	77
			Amphipappus fremontii	0.22	3
			Atriplex confertifolia	<0.01	-
			Bebbia juncea	<0.01	-
			Encelia virginensis	0.01	2
			Ephedra nevadensis	0.07	12
			Ephedra torreyana	0.43	18
			Ferocactus cylindraceus	<0.01	-
			Hymenoclea salsola	0.03	<1
			Krameria erecta	0.78	5
			Krameria grayi	0.07	11
			Larrea tridentata	0.50	29
			Lycium andersonii	<0.01	<1
			Opuntia acanthocarpa	<0.01	<1
			Opuntia basilaris	0.15	<1
			Psorothamnus fremontii	0.61	15
			Suaeda moquinii	<0.01	-

Table 33 Perennial plant species cover, density/ha, and species richness/0.09ha for the soil taxonomic subgroup Typic Torriorthents for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Soil Subgroup	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
Typic Torriorthents	16			5.04	219
	4	Forb		0.35	30
			Dalea mollissimai	0.01	-
			Eriogonum inflatum	0.01	-
			Sphaeralcea ambigua	0.02	10
			Tiquilia latior	0.31	20
	1	Grass		<0.01	-
			Pleuraphis rigida	<0.01	-
	11	Shrub		4.69	189
			Acacia greggii	0.66	9
			Ambrosia dumosa	0.66	24
			Bebbia juncea	<0.01	39
			Ephedra nevadensis	0.55	3
			Ephedra torreyana	0.05	11
			Hymenoclea salsola	1.98	63
			Krameria grayi	<0.01	3
			Larrea tridentata	0.09	21
			Lepidium fremontii	<0.01	-
			Opuntia basilaris	<0.01	-
			Psorothamnus fremontii	0.69	16

Table 34 Perennial plant species cover, density/ha, and species richness/0.09ha for the general soil parent material category gypsum for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Parent Material	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
gypsum	31			3.80	246
	9	Forb		0.13	36
			Arctomecon californica	0.01	1
			Astragalus preussii	0.01	4
			Delphinium parishii	<0.01	-
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.05	1
			Eriogonum inflatum	0.02	12
			Sphaeralcea ambigua	0.02	5
			Stephanomeria pauciflora	0.01	5
			Tiquilia latior	0.01	8
	2	Grass		0.22	15
			Dasyochloa pulchella	<0.01	-
			Pleuraphis rigida	0.22	15
	20	Shrub		3.45	196
			Acacia greggii	<0.01	<1
			Ambrosia dumosa	1.05	91
			Amphipappus fremontii	<0.01	<1
			Atriplex canescens	0.01	1
			Atriplex confertifolia	0.20	12
			Atriplex hymenelytra	<0.01	-
			Bebbia juncea	-	2
			Encelia virginensis	<0.01	-
			Ephedra nevadensis	0.01	1
			Ephedra torreyana	0.64	19
			Gutierrezia sarothrae	<0.01	-
			Hymenoclea salsola	0.21	6
			Isocoma acradenia	0.03	-
			Krameria grayi	0.01	6
			Larrea tridentata	0.35	14
			Lepidium fremontii	<0.01	-
			Lycium andersonii	<0.01	2
			Lycium cooperi	0.04	<1
			Opuntia acanthocarpa	-	<1
			Opuntia basilaris	<0.01	<1
			Psorothamnus fremontii	0.75	32
			Suaeda moquinii	0.14	9

Table 35 Perennial plant species cover, density/ha, and species richness/0.09ha for the general soil parent material category igneous-metamorphic for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Parent Material	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
igneous-metamorphic	15			6.96	117
		4	Forb	0.20	23
			Dichelostemma capitatum	0.01	-
			Eriogonum inflatum	0.01	10
			Sphaeralcea ambigua	0.17	3
			Tiquilia latior	<0.01	10
		1	Grass	0.19	-
			Pleuraphis rigida	0.19	-
		10	Shrub	6.58	93
			Ambrosia dumosa	0.10	17
			Amphipappus fremontii	0.15	-
			Atriplex confertifolia	0.08	-
			Ephedra nevadensis	0.31	-
			Ephedra torreyana	0.50	3
			Krameria grayi	0.75	10
			Larrea tridentata	4.33	23
			Opuntia basilaris	<0.01	-
			Psorothamnus fremontii	0.03	-
			Suaeda moquinii	0.32	40

Table 36 Perennial plant species cover, density/ha, and species richness/0.09ha for the general soil parent material category mixed alluvium for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Parent Material	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
mixed alluvium	29			3.44	233
		9	Forb	0.22	58
			Arctomecon californica	0.01	-
			Baileya multiradiata	0.03	5
			Dalea mollissimai	<0.01	-
			Dichelostemma capitatum	<0.01	-
			Enceliopsis argophylla	0.01	1
			Eriogonum inflatum	0.06	26
			Sphaeralcea ambigua	0.01	7
			Stephanomeria pauciflora	0.02	2
			Tiquilia latior	0.08	18
		2	Grass	0.05	3
			Dasyochloa pulchella	0.01	-
			Pleuraphis rigida	0.04	3
		18	Shrub	3.17	172
			Acacia greggii	0.11	2
			Ambrosia dumosa	0.58	57
			Amphipappus fremontii	0.14	4
			Atriplex confertifolia	<0.01	-
			Bebbia juncea	<0.01	8
			Encelia virginensis	0.01	2
			Ephedra nevadensis	0.13	8
			Ephedra torreyana	0.28	18
			Ferocactus cylindraceus	<0.01	-
			Hymenoclea salsola	0.32	13
			Krameria erecta	0.45	5
			Krameria grayi	0.08	11
			Larrea tridentata	0.45	29
			Lepidium fremontii	<0.01	-
			Lycium andersonii	<0.01	0
			Opuntia acanthocarpa	<0.01	1
			Opuntia basilaris	0.09	1
			Psorothamnus fremontii	0.52	16

Table 37 Perennial plant species cover, density/ha, and species richness/0.09ha for the general soil parent material category sedimentary for the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert. Species richness and cover acquired from Northshore Rd reference sites and density/ha compiled from Northshore Rd reference sites and the Pre-reconstruction Northshore Rd sites. A dash represents that species not identified within that parameter.

Parent Material	Species Richness/0.09ha	Growth Habit	Species	% Cover	Density/ha
sedimentary	19			7.51	530
(sandstone)	8	Forb		0.05	17
			Baileya multiradiata	<0.01	0
			Dichelostemma capitatum	0.01	0
			Eriogonum inflatum	0.03	10
			Sphaeralcea ambigua	<0.01	3
			Stephanomeria pauciflora	<0.01	3
	1	Grass		0.38	0
			Pleuraphis rigida	0.38	0
	10	Shrub		7.08	513
			Acacia greggii	<0.01	0
			Ambrosia dumosa	4.49	373
			Amphipappus fremontii	0.01	0
			Ephedra nevadensis	<0.01	10
			Ephedra torreyana	0.78	23
			Krameria erecta	0.63	30
			Krameria grayi	0.19	3
			Larrea tridentata	0.81	60
			Opuntia acanthocarpa	<0.01	3
			Opuntia basilaris	0.03	0
			Psorothamnus fremontii	0.15	10

Table 38 The total number of identified perennial plant species, mean percent cover, and density/ha per general soil parent material acquired from Northshore Rd reference and Northshore Rd pre-reconstruction sites along the Northshore Rd corridor between mile posts 27-48, Lake Mead National Recreation Area, Mojave Desert. No grass was identified in the density plots in igneous-metamorphic-derived soils.

Parent Material	Number of Individual Species	Growth Habit	Cover (%)	Density/ha
Gypsum	*33*		*3.80*	*246*
	9	Forb	0.13	36
	2	Grass	0.22	15
	22	Shrub	3.45	196
Igneous-metamorphic	*15*		*6.96*	*117*
	4	Forb	0.20	23
	1	Grass	0.19	-
	10	Shrub	6.58	93
Mixed alluvium	*29*		*3.44*	*233*
	9	Forb	0.22	58
	2	Grass	0.05	3
	18	Shrub	3.17	172
Sedimentary	*19*		*7.51*	*530*
	8	Forb	0.05	17
	1	Grass	0.38	<1
	10	Shrub	7.08	513

Table 39 Indicator species analysis for Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, Mojave Desert, grouped by soil taxonomic great groups, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier:		Monte Carlo Test of Significance			
Great Groups	Species	Value (IV)	Mean	S.Dev	*P*
Calciargids	*Dichelostemma capitatum*	37	16.6	9.24	**0.035**
Calciargids	*Sphaeralcea ambigua*	34.4	22.7	6.13	**0.0214**
Calciargids	*Suaeda moquinii*	43.8	15.9	8.84	**0.0142**
Haplodurids	*Amphipappus fremontii*	37.2	19.7	8.27	**0.0486**
Petrogypsids	*Atriplex canescens*	26.1	14.7	8.43	*0.0842*
Petrogypsids	*Atriplex confertifolia*	34.8	20.6	8.01	*0.0708*
Petrogypsids	*Isocoma acradenia*	34.8	15.3	8.7	*0.0526*
Torriorthents	*Dalea mollissimai*	75	12.4	8.69	**0.0006**
Torriorthents	*Hymenoclea salsola*	56.5	15.3	8.81	**0.0024**

Table 40 Indicator species analysis for Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, Mojave Desert, grouped by soil taxonomic subgroups, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier:		Monte Carlo Test of Significance			
soil subgroups	Species	Value (IV)	Mean	S.Dev	*P*
Typic Calciargids	*Sphaeralcea ambigua*	30.7	21.2	5.69	0.0232
Typic Calciargids	*Suaeda moquinii*	43.8	16.8	9.92	**0.0184**
Typic Haplocalcids	*Krameria erecta*	38.7	16.7	10.02	*0.0538*
Typic Petrogypsids	*Atriplex confertifolia*	34.1	20.3	7.81	*0.0998*
Typic Petrogypsids	*Isocoma acradenia*	34.8	16.5	9.84	*0.0758*
Typic Torriorthents	*Hymenoclea salsola*	56.5	16.6	9.78	**0.0042**

Table 41 Indicator species analysis for Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil parent material categories, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier:		Monte Carlo Test of Significance			
Parent Material	Species	Value (IV)	Mean	S.Dev	*P*
gypsum	*Atriplex canescens*	26.1	17.1	9.93	*0.0576*
gypsum	*Atriplex confertifolia*	36.8	24.8	10.32	*0.0992*
gypsum	*Isocoma acradenia*	34.8	18.4	10.27	*0.098*
sedimentary	*Krameria erecta*	49.5	18.6	10.3	**0.0044**
sedimentary	*Opuntia acanthocarpa*	24.8	14.9	10.85	*0.0742*

Table 42 Mean perennial plant species cover across three elevation categories complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Elevation Category	(m)	% Cover
1	149-940	6.16
2	491-776	11.89
3	777-1222	19.69
Total Mean		*10.66*

Table 43 Species richness (0.09/ha) and mean cover for soil derived from gypsum parent material at 149-490 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
gypsum	38			4.33
	12	Forb		0.22
			Anulocaulis leiosolenus	0.02
			Arctomecon californica	0.01
			Astragalus preussii	0.01
			Baileya multiradiata	<0.01
			Delphinium parishii	<0.01
			Dichelostemma capitatum	<0.01
			Enceliopsis argophylla	0.04
			Eriogonum inflatum	0.05
			Petalonyx parryi	0.02
			Sphaeralcea ambigua	0.02
			Stephanomeria pauciflora	0.03
			Tiquilia latior	0.02
	3	Grass		0.22
			Dasyochloa pulchella	<0.01
			Distichlis spicata	0.02
			Pleuraphis rigida	0.20
	23	Shrub		3.90
			Acacia greggii	0.13
			Allenrolfea occidentalis	0.04
			Ambrosia dumosa	0.92
			Amphipappus fremontii	<0.01
			Atriplex canescens	0.01
			Atriplex confertifolia	0.33
			Atriplex hymenelytra	<0.01
			Encelia virginensis	<0.01
			Ephedra nevadensis	0.06
			Ephedra torreyana	0.55
			Gutierrezia sarothrae	<0.01
			Hymenoclea salsola	0.17
			Isocoma acradenia	0.03
			Krameria grayi	0.15
			Larrea tridentata	0.52
			Lepidium fremontii	0.05
			Lycium andersonii	<0.01
			Lycium cooperi	0.04
			Opuntia basilaris	0.02
			Peucephyllum schottii	0.02
			Pluchea sericea	0.02
			Psorothamnus fremontii	0.71
			Suaeda moquinii	0.13

Table 44 Species richness (0.09/ha) and mean cover for soil derived from gypsum parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
gypsum	25			5.04
	9	Forb		0.87
			Arctomecon californica	<0.01
			Enceliopsis argophylla	0.08
			Eriogonum inflatum	0.09
			Petalonyx parryi	0.18
			Sphaeralcea ambigua	0.22
			Stanleya pinnata	0.07
			Stephanomeria pauciflora	0.22
			Tidestromia oblongifolia	<0.01
			Tiquilia latior	0.01
	1	Grass		0.14
			Pleuraphis rigida	0.14
	15	Shrub		4.02
			Acacia greggii	0.29
			Ambrosia dumosa	0.41
			Atriplex confertifolia	0.37
			Atriplex hymenelytra	0.14
			Encelia farinosa	<0.01
			Ephedra torreyana	1.00
			Hymenoclea salsola	0.36
			Krameria erecta	<0.01
			Krameria grayi	0.21
			Larrea tridentata	0.51
			Lepidium fremontii	0.07
			Lycium andersonii	0.26
			Opuntia basilaris	<0.01
			Psorothamnus fremontii	0.39
			Salazaria mexicana	<0.01

Table 45 Species richness (0.09/ha) and mean cover for soil derived from gypsum parent material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
gypsum	22			20.99
	5	Forb		0.51
			Eriogonum inflatum	<0.01
			Petalonyx parryi	<0.01
			Sphaeralcea ambigua	0.25
			Stephanomeria pauciflora	<0.01
			Tiquilia latior	0.25
	1	Grass		<0.01
			Aristida purpurea	<0.01
	16	Shrub		20.47
			Acamptopappus sphaerocephalus	0.25
			Adenophyllum porophylloides	<0.01
			Ambrosia dumosa	4.00
			Cylindropuntia acanthoca	0.25
			Echinocereus engelmannii	0.25
			Ephedra torreyana	1.00
			Ferocactus cylindraceus	0.25
			Hymenoclea salsola	1.46
			Krameria erecta	0.25
			Larrea tridentata	1.17
			Lepidium fremontii	0.25
			Lycium andersonii	5.46
			Opuntia basilaris	<0.01
			Psorothamnus fremontii	4.88
			Xylorhiza tortifolia	0.25
			Yucca schidigera	0.75

Table 46 Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic parent material at 149-490 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
igneous-metamorphic	31			7.33
		9	Forb	0.18
			Calochortus flexuosus	<0.01
			Chamaesyce polycarpa	<0.01
			Cynanchum utahense	0.06
			Dichelostemma capitatum	<0.01
			Enceliopsis argophylla	0.06
			Eriogonum inflatum	0.01
			Sphaeralcea ambigua	0.06
			Stephanomeria pauciflora	<0.01
			Tiquilia latior	<0.01
		1	Grass	0.06
			Pleuraphis rigida	0.06
		21	Shrub	7.09
			Acacia greggii	0.06
			Ambrosia dumosa	0.61
			Amphipappus fremontii	0.05
			Asclepias subulata	0.06
			Atriplex confertifolia	0.03
			Bebbia juncea	0.20
			Cylindropuntia acanthoca	0.11
			Cylindropuntia echinocarpa	<0.01
			Cylindropuntia ramosissima	0.33
			Encelia farinosa	0.17
			Ephedra nevadensis	0.10
			Ephedra torreyana	0.17
			Hymenoclea salsola	<0.01
			Krameria erecta	0.11
			Krameria grayi	0.53
			Larrea tridentata	3.57
			Opuntia basilaris	0.06
			Pluchea sericea	0.39
			Psorothamnus fremontii	0.40
			Senna covesii	0.06
			Suaeda moquinii	0.11

Table 47 Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
igneous-metamorphic	48			16.08
	9	Forb		0.58
			Androstephium breviflorum	<0.01
			Argythamnia neomexicana	<0.01
			Baileya multiradiata	0.08
			Cynanchum utahense	0.04
			Delphinium parishii	<0.01
			Eriogonum inflatum	0.11
			Mirabilis laevis	0.05
			Sphaeralcea ambigua	0.21
			Stephanomeria pauciflora	0.08
	3	Grass		0.13
			Aristida purpurea	<0.01
			Dasyochloa pulchella	0.04
			Pleuraphis rigida	0.08

Table 47 *continued* Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
	36	Shrub		15.38
			Acacia greggii	0.33
			Acamptopappus sphaerocephalus	0.61
			Adenophyllum porophylloides	0.04
			Ambrosia dumosa	3.9
			Bebbia juncea	0.25
			Cylindropuntia acanthoca	0.17
			Cylindropuntia echinocarpa	0.04
			Cylindropuntia ramosissima	<0.01
			Echinocereus engelmannii	0.08
			Echinomastus johnsonii	<0.01
			Encelia farinosa	1.12
			Encelia virginensis	0.04
			Ephedra nevadensis	0.21
			Ephedra torreyana	0.13
			Ephedra viridis	0.08
			Eriogonum fasciculatum	0.13
			Ferocactus cylindraceus	0.04
			Fouquieria splendens	0.04
			Hymenoclea salsola	0.21
			Krameria erecta	0.56
			Krameria grayi	0.42
			Larrea tridentata	5.8
			Lycium andersonii	0.17
			Menodora spinescens	<0.01
			Opuntia basilaris	0.37
			Opuntia polyacantha	<0.01
			Physalis crassifolia	<0.01
			Porophyllum gracile	0.13
			Psorothamnus fremontii	0.13
			Salazaria mexicana	0.04
			Senna armata	0.04
			Senna covesii	<0.01
			Tiquilia canescens	0.04
			Viguiera parishii	0.04
			Xylorhiza tortifolia	0.09
			Yucca schidigera	0.13

Table 48 Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09ha)	Growth Habit	Species	% Cover
igneous-metamorphic	75			20.85
	14	Forb		0.7
			Arabis perennans	<0.01
			Argythamnia neomexicana	0.03
			Calochortus flexuosus	<0.01
			Cynanchum utahense	0.03
			Delphinium parishii	0.03
			Eriogonum inflatum	0.07
			Galium stellatum	0.05
			Machaeranthera pinnatifida	<0.01
			Menodora scabra	<0.01
			Mirabilis laevis	0.04
			Penstemon palmeri	0.04
			Psilostrophe cooperi	0.03
			Sphaeralcea ambigua	0.27
			Stephanomeria pauciflora	0.09
	6	Grass		1.69
			Achnatherum speciosum	0.19
			Aristida purpurea	0.01
			Dasyochloa pulchella	0.03
			Muhlenbergia porteri	0.1
			Pleuraphis rigida	1.36
			Poa secunda	<0.01

Table 48 *continued* Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09ha)	Growth Habit	Species	% Cover
	55	Shrub		18.45
			Acacia greggii	0.4
			Acamptopappus sphaerocephalus	0.18
			Adenophyllum porophylloides	0.07
			Ambrosia dumosa	1.83
			Brickellia arguta	0.03
			Coleogyne ramosissima	1.39
			Cylindropuntia acanthoca	0.14
			Cylindropuntia echinocarpa	0.03
			Cylindropuntia ramosissima	0.17
			Echinocereus engelmannii	0.07
			Echinomastus johnsonii	<0.01
			Encelia farinosa	1.7
			Encelia virginensis	0.41
			Ephedra nevadensis	0.32
			Ephedra torreyana	0.36
			Ephedra viridis	0.03
			Ericameria cooperi	0.03
			Ericameria laricifolia	<0.01
			Ericameria linearifolia	0.03
			Eriogonum fasciculatum	2.02
			Eriogonum microthecum	0.28
			Eriogonum wrightii	0.03
			Ferocactus cylindraceus	0.26
			Fouquieria splendens	0.09
			Grayia spinosa	0.03
			Gutierrezia microcephala	0.03
			Gutierrezia sarothrae	0.03
			Hymenoclea salsola	0.07

Table 48 *continued* Species richness (0.09/ha) and mean cover for soil derived from igneous-metamorphic material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09ha)	Growth Habit	Species	% Cover
			Juniperus californica	0.94
			Krameria erecta	1
			Krameria grayi	0.23
			Larrea tridentata	1.78
			Lepidium fremontii	<0.01
			Lycium andersonii	0.33
			Mammillaria tetrancistra	<0.01
			Menodora spinescens	0.03
			Nolina bigelovii	0.07
			Opuntia basilaris	0.03
			Opuntia polyacantha	0.03
			Phoradendron californicum	<0.01
			Porophyllum gracile	0.12
			Prunus fasciculata	0.08
			Psorothamnus fremontii	0.8
			Quercus turbinella	0.23
			Salazaria mexicana	0.15
			Salvia mohavensis	0.03
			Sclerocactus polyancistrus	0.07
			Senna armata	0.28
			Senna covesii	<0.01
			Tetradymia stenolepis	0.1
			Thamnosma montana	0.83
			Tiquilia canescens	0.02
			Viguiera parishii	0.1
			Xylorhiza tortifolia	0.13
			Yucca schidigera	1

Table 49 Species richness (0.09/ha) and mean cover for soil derived from mixed alluvium parent material at 149-490 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
mixed alluvium	41			6.22
	11	Forb		0.15
			Arctomecon californica	<0.01
			Baileya multiradiata	0.02
			Calochortus flexuosus	<0.01
			Cynanchum utahense	<0.01
			Dalea mollissimai	<0.01
			Dichelostemma capitatum	<0.01
			Enceliopsis argophylla	0.01
			Eriogonum inflatum	0.04
			Sphaeralcea ambigua	0.01
			Stephanomeria pauciflora	0.02
			Tiquilia latior	0.05
	2	Grass		0.07
			Dasyochloa pulchella	<0.01
			Pleuraphis rigida	0.06
	28	Shrub		6.01
			Acacia greggii	0.16
			Ambrosia dumosa	0.97
			Amphipappus fremontii	0.09
			Atriplex canescens	0.73
			Atriplex confertifolia	<0.01
			Atriplex hymenelytra	0.04
			Bebbia juncea	0.03
			Cylindropuntia echinocarpa	0.01
			Cylindropuntia ramosissima	0.10
			Encelia virginensis	0.01
			Ephedra nevadensis	0.10
			Ephedra torreyana	0.18
			Ephedra viridis	0.01
			Ferocactus cylindraceus	<0.01
			Hymenoclea salsola	0.49
			Krameria erecta	0.31
			Krameria grayi	0.16
			Larrea tridentata	1.84
			Lepidium fremontii	<0.01
			Lycium andersonii	<0.01
			Opuntia acanthocarpa	<0.01
			Opuntia basilaris	0.08
			Parkinsonia microphylla	0.01
			Phoradendron californicum	0.01
			Pluchea sericea	0.09
			Prosopis pubescens	0.19
			Psorothamnus fremontii	0.38
			Sclerocactus polyancistrus	<0.01

Table 50 Species richness (0.09/ha) and mean cover for soil derived from mixed alluvium parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
mixed-alluvium	39			8.23
	7	Forb		0.06
			Androstephium breviflorum	<0.01
			Baileya multiradiata	0.03
			Calochortus flexuosus	<0.01
			Delphinium parishii	<0.01
			Eriogonum inflatum	0.03
			Psilostrophe cooperi	<0.01
			Stephanomeria pauciflora	<0.01
	3	Grass		0.25
			Dasyochloa pulchella	0.03
			Pleuraphis rigida	0.19
			Tridens muticus	0.03
	29	Shrub		7.92
			Acacia greggii	0.35
			Acamptopappus sphaerocephalus	0.08
			Ambrosia dumosa	2.40
			Amphipappus fremontii	0.03
			Atriplex lentiformis	0.03
			Coleogyne ramosissima	0.45
			Cylindropuntia acanthoca	0.04
			Cylindropuntia echinocarpa	0.08
			Cylindropuntia ramosissima	0.03
			Echinomastus johnsonii	0.03
			Encelia farinosa	0.03
			Ephedra nevadensis	0.01
			Ephedra torreyana	<0.01
			Eriogonum fasciculatum	0.03
			Krameria erecta	0.65
			Krameria grayi	0.03
			Larrea tridentata	3.03
			Lycium andersonii	0.11
			Mammillaria tetrancistra	<0.01
			Opuntia basilaris	0.08
			Peucephyllum schottii	0.08
			Pleurocoronis pluriseta	0.03
			Psorothamnus fremontii	0.03
			Sclerocactus polyancistrus	0.03
			Thamnosma montana	0.08
			Tiquilia canescens	0.03
			Xylorhiza tortifolia	<0.01
			Yucca brevifolia	0.03
			Yucca schidigera	0.11

Table 51 Species richness (0.09/ha) and mean cover for soil derived from mixed alluvium material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
mixed alluvium	74			18.52
	16	Forb		0.55
			Allionia incarnata	<0.01
			Androstephium breviflorum	<0.01
			Argythamnia neomexicana	0.02
			Baileya multiradiata	0.04
			Calochortus flexuosus	<0.01
			Castilleja angustifolia	0.04
			Cymopterus multinervatus	0.04
			Delphinium parishii	0.01
			Eriogonum inflatum	0.1
			Galium stellatum	<0.01
			Mirabilis laevis	0.04
			Mirabilis multiflora	<0.01
			Psilostrophe cooperi	<0.01
			Sphaeralcea ambigua	0.13
			Sphaeralcea rusbyi	0.04
			Stephanomeria pauciflora	0.08
	6	Grass		0.61
			Achnatherum speciosum	0.04
			Aristida purpurea	<0.01
			Dasyochloa pulchella	0.01
			Muhlenbergia porteri	0.15
			Pleuraphis rigida	0.33
			Tridens muticus	0.07

Table 51 *continued* Species richness (0.09/ha) and mean cover for soil derived from mixed alluvium material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
	52	Shrub		17.37
			Acacia greggii	0.5
			Acamptopappus sphaerocephalus	0.47
			Agave utahensis	0.02
			Aloysia wrightii	0.13
			Ambrosia dumosa	1.33
			Ambrosia eriocentra	0.52
			Brickellia arguta	0.04
			Brickellia californica	0.04
			Coleogyne ramosissima	1.23
			Cylindropuntia acanthoca	0.21
			Cylindropuntia echinocarpa	0.04
			Cylindropuntia ramosissima	<0.01
			Echinocereus engelmannii	0.13
			Echinomastus johnsonii	0.08
			Encelia farinosa	<0.01
			Ephedra nevadensis	0.4
			Ephedra torreyana	0.17
			Ephedra viridis	0.15
			Eriogonum fasciculatum	0.33
			Eriogonum wrightii	0.04
			Ferocactus cylindraceus	0.28
			Fouquieria splendens	0.29
			Grayia spinosa	0.91
			Gutierrezia sarothrae	0.04
			Hymenoclea salsola	0.34
			Juniperus californica	<0.01
			Krameria erecta	0.91

Table 51 *continued* Species richness (0.09/ha) and mean cover for soil derived from mixed alluvium material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
			Krameria grayi	0.15
			Krascheninnikovia lanata	<0.01
			Larrea tridentata	3.99
			Lepidium fremontii	0.08
			Lycium andersonii	0.23
			Lycium pallidum	0.04
			Mammillaria tetrancistra	0.04
			Menodora spinescens	0.13
			Opuntia basilaris	0.08
			Opuntia phaeacantha	0.63
			Opuntia polyacantha	0.13
			Parthenium incanum	0.04
			Porophyllum gracile	0.04
			Psorothamnus fremontii	0.04
			Salazaria mexicana	0.13
			Salvia mohavensis	0.04
			Sclerocactus polyancistrus	0.08
			Tetradymia stenolepis	0.17
			Thamnosma montana	0.33
			Tiquilia canescens	0.08
			Viguiera parishii	0.15
			Xylorhiza tortifolia	0.18
			Yucca baccata	0.24
			Yucca brevifolia	0.62
			Yucca schidigera	1.1

Table 52 Species richness (0.09/ha) and mean cover for soil derived from sedimentary parent material at 149-490 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
sedimentary	33			10.37
	11	Forb		0.61
			Argythamnia neomexicana	0.06
			Baileya multiradiata	<0.01
			Calochortus flexuosus	<0.01
			Cynanchum utahense	0.03
			Dichelostemma capitatum	<0.01
			Eriogonum inflatum	0.12
			Petalonyx parryi	0.01
			Sphaeralcea ambigua	0.11
			Stephanomeria pauciflora	0.17
			Thymophylla pentachaeta	0.06
			Tiquilia latior	0.06
	2	Grass		0.31
			Achnatherum hymenoides	<0.01
			Dasyochloa pulchella	<0.01
			Pleuraphis rigida	0.30
	20	Shrub		9.45
			Acacia greggii	0.39
			Ambrosia dumosa	2.63
			Amphipappus fremontii	0.06
			Asclepias subulata	0.17
			Atriplex canescens	0.06
			Cylindropuntia echinocarpa	<0.01
			Encelia farinosa	0.06
			Encelia virginensis	<0.01
			Ephedra nevadensis	0.11
			Ephedra torreyana	1.03
			Krameria erecta	0.50
			Krameria grayi	0.65
			Krascheninnikovia lanata	<0.01
			Larrea tridentata	2.50
			Menodora spinescens	<0.01
			Opuntia acanthocarpa	<0.01
			Opuntia basilaris	0.12
			Porophyllum gracile	0.11
			Psorothamnus fremontii	1.01
			Tiquilia canescens	0.06

Table 53 Species richness (0.09/ha) and mean cover for soil derived from sedimentary parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
sedimentary	64			14.44
	16	Forb		0.69
			Argythamnia neomexicana	<0.01
			Baileya multiradiata	<0.01
			Calochortus flexuosus	<0.01
			Chamaesyce albomarginata	0.02
			Cryptantha virginensis	<0.01
			Delphinium parishii	<0.01
			Enceliopsis argophylla	0.02
			Eriogonum inflatum	0.18
			Galium stellatum	<0.01
			Machaeranthera pinnatifida	0.01
			Mirabilis laevis	<0.01
			Petalonyx parryi	<0.01
			Sphaeralcea ambigua	0.23
			Stephanomeria pauciflora	0.14
			Tidestromia oblongifolia	0.04
			Tiquilia latior	0.04
	4	Grass		0.21
			Achnatherum hymenoides	<0.01
			Aristida purpurea	0.04
			Dasyochloa pulchella	0.02
			Pleuraphis rigida	0.15

Table 53 *continued* Species richness (0.09/ha) and mean cover for soil derived from sedimentary parent material at 491-776 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
	44	Shrub		13.54
			Acacia greggii	0.32
			Acamptopappus sphaerocephalus	0.02
			Ambrosia dumosa	3.79
			Amphipappus fremontii	0.12
			Atriplex confertifolia	0.36
			Atriplex hymenelytra	0.38
			Atriplex lentiformis	0.12
			Bebbia juncea	<0.01
			Cylindropuntia acanthoca	0.04
			Cylindropuntia echinocarpa	0.08
			Cylindropuntia ramosissima	<0.01
			Echinocereus engelmannii	0.06
			Encelia farinosa	0.17
			Encelia virginensis	0.11
			Ephedra nevadensis	<0.01
			Ephedra torreyana	0.73
			Eriogonum fasciculatum	0.04
			Eucnide urens	0.02
			Ferocactus cylindraceus	0.04
			Fouquieria splendens	0.02
			Gutierrezia sarothrae	0.04
			Hymenoclea salsola	0.04
			Krameria erecta	0.51
			Krameria grayi	0.44
			Krascheninnikovia lanata	0.02
			Larrea tridentata	3.79
			Lepidium fremontii	0.06
			Lycium andersonii	0.1
			Mammillaria tetrancistra	<0.01
			Menodora spinescens	<0.01
			Opuntia basilaris	0.17
			Opuntia polyacantha	0.02
			Peucephyllum schottii	0.16
			Pleurocoronis pluriseta	<0.01
			Porophyllum gracile	0.06
			Prunus fasciculata	0.14
			Psorothamnus fremontii	1.35
			Salazaria mexicana	0.02
			Sclerocactus polyancistrus	0.06
			Suaeda moquinii	0.02
			Tetradymia stenolepis	<0.01
			Tiquilia canescens	0.02
			Xylorhiza tortifolia	<0.01
			Yucca schidigera	0.06

Table 54 Species richness (0.09/ha) and mean cover for soil derived from sedimentary material at 777-1222 m elevation compiled from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

Parent Material	Species Richness (0.09)	Growth Habit	Species	% Cover
sedimentary	36			18.51
	9	Forb		0.68
			Argemone munita	0.10
			Calochortus flexuosus	<0.01
			Delphinium parishii	<0.01
			Eriogonum inflatum	0.10
			Galium stellatum	<0.01
			Machaeranthera pinnatifida	0.10
			Sphaeralcea ambigua	0.17
			Sphaeralcea emoryi	0.10
			Stephanomeria pauciflora	0.10
	3	Grass		0.30
			Achnatherum speciosum	0.10
			Dasyochloa pulchella	<0.01
			Pleuraphis rigida	0.20
	24	Shrub		17.53
			Acamptopappus sphaerocephalus	0.17
			Ambrosia dumosa	5.15
			Amphipappus fremontii	0.80
			Cylindropuntia echinocarpa	0.10
			Encelia farinosa	0.58
			Encelia virginensis	0.10
			Ephedra nevadensis	0.95
			Ephedra torreyana	0.60
			Ephedra viridis	0.10
			Grusonia parishii	<0.01
			Krameria erecta	0.10
			Krameria grayi	1.93
			Krascheninnikovia lanata	0.10
			Larrea tridentata	0.93
			Lepidium fremontii	0.20
			Lycium andersonii	2.78
			Menodora spinescens	0.35
			Opuntia basilaris	0.10
			Psorothamnus fremontii	0.88
			Sclerocactus polyancistrus	<0.01
			Thamnosma montana	0.59
			Tiquilia canescens	0.10
			Xylorhiza tortifolia	0.10
			Yucca brevifolia	0.80

Table 55 Indicator species analysis results for LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic great groups, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier		Monte Carlo Test of Significance			
Soil Great Group	Species	Value (IV)	Mean	S.Dev	*P*
Argidurids	*Eriogonum fasciculatum*	38.6	12.8	7.91	**0.0339**
Argidurids	*Yucca schidigera*	40.2	12.9	8.28	**0.0343**
Argidurids	*Acamptopappus sphaerocephalus*	38.7	12.9	8.11	**0.0348**
Argidurids	*Lycium andersonii*	35.6	12.7	7.91	**0.0354**
Argidurids	*Opuntia acanthocarpa*	37.7	13.1	8.59	**0.0403**
Argidurids	*Krascheninnikovia lanata*	39	10.5	11.57	*0.059*
Argidurids	*Psilostrophe cooperi*	37.4	9.7	11.3	*0.0833*
Argidurids	*Tetradymia stenolepis*	35.3	10.4	11.39	*0.0924*
Argidurids	*Viguiera parishii*	31.6	11.8	11.38	*0.0935*
Haplocambids	*Opuntia polyacantha*	43.5	11.3	11.45	**0.0027**
Haplocambids	*Ferocactus cylindraceus*	25	12.9	9.02	**0.0297**
Petrogypsids	*Arctomecon californica*	29.2	13.1	9.36	**0.0241**
Petrogypsids	*Atriplex confertifolia*	28.7	12.7	7.86	*0.0943*
Torrifluvents	*Pluchea sericea*	82.2	10.5	11.54	**0.0011**
Torrifluvents	*Atriplex canescens*	32.1	12.1	11.32	*0.0512*
Torripsamments	*Cynanchum utahense*	41.7	10.9	11.5	**0.0026**

Table 56 Indicator species analysis results for LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic subgroups, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier		Monte Carlo Test of Significance			
Soil Subgroup	Species	Value (IV)	Mean	S.Dev	*P*
Cambidic Haplodurids	*Eriogonum wrightii*	41.7	12.8	12.75	*0.0675*
Cambidic Haplodurids	*Machaeranthera pinnatifida*	30.7	14.3	10.93	*0.0721*
Typic Argidurids	*Opuntia acanthocarpa*	32.4	12.7	7.71	*0.0568*
Typic Argidurids	*Acamptopappus sphaerocephalus*	30.4	12.6	7.55	*0.0649*
Typic Argidurids	*Lycium andersonii*	26.5	11.6	7.17	*0.0724*
Typic Argidurids	*Eriogonum fasciculatum*	28.7	11.9	7.28	*0.0757*
Typic Argidurids	*Yucca schidigera*	27.9	12.4	7.47	*0.0765*
Typic Haplocambids	*Opuntia polyacantha*	38.2	14.2	11.44	**0.0062**
Typic Petrogypsids	*Arctomecon californica*	26.2	13.4	8.28	**0.0439**
Typic Torrifluvents	*Pluchea sericea*	81.6	13.6	12.41	**0.0015**
Typic Torrifluvents	*Atriplex canescens*	32.1	14.2	10.1	**0.0097**
Typic Torripsamments	*Cynanchum utahense*	35.6	13.9	11.85	*0.0635*
Ustic Haplargids	*Ephedra viridis*	69.1	14.3	9.73	0.0024
Ustic Haplargids	*Achnatherum speciosum*	28.6	14.3	10.49	*0.0785*

Table 57 Indicator species analysis results for LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil rock origin material types, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier		Monte Carlo Test of Significance			
Rock Origin Category	Species	Value (IV)	Mean	S.Dev	*P*
basalt	*Cylindropuntia echinocarpa*	25.3	9.2	5.45	0.0313
gypsum	*Atriplex confertifolia*	30.4	9.8	5.69	0.0071
granite	*Eriogonum fasciculatum*	32	9.4	5.71	0.0049

Table 58 Indicator species analysis results for LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert, grouped by general soil parent material categories, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier		Monte Carlo Test of Significance			
Rock Origin Category	Species	Value (IV)	Mean	S.Dev	*P*
gypsum	*Ambrosia dumosa*	27.1	24.5	1.24	**0.0245**
gypsum	*Arctomecon californica*	26.7	5.3	1.95	**0.0001**
gypsum	*Atriplex canescens*	49.1	8.5	2.23	**0.0001**
gypsum	*Enceliopsis argophylla*	26.2	5.9	1.99	**0.0001**
gypsum	*Ephedra torreyana*	33.9	17	2.29	**0.0001**
gypsum	*Eriogonum inflatum*	25.2	18.2	2.21	**0.0095**
gypsum	*Psorothamnus fremontii*	34.8	17.3	2.27	**0.0001**
igneous-metamorphic	*Eriogonum fasciculatum*	28.2	7.5	2.17	**0.0001**
sedimentary	*Larrea tridentata*	27.5	24.5	1.23	**0.0136**

Table 59 Indicator species analysis results for LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert, grouped by elevation category (1 = 149 – 490 m; 2 = 491 – 776 m; 3 = 777 – 1222 m) and soil parent material categories, with species indicator values (IV), mean occurrence and standard deviation, and the *P*-value per species.

Identifier		Monte Carlo Test of Significance			
Rock Origin Category	Species	Value (IV)	Mean	S.Dev	*P*
Elv 1 x gypsum	*Atriplex confertifolia*	29	8	4.31	0.0057
Elv 3 x mixed alluvium	*Muhlenbergia porteri*	30.3	6.9	4.91	0.0078
Elv 1 x gypsum	*Arctomecon californica*	33.2	7.4	4.75	0.0018
Elv 1 x gypsum	*Isocoma acradenia*	33.3	7	5.14	0.007

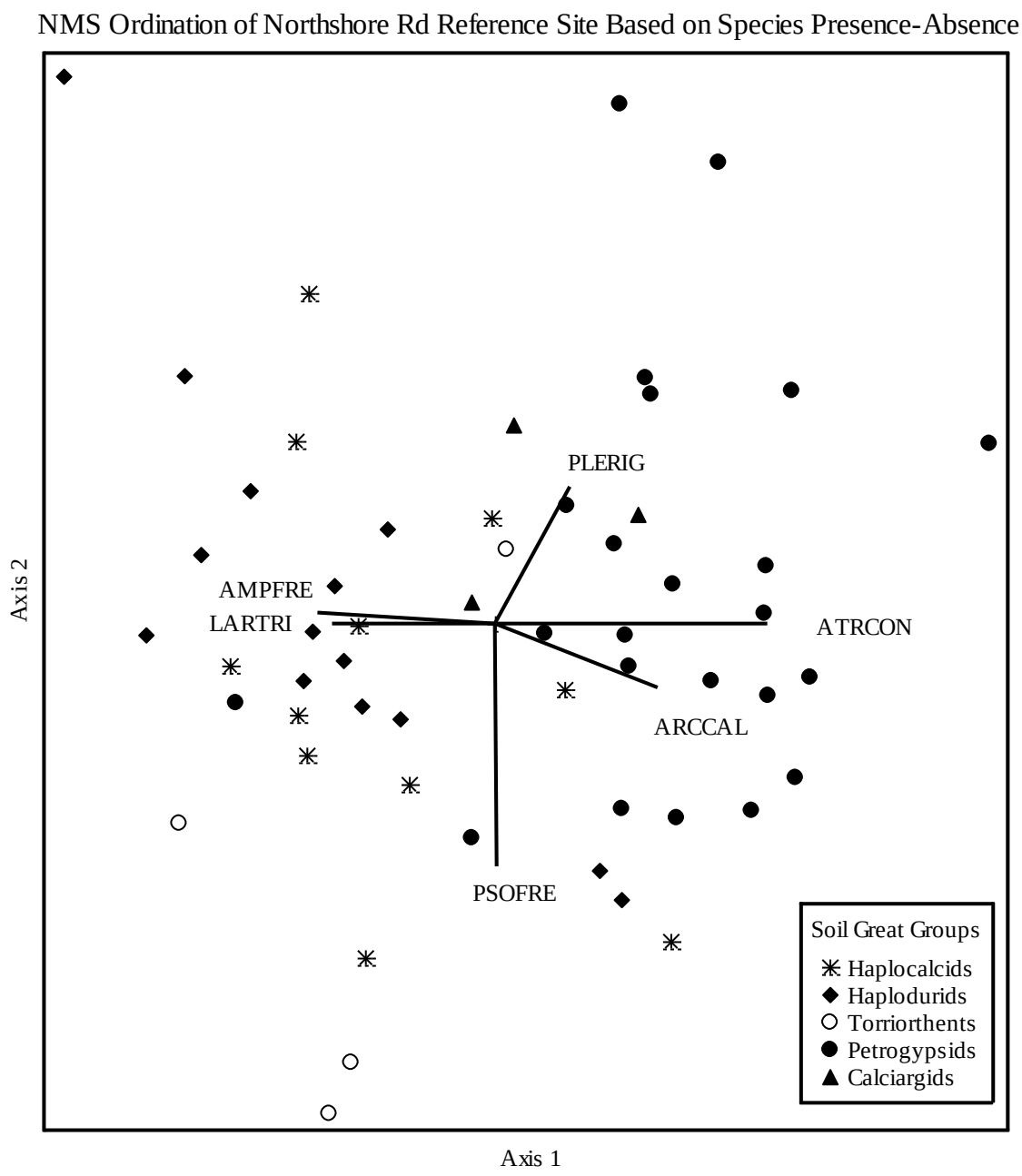


Figure 35 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic great groups, with vegetation vector overlay of perennial plant species with a cutoff $r^2 \geq 0.30$: AMFPRE, *Amphipappus fremonti*; ARCCAL, *Arctomecon californica*; ATRCON, *Atriplex confertifolia*; LARTRI, *Larrea tridentata*, PLERIG, *Pleuraphis rigida*; and PSOFRE, *Psorothamnus fremontii*.

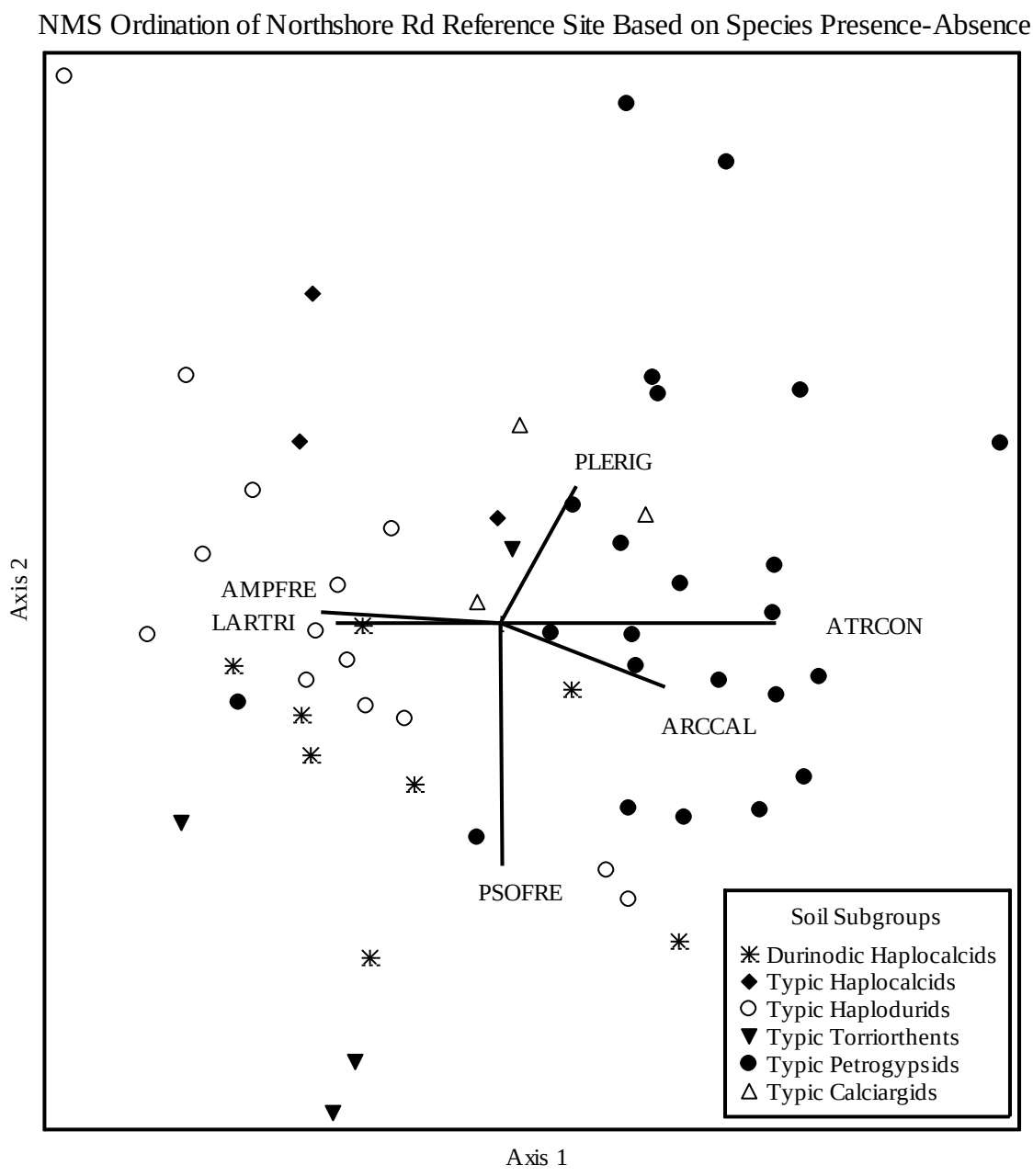


Figure 36 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic subgroups, with vegetation vector overlay of perennial plant species with a cutoff $r^2 \geq 0.30$: AMFPRE, *Amphipappus fremontii*; ARCCAL, *Arctomecon californica*; ATRCON, *Atriplex confertifolia*; LARTRI, *Larrea tridentata*, PLERIG, *Pleuraphis rigida*; and PSOFRE, *Psorothamnus fremontii*.

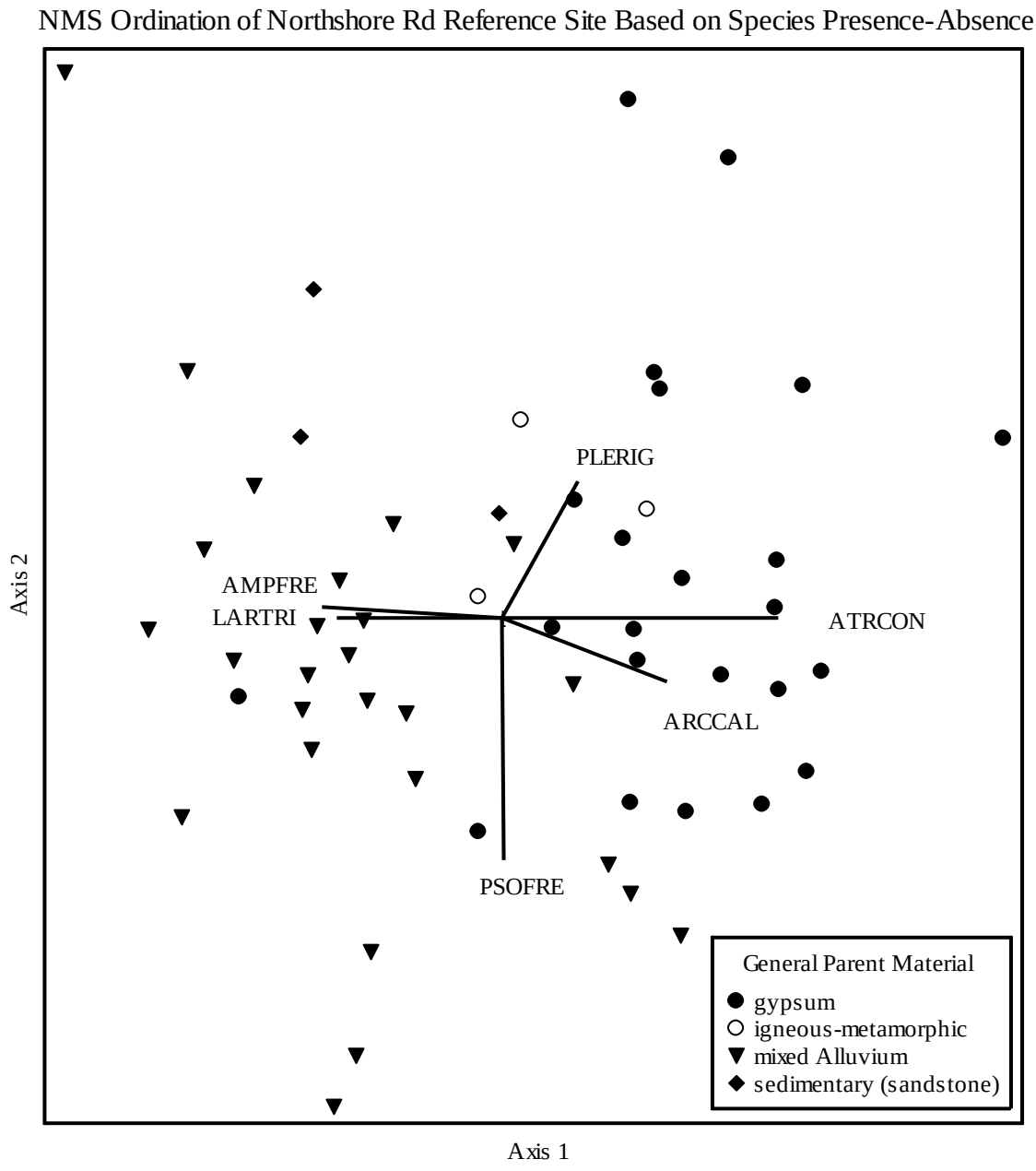


Figure 37 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil parent material categories with vegetation vector overlay of perennial plant species with a cutoff $r^2 \geq 0.30$: AMFPRE, *Amphipappus fremontii*; ARCCAL, *Arctomecon californica*; ATRCON, *Atriplex confertifolia*; LARTRI, *Larrea tridentata*, PLERIG, *Pleuraphis rigida*; and PSOFRE, *Psorothamnus fremontii*.

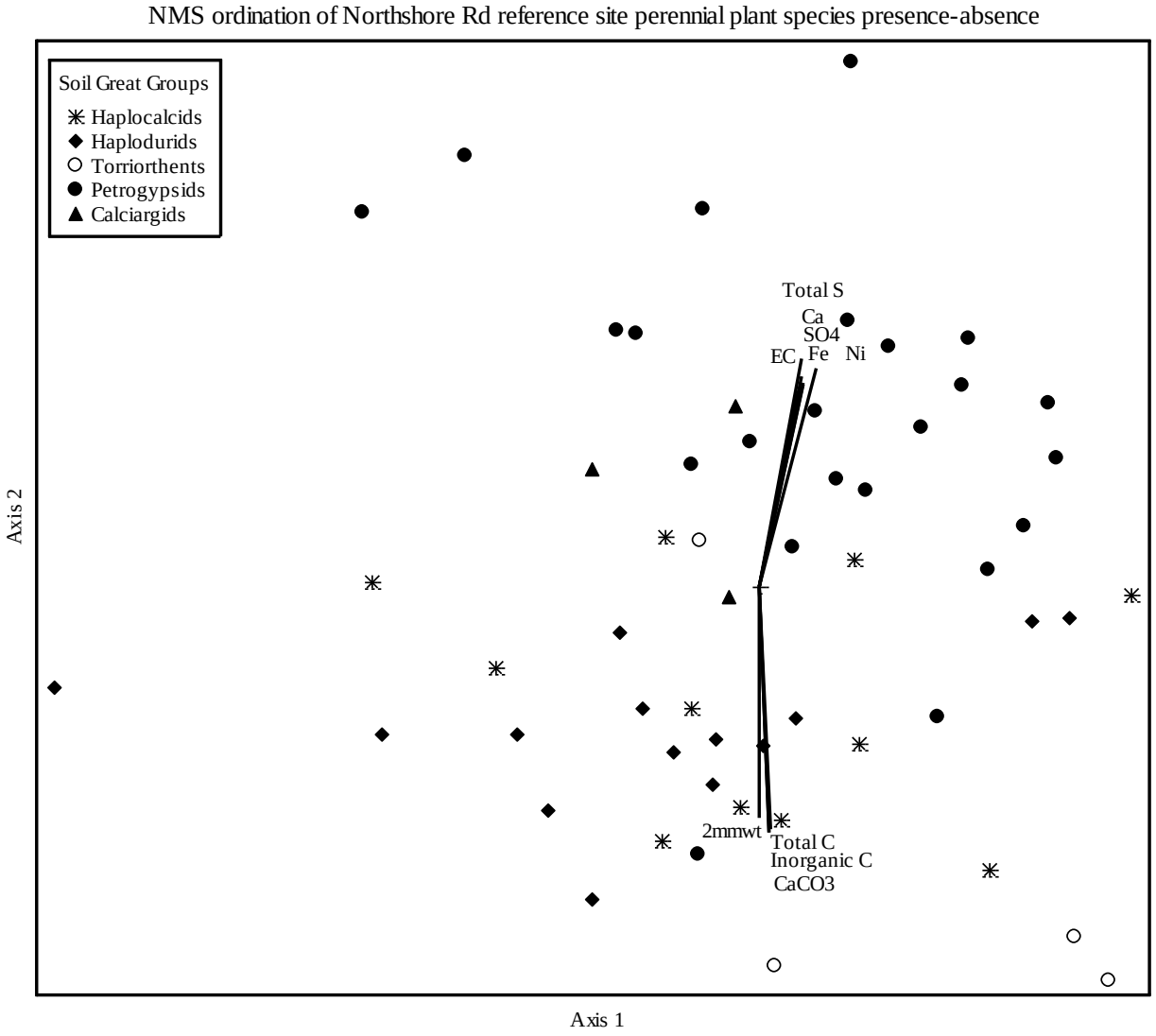


Figure 38 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic great groups, with soil variable vector overlay with a cutoff $r^2 \geq 0.30$: Total S, Ni, SO4, Ca, Fe, EC, Total C, Inorganic C, CaCO3, and >2mm (rock) wt.

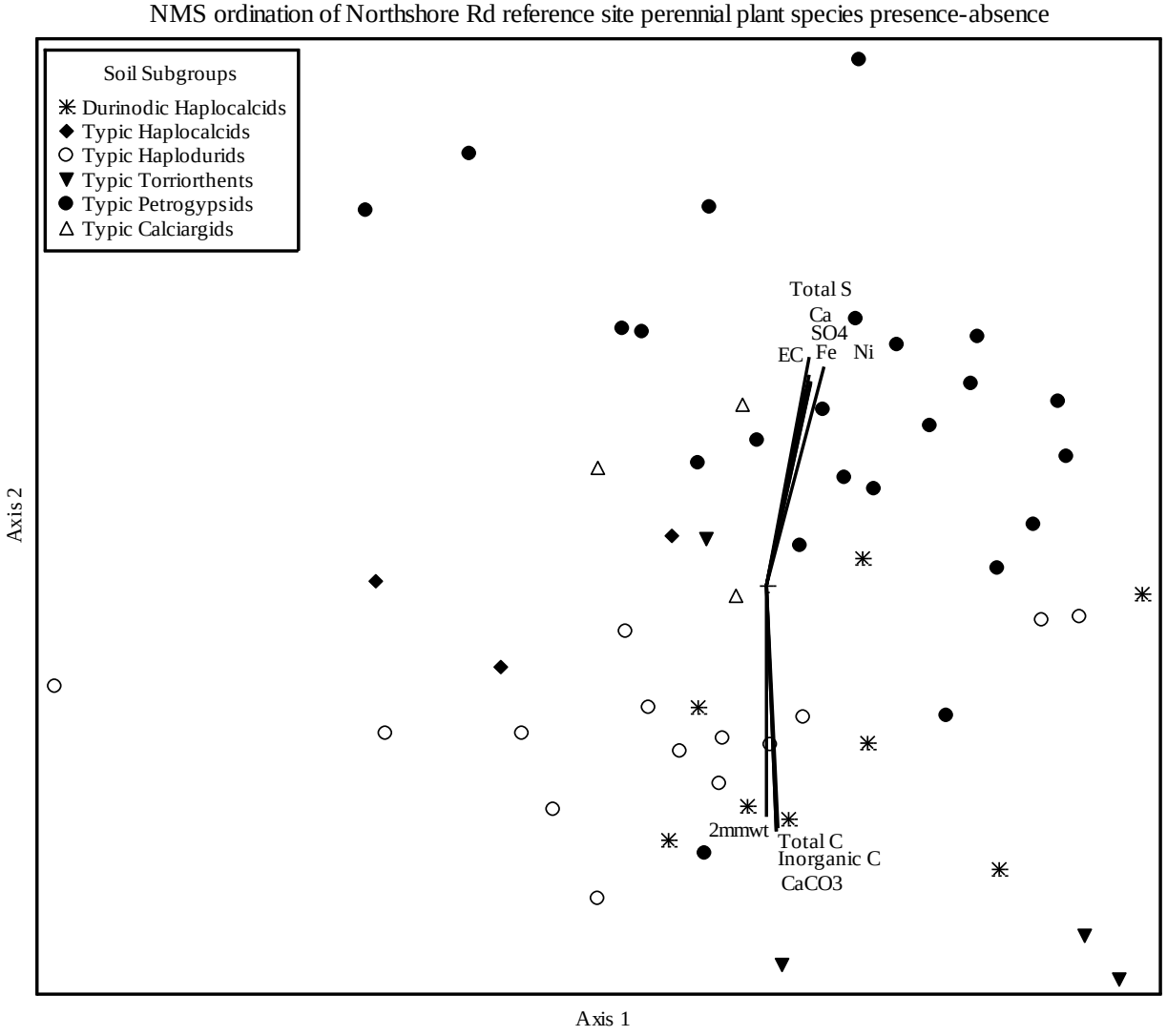


Figure 39 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil taxonomic subgroups with soil variable vector overlay with a cutoff $r^2 \geq 0.30$: Total S, Ni, SO4, Ca, Fe, EC, Total C, Inorganic C, CaCO3, and >2mm (rock) wt.

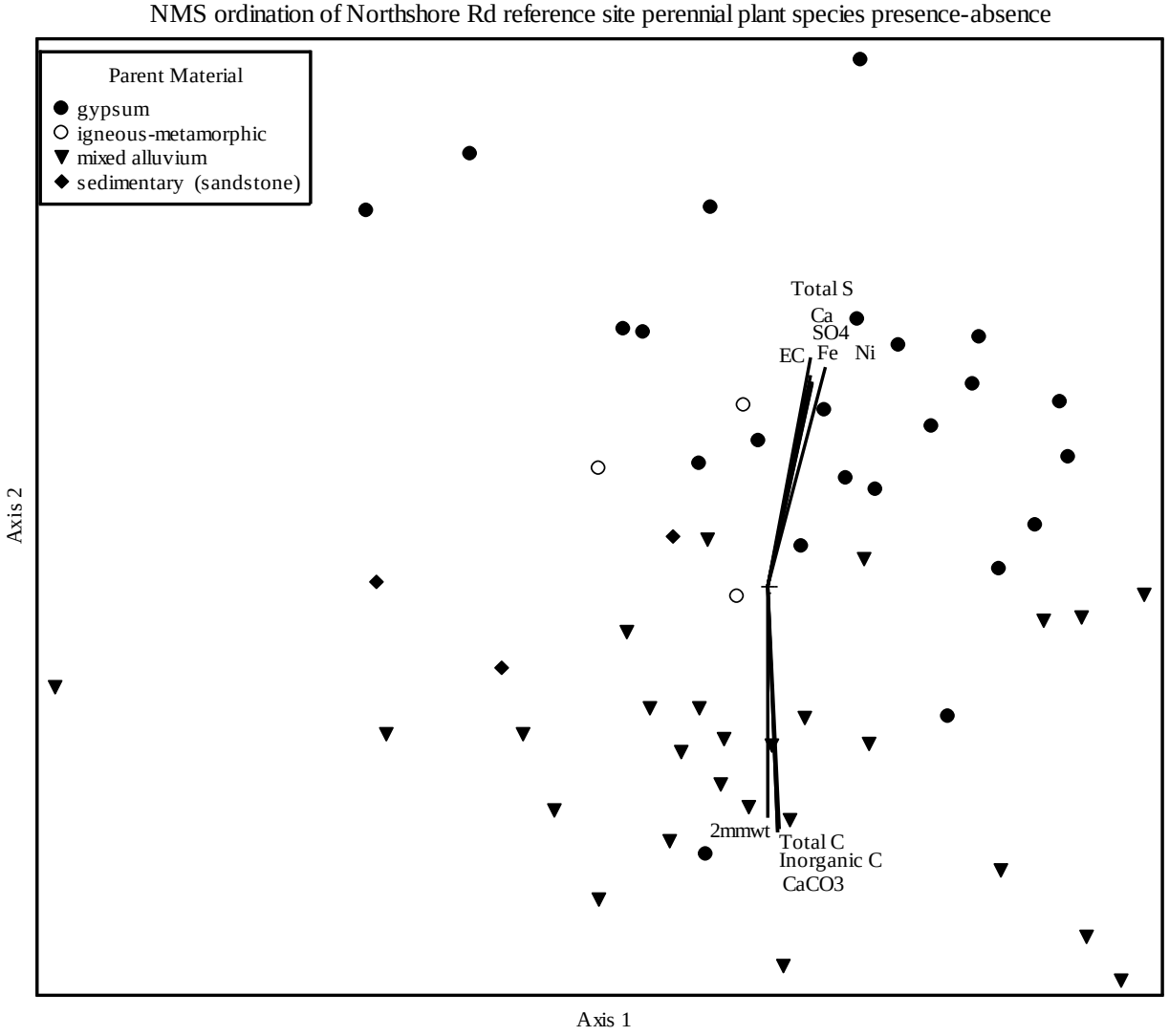
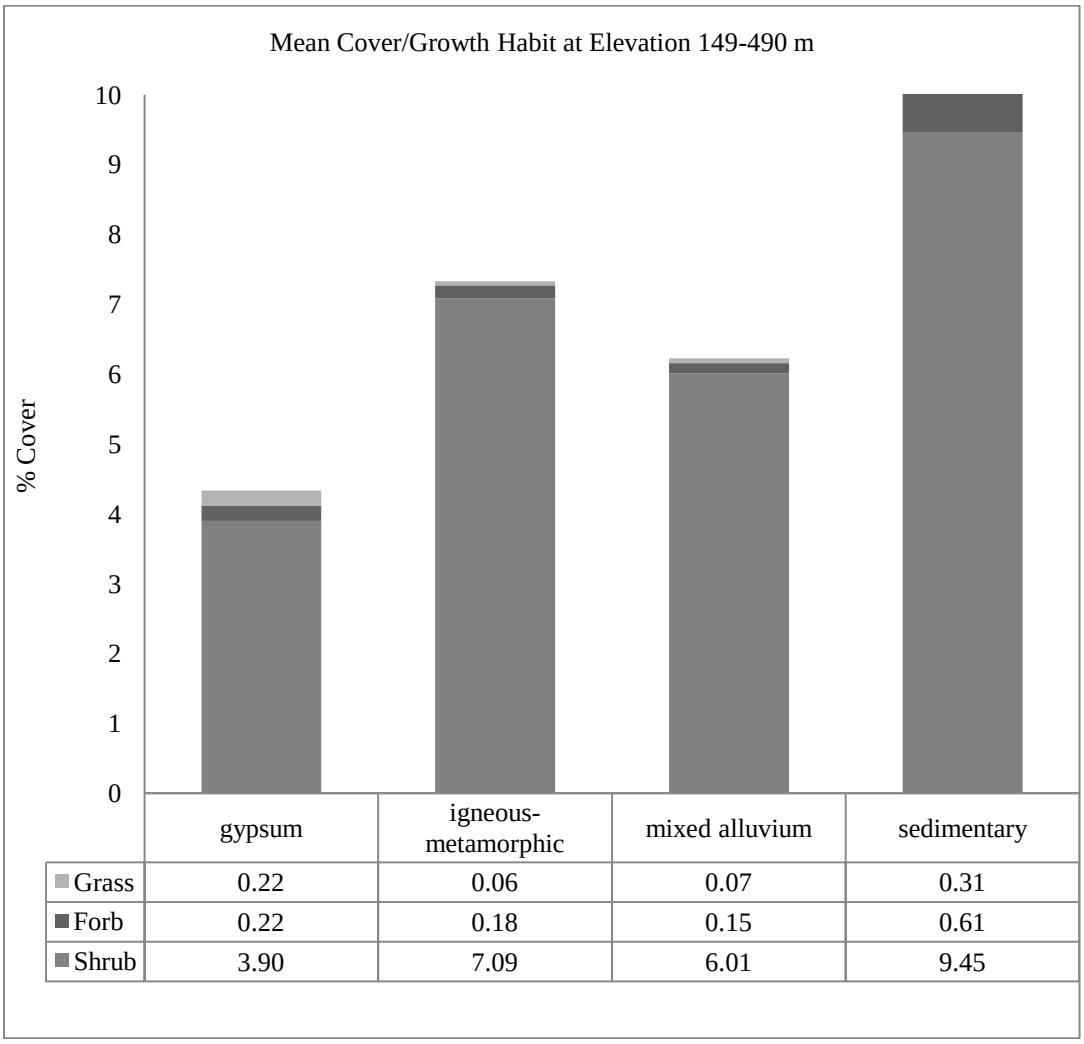


Figure 40 Nonmetric multidimensional scaling ordination based on presence-absence of perennial plant species with Northshore Rd reference sites along the northern areas of Northshore Rd, between mile posts 27-48, Lake Mead National Recreation Area, eastern Mojave Desert, grouped by soil parent material categories, with soil variable vector overlay with cutoff $r^2 \geq 0.30$: Total S, Ni, SO4, Ca, Fe, EC, Total C, Inorganic C, CaCO3, and >2mm (rock) wt.



	gypsum	igneous-metamorphic	mixed alluvium	sedimentary
Grass	0.22	0.06	0.07	0.31
Forb	0.22	0.18	0.15	0.61
Shrub	3.90	7.09	6.01	9.45

Figure 41 Perennial plant species mean percent cover per growth habit per soil parent material category within the elevation range 149-490 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

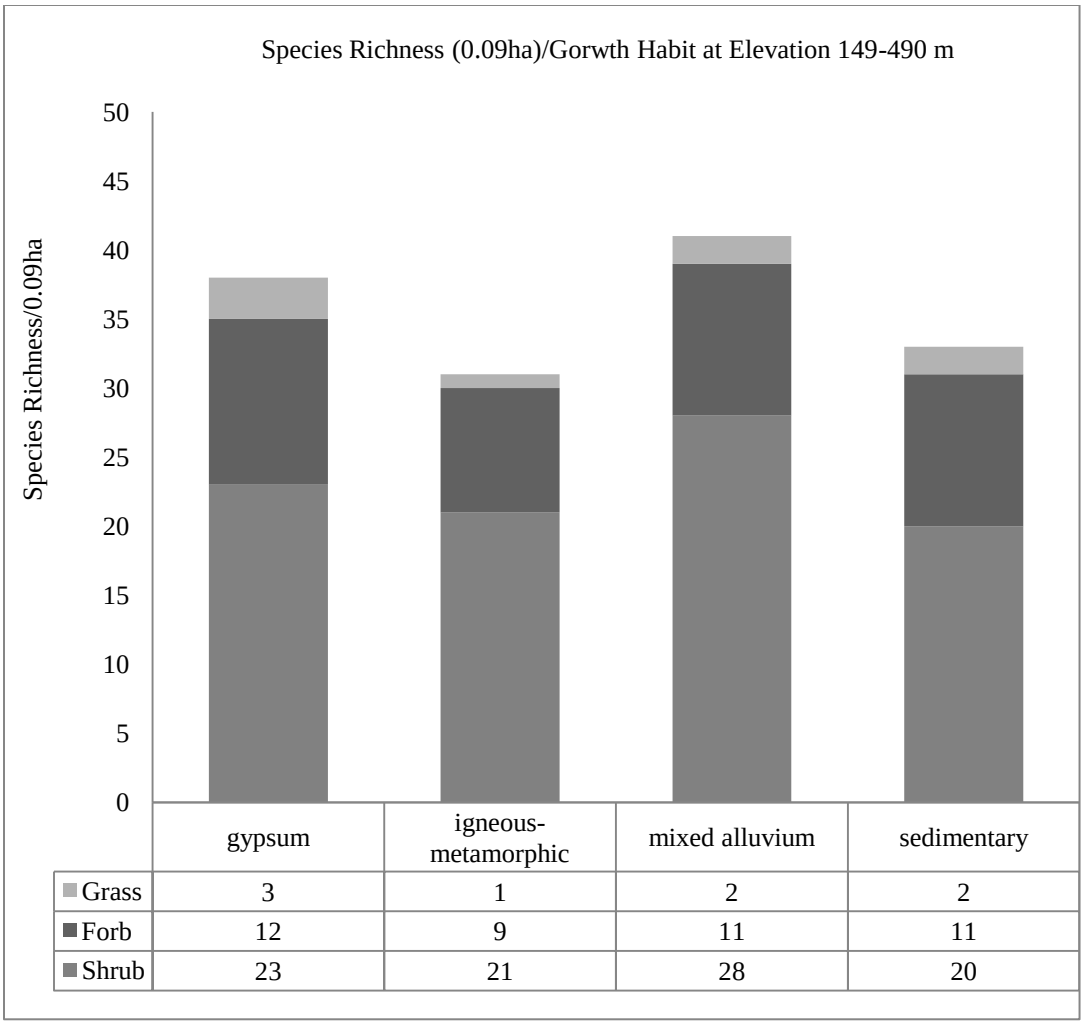


Figure 42 Perennial plant richness (0.09ha) per growth habit per soil parent material category within the elevation range 149-490 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

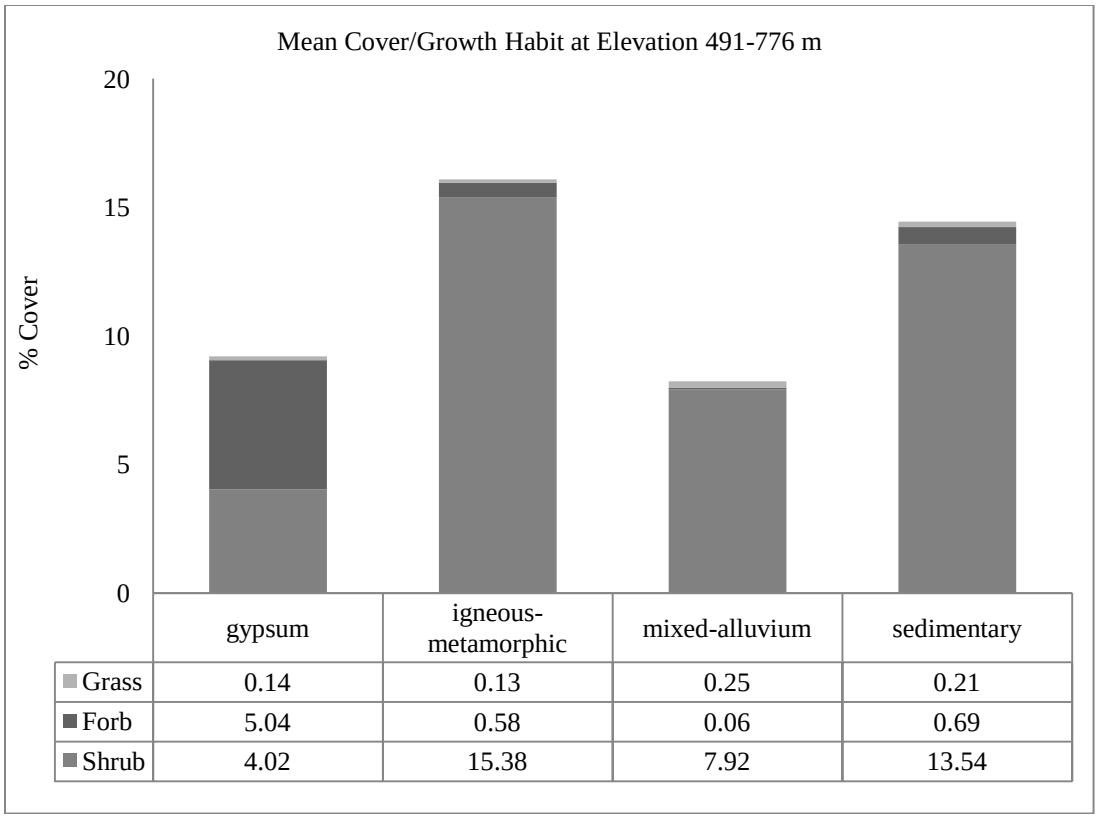
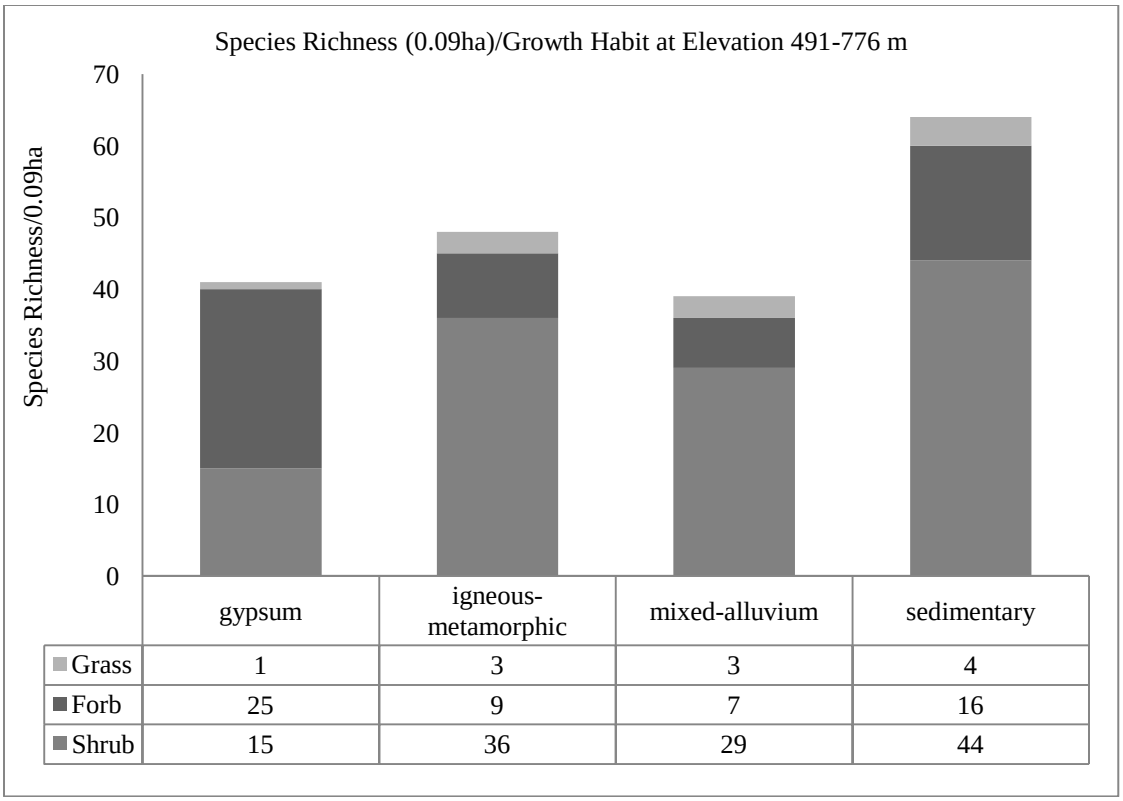
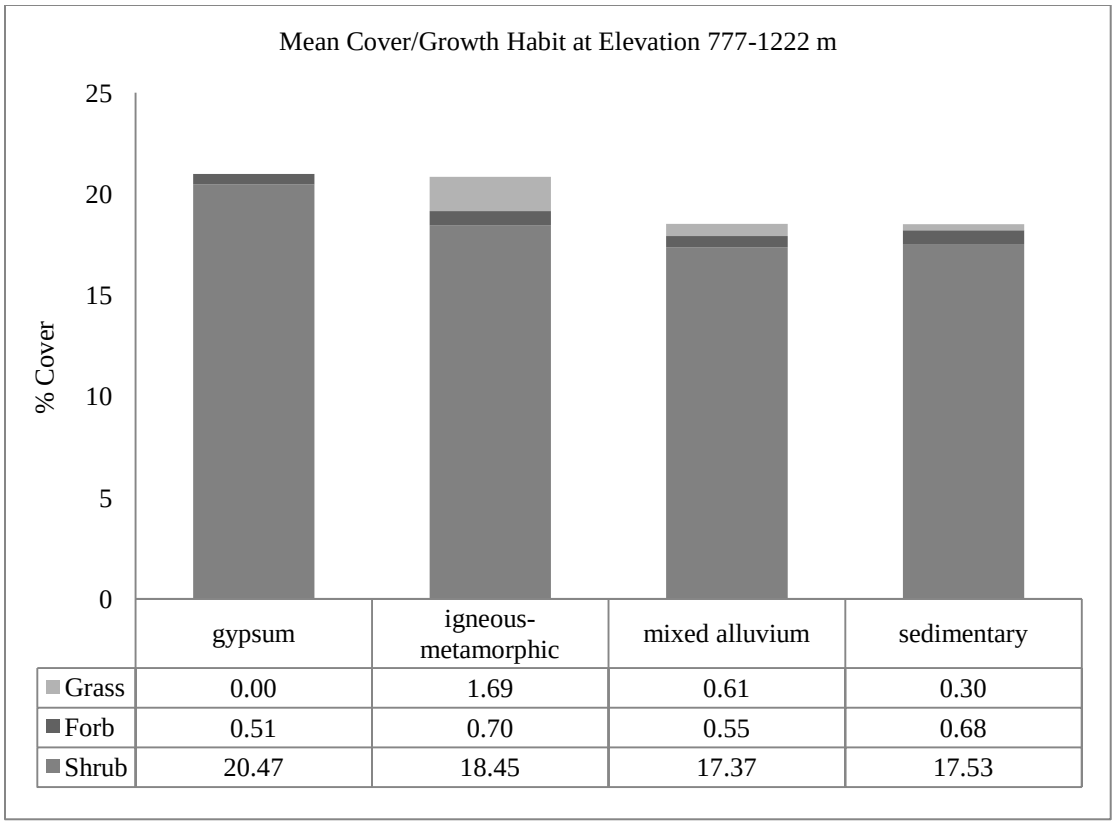


Figure 43 Perennial plant species mean percent cover per growth habit per soil parent material category within the elevation range 491-776 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.



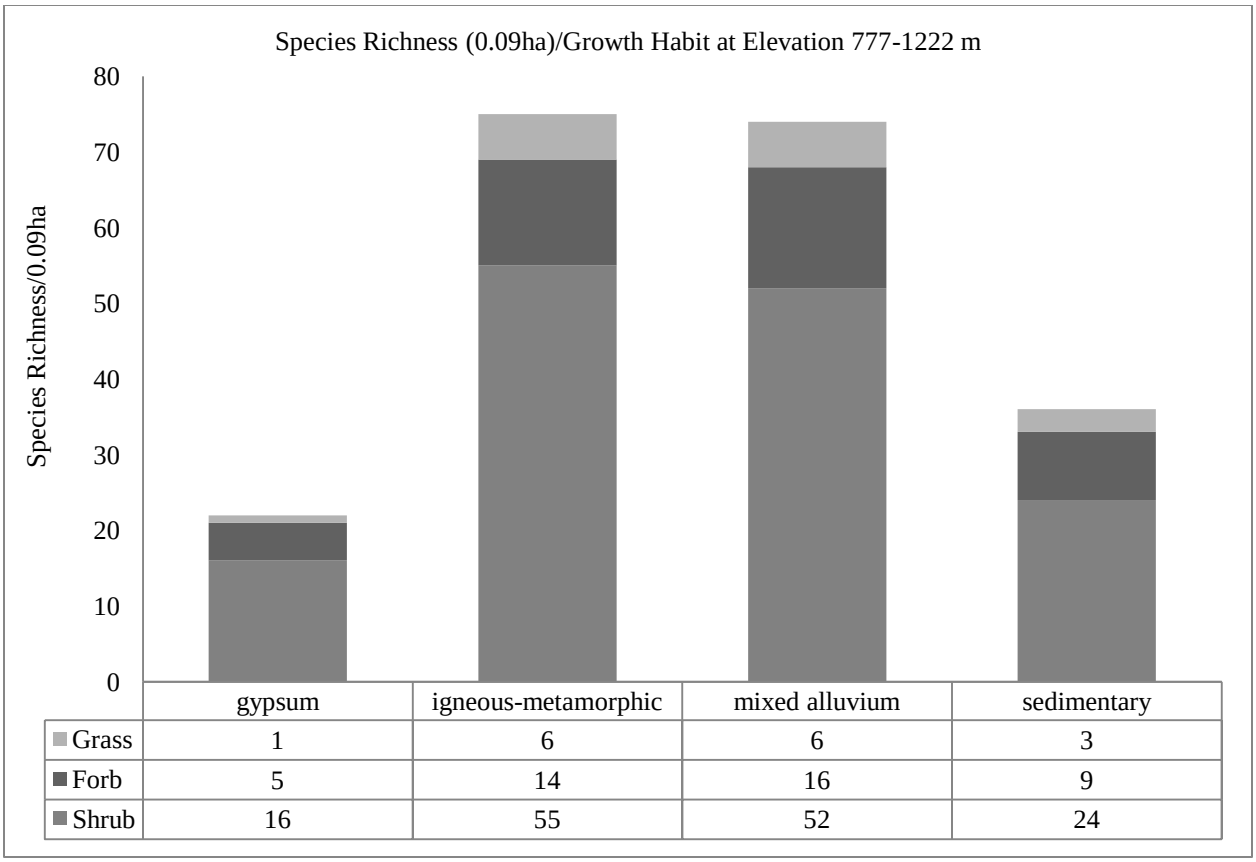
	gypsum	igneous-metamorphic	mixed-alluvium	sedimentary
Grass	1	3	3	4
Forb	25	9	7	16
Shrub	15	36	29	44

Figure 44 Perennial plant richness (0.09ha) per growth habit per soil parent material category within the elevation range 491-776 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.



	gypsum	igneous-metamorphic	mixed alluvium	sedimentary
Grass	0.00	1.69	0.61	0.30
Forb	0.51	0.70	0.55	0.68
Shrub	20.47	18.45	17.37	17.53

Figure 45 Perennial plant species mean percent cover per growth habit per soil parent material category within the elevation range 777-1222 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.



	gypsum	igneous-metamorphic	mixed alluvium	sedimentary
Grass	1	6	6	3
Forb	5	14	16	9
Shrub	16	55	52	24

Figure 46 Perennial plant richness (0.09ha) per growth habit per soil parent material within the elevation range 777-1222 m, complied from LTV and Northshore Rd reference sites in and around Lake Mead National Recreation Area, eastern Mojave Desert.

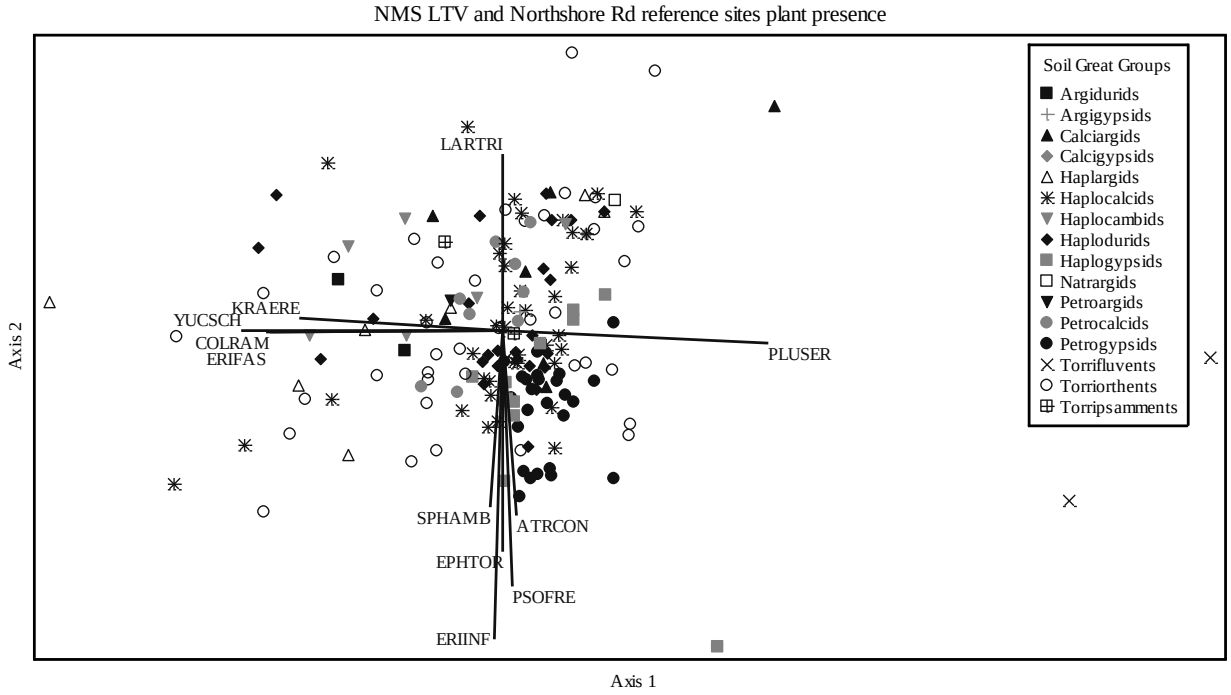


Figure 47 Nonmetric multidimensional scaling ordination of vegetative species for the LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil taxonomic great groups, with vegetation vector overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; ERIFAS, *Eriogonum fasciculatum*; EPHTOR, *Ephedra torreyana*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PROPUB, (*Prosopis pubescens*); PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

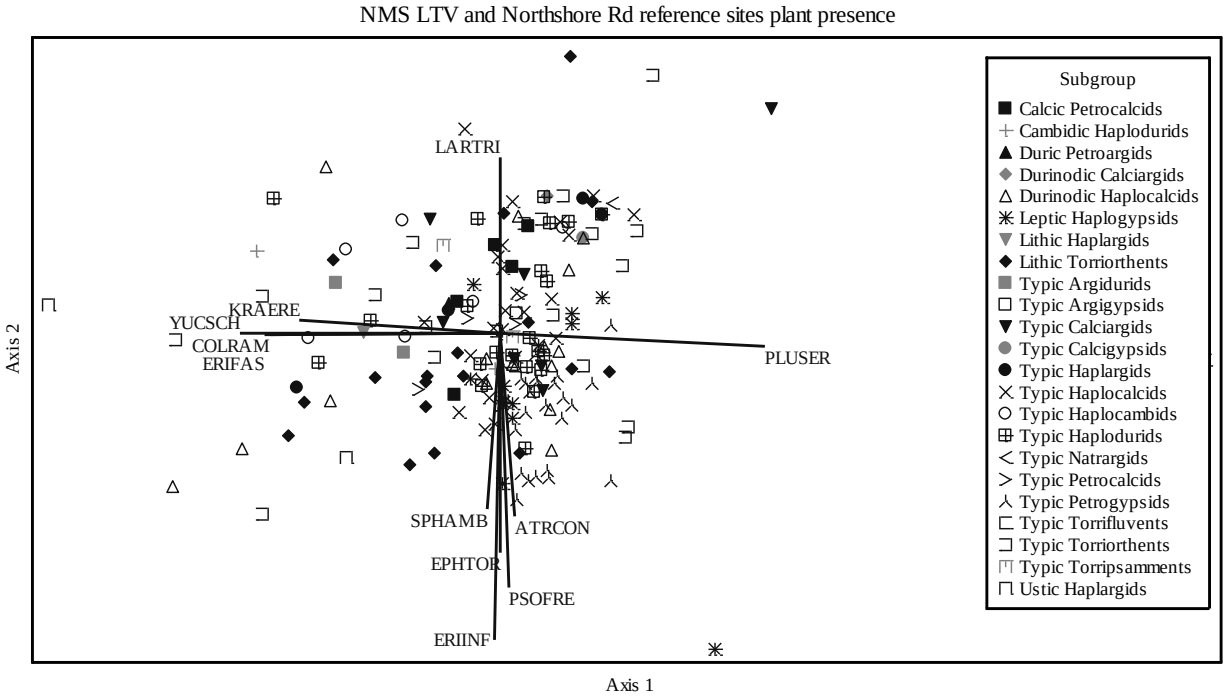


Figure 48 Nonmetric multidimensional scaling ordination of vegetative species for the LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil taxonomic subgroups, with vegetation vector overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; ERIFAS, *Eriogonum fasciculatum*; EPHTOR, *Ephedra torreyana*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PROPUB, (*Prosopis pubescens*); PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

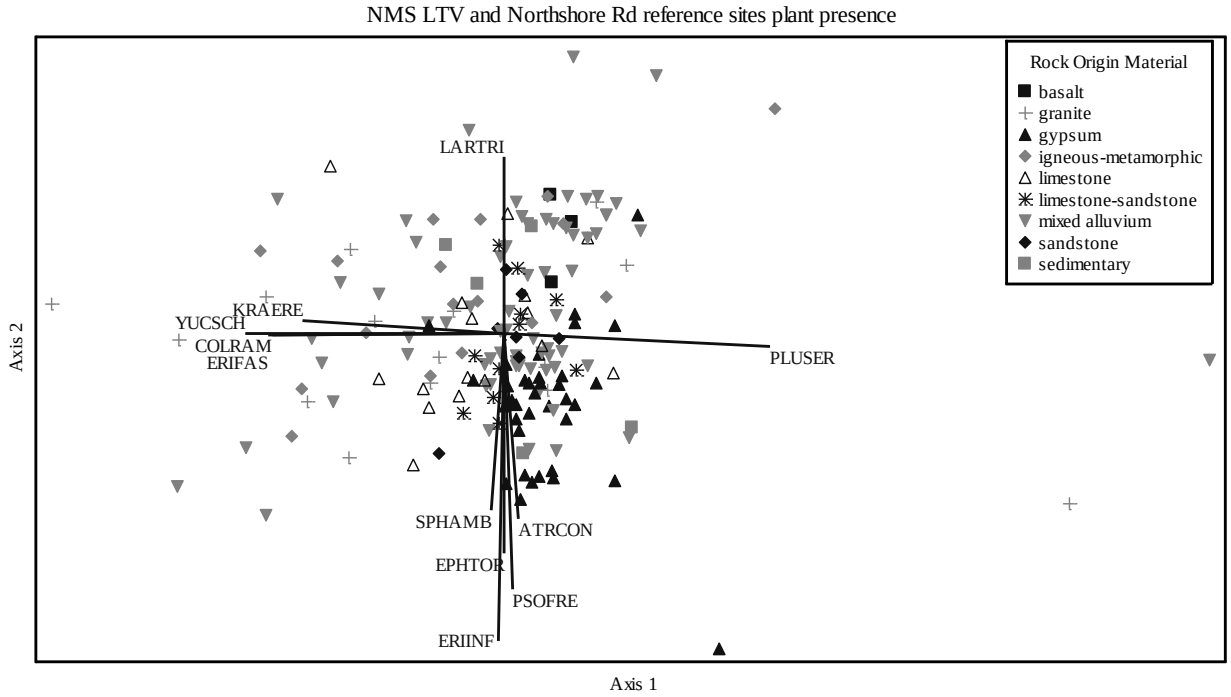


Figure 49 Nonmetric multidimensional scaling ordination of vegetative species for the 126 LTV and 55 Northshore Rd reference sites in the Mojave Desert, grouped by rock origin material types with vegetation vectors overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; ERIFAS, *Eriogonum fasciculatum*; EPHTOR, *Ephedra torreyana*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PROPUB, (*Prosopis pubescens*); PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

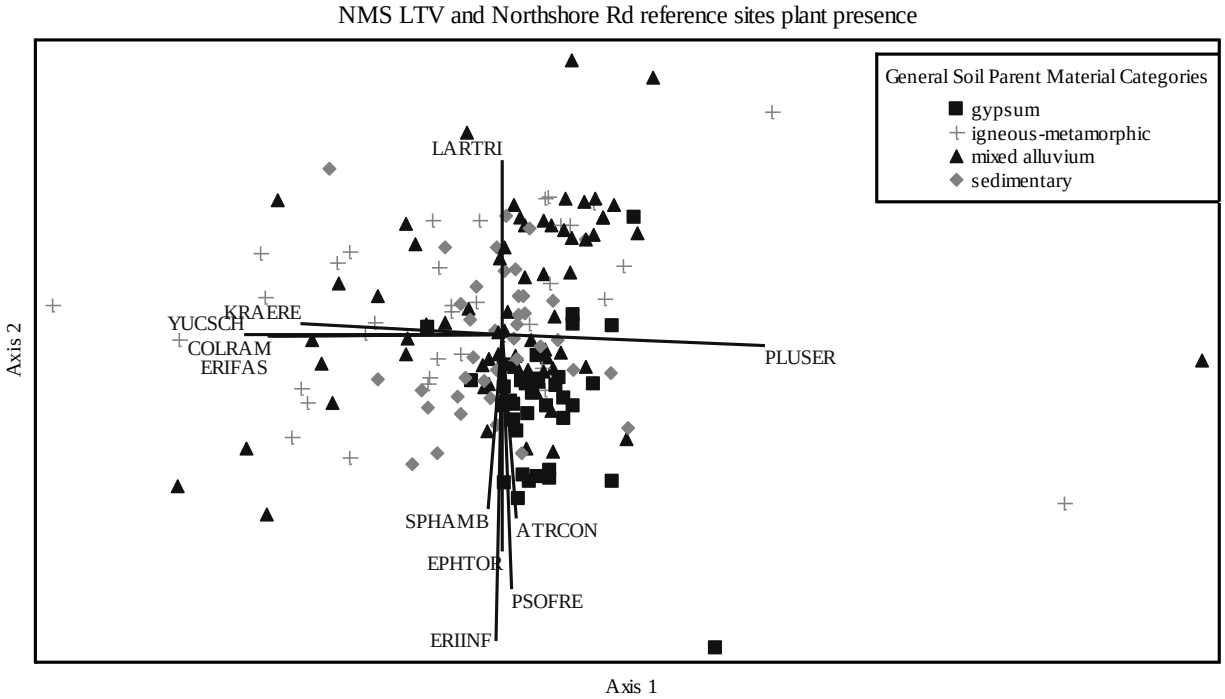


Figure 50 Nonmetric multidimensional scaling ordination of vegetative species for the LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil parent material categories with vegetation vector overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; ERIFAS, *Eriogonum fasciculatum*; EPHTOR, *Ephedra torreyana*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PROPUB, (*Prosopis pubescens*); PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

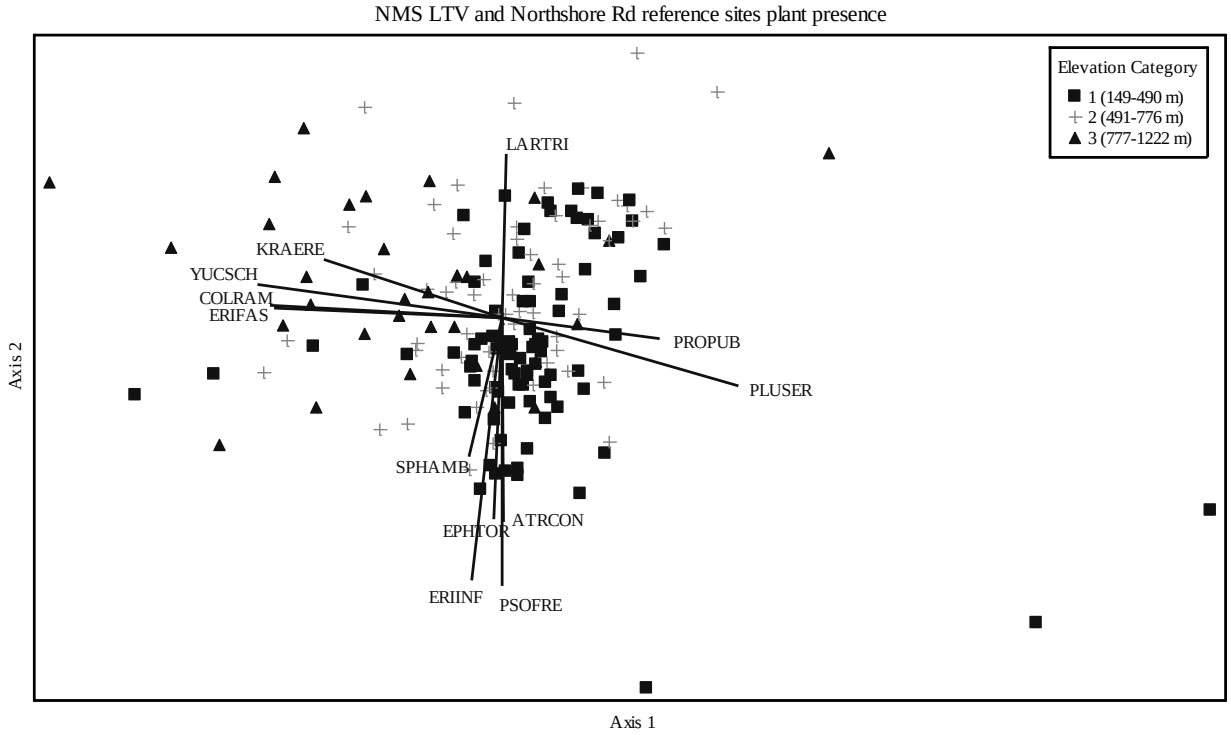


Figure 51 Nonmetric multidimensional scaling ordination of vegetative species for the LTV and Northshore Rd reference sites in the Mojave Desert, grouped by elevation categories, with vegetation vector overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; ERIFAS, *Eriogonum fasciculatum*; EPHTOR, *Ephedra torreyana*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PROPUB, (*Prosopis pubescens*); PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

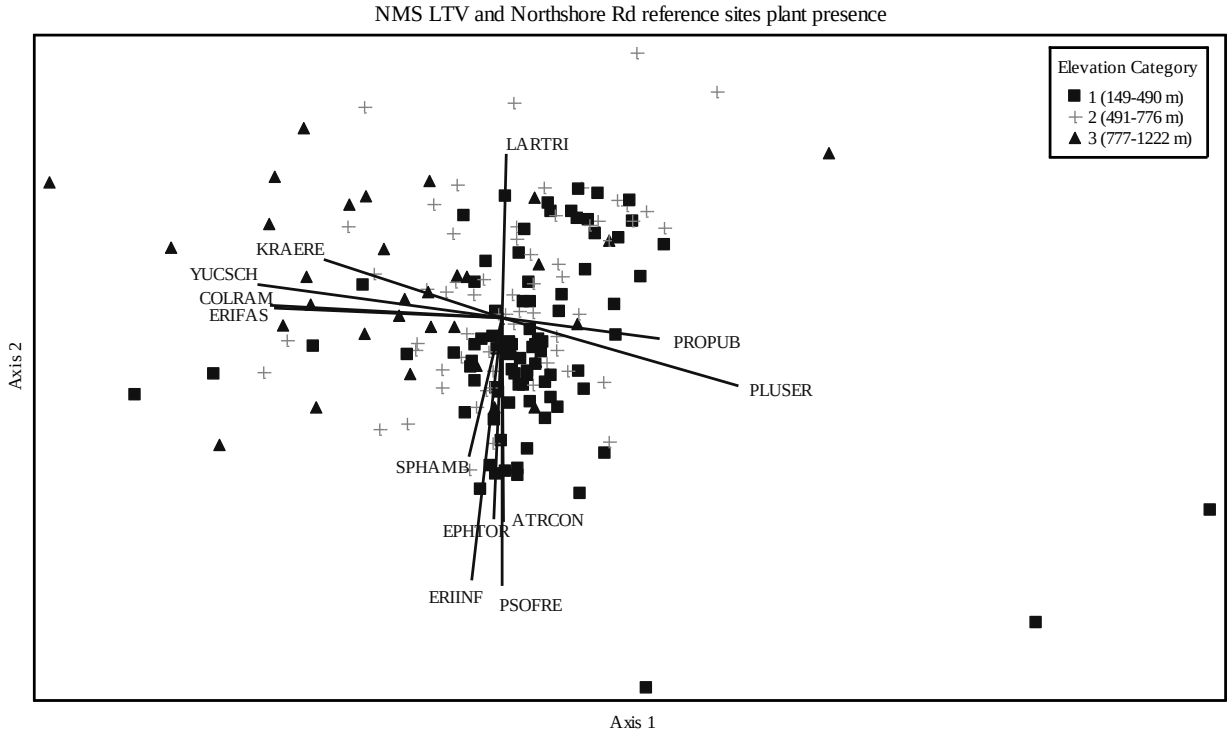


Figure 52 Nonmetric multidimensional scaling ordination of vegetative species for the LTV and Northshore Rd reference sites in the Mojave Desert, grouped by elevation categories (1 = 149-490 m; 2 = 491-776 m ; 3 = 777-1222 m) and soil parent material categories with vegetation vector overlay with a cutoff $r^2 \geq 0.20$ and with axes and are abbreviated as: ATRCON, *Atriplex confertifolia;* COLRAM, *Coleogyne ramosissima*; ERIINF, *Eriogonum inflatum*; EPHTOR, *Ephedra torreyana*; ERIFAS, *Eriogonum fasciculatum*; KRAERE, *Krameria erecta*; LARTRI, *Larrea tridentata*; PLUSER, *Pluchea sericea*; PSOFRE, *Psorothamnus fremontii*; SPHAMB, S*phaeralcea ambigua;* and YUCSH, *Yucca schidigera*.

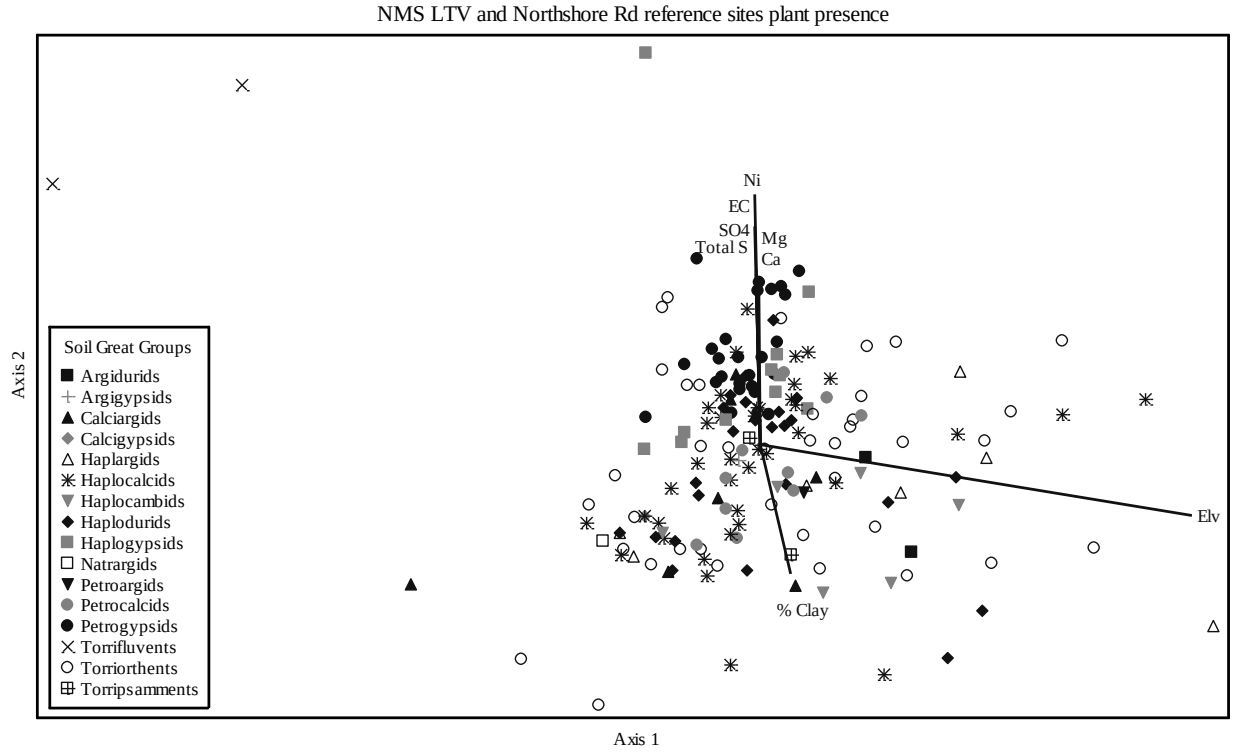


Figure 53 Nonmetric multidimensional scaling ordination of vegetative species for LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil taxonomic great groups, with soil variables vector overlay with a cutoff $r^2 \geq 0.15$. Soil sampling occurred in soil 0-5 cm depth.

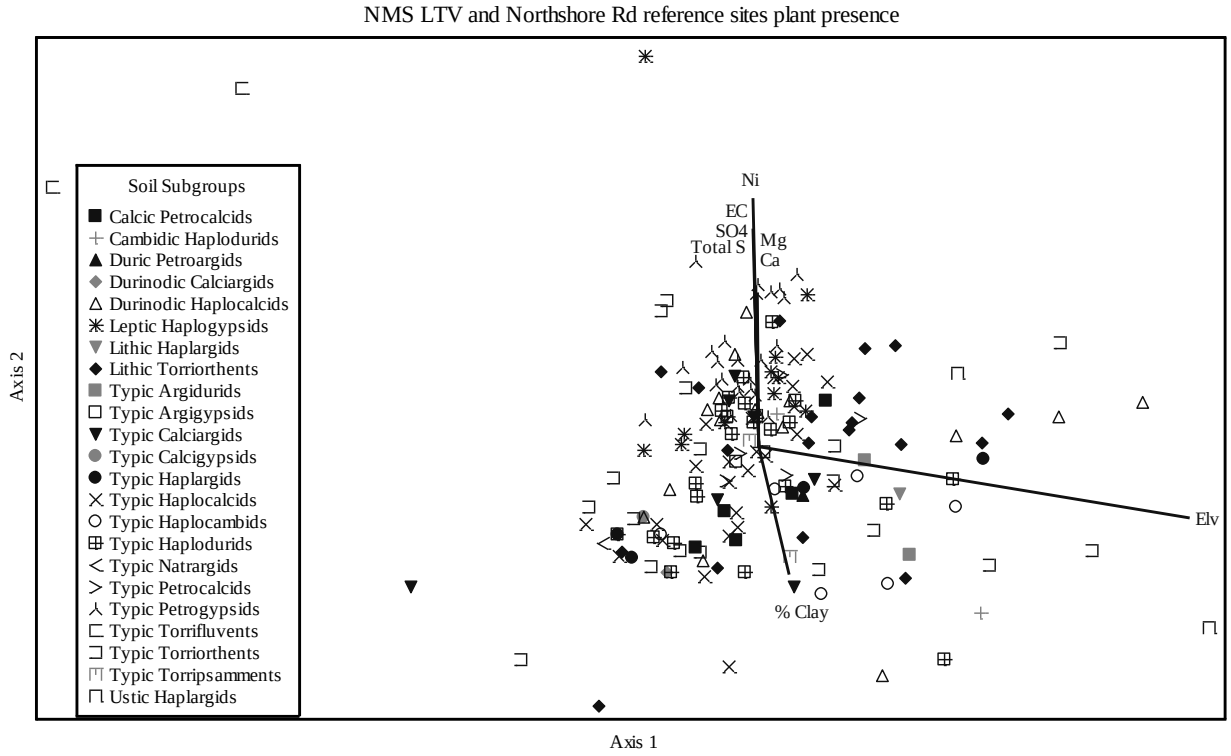


Figure 54 Nonmetric multidimensional scaling ordination of vegetative species for LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil taxonomic subgroups, with soil variables vector overlay with a cutoff $r^2 \geq 0.15$. Soil sampling occurred in soil 0-5 cm depth.

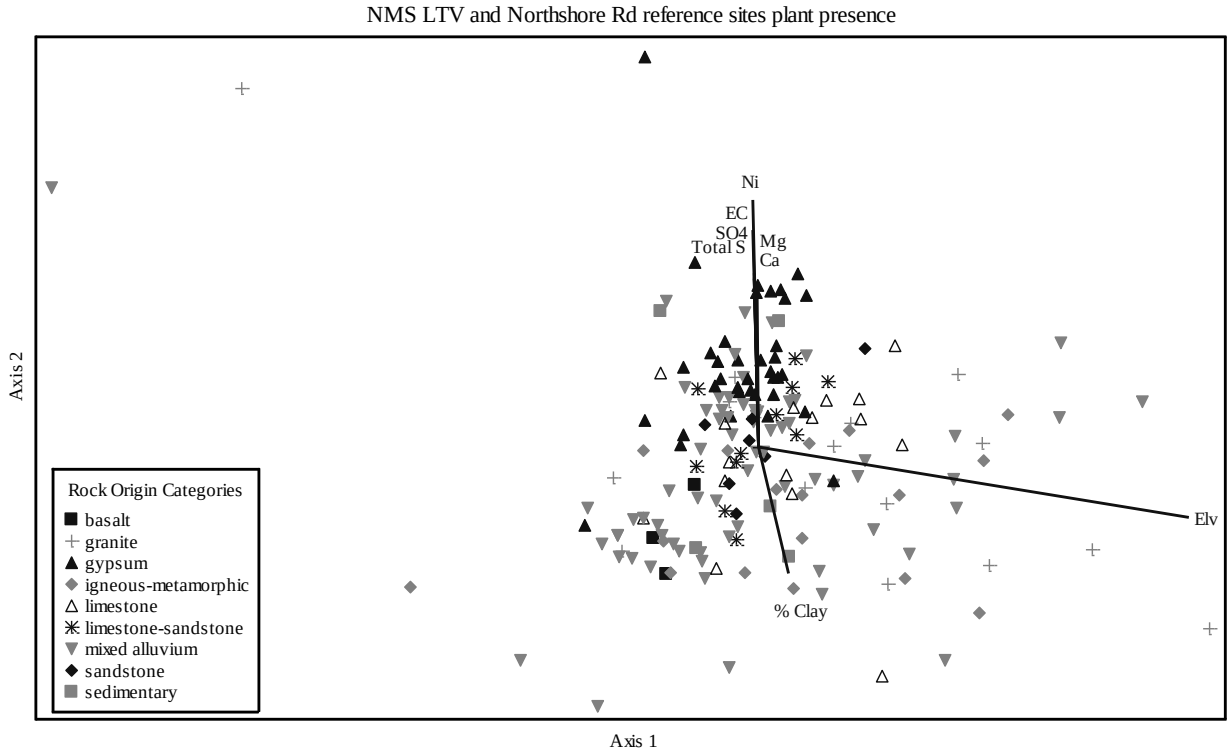


Figure 55 Nonmetric multidimensional scaling ordination of vegetative species for the 126 LTV and 55 Northshore Rd reference sites in the Mojave Desert, grouped by rock origin material type, with soil variables vector overlay with a cutoff $r^2 \geq 0.15$. Soil sampling occurred in soil 0-5 cm depth.

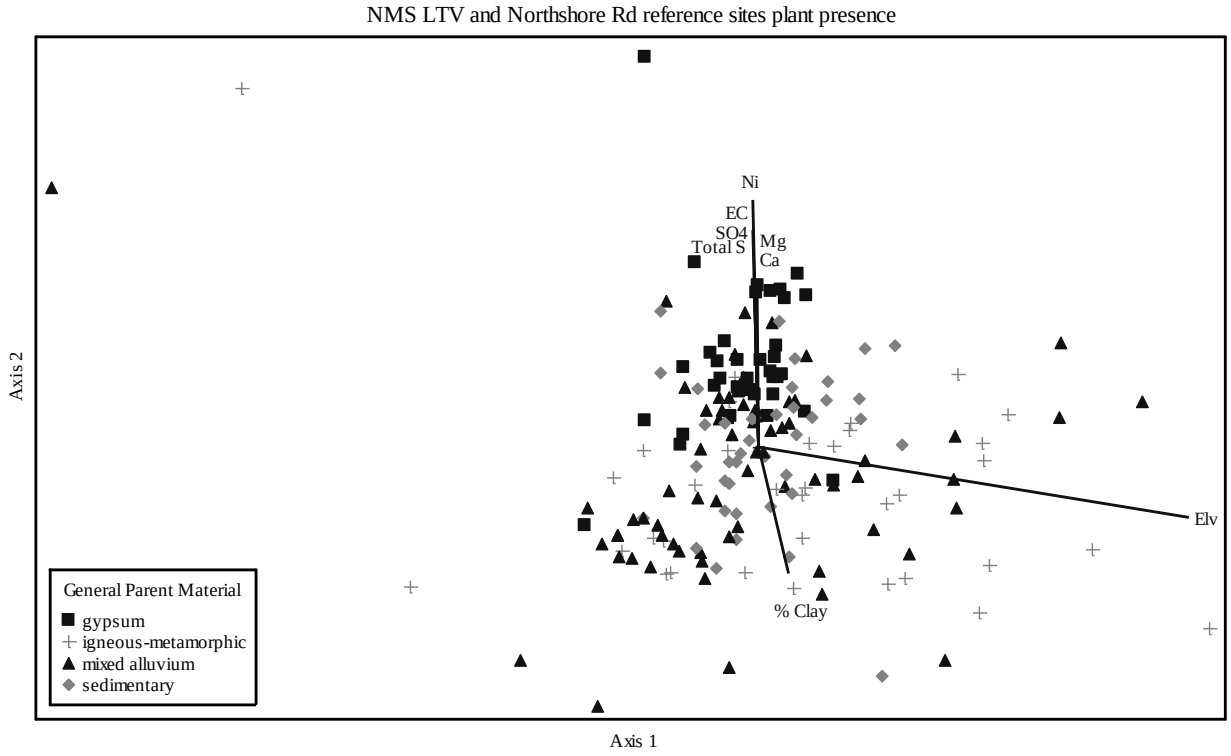


Figure 56 Nonmetric multidimensional scaling ordination of vegetative species for LTV and Northshore Rd reference sites in the Mojave Desert, grouped by soil parent material categories, with soil variables vector overlay with a cutoff $r^2 \geq 0.15$. Soil sampling occurred in soil 0-5 cm depth.

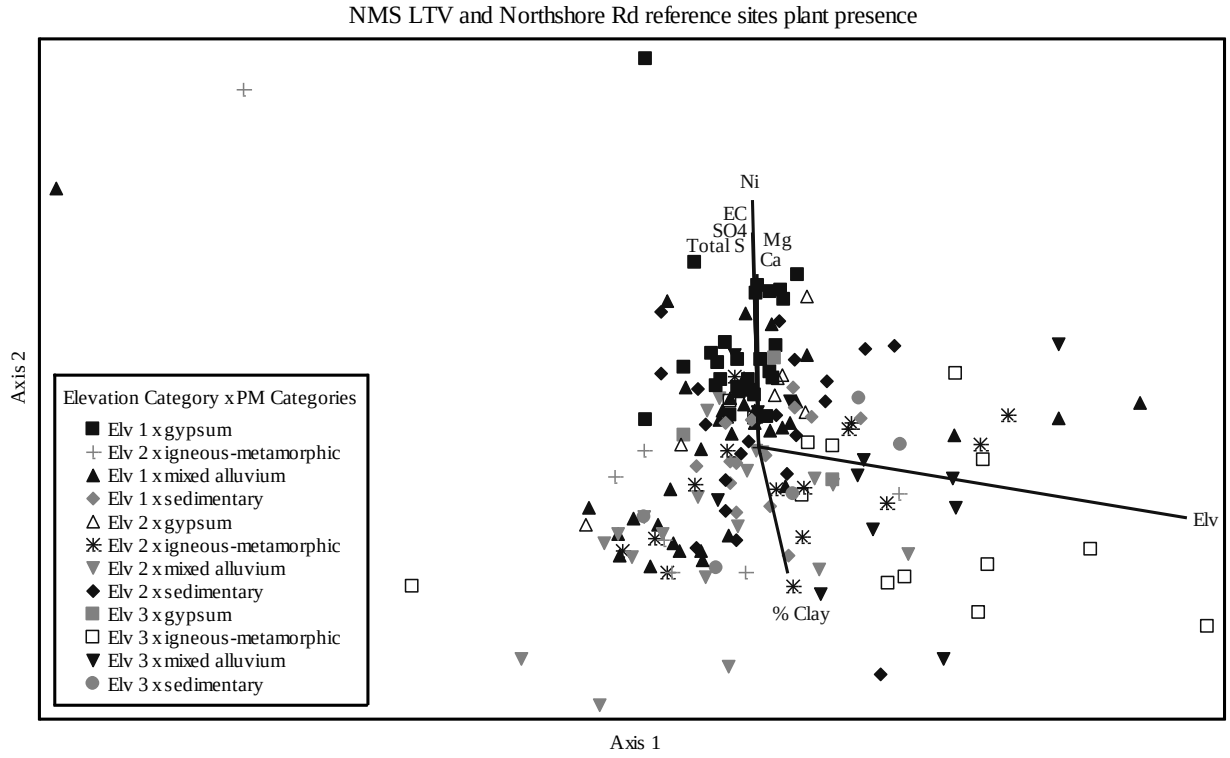


Figure 57 Nonmetric multidimensional scaling ordination of vegetative species for LTV and Northshore Rd reference sites in the Mojave Desert, grouped by elevation categories (1= 149-490 m; 2 = 491-776 m; 3 = 777-1222 m) and soil parent material categories, with soil variable vector overlay with a cutoff $r^2 \geq 0.15$. Soil variables are included soils at 0-5 cm depth.

Seed Bank

A full analysis of the Las Vegas bearpoppy soil seed bank which inhabits gypsum-rich soils can be found in Section II of this report. Specific to the Northshore Rd region of LMNRA (mile post 27-48), eight species emerged during the extent of the seed bank study. Most of the individuals that emerged were the non-native grass, *Schismus arabica*, averaging 67% ± 31% (mean ± S.D) of the individuals in a given soil sample. The rest of the community was dominated by native forbs, many of which perished during winter conditions before they were able to be identified to species Figure 60. Identifiable species included *Ambrosia dumosa*, *Camissonia* sp., *Chaenactis* sp., *Plantago ovata*, *Phacelia* sp., *Suaeda moquinii*, and *Typha* sp. *Typha* sp. Is unlikely to germinate under natural conditions in the field and the seed is likely sourced from a local mesic site.

While there were some trends toward differences in abundance of *Schismus* among different microsites, there was no significant statistical relationship ($P > 0.05$; Table 60). There were some differences in total native forb abundance in the seed bank, but differences among microsites were minimal, with *A. dumosa* microsites having greater total form abundance than interspace microsites ($P = 0.04$; Table 61).

Table 60 Mean abundance and standard deviation (SD) of *Schismus arabica* in the seedbank from samples collected from microsites along the new road pathway of Northshore Road between mile posts 27-48 in Lake Mead National Recreation Area Lake Mead National Recreation Area, Mojave Desert.

Microsite	Mean ± S.D.
Ambrosia dumosa	17.9 ± 26.2
Ephedra nevadensis	18.5 ± 26.2
Interspace	9.0 ± 9.4
Larrea tridentata	24.0 ± 25.0
Psorothamnus fremontii	17.3 ± 17.9

Table 61 Mean abundance and standard deviation (SD) of native forbs in the seed bank from samples collected along the new road pathway of Northshore Road between mile posts 27-48 in Lake Mead National Recreation Area Lake Mead National Recreation Area, Mojave Desert.

Microsite	Mean ± S.D.
Ambrosia dumosa	6.3 ± 5.1
Ephedra nevadensis	4.4 ± 5.1
Interspace	2.4 ± 1.9
Larrea tridentate	4.2 ± 3.7
Psorothamnus fremontii	3.6 ± 3.0

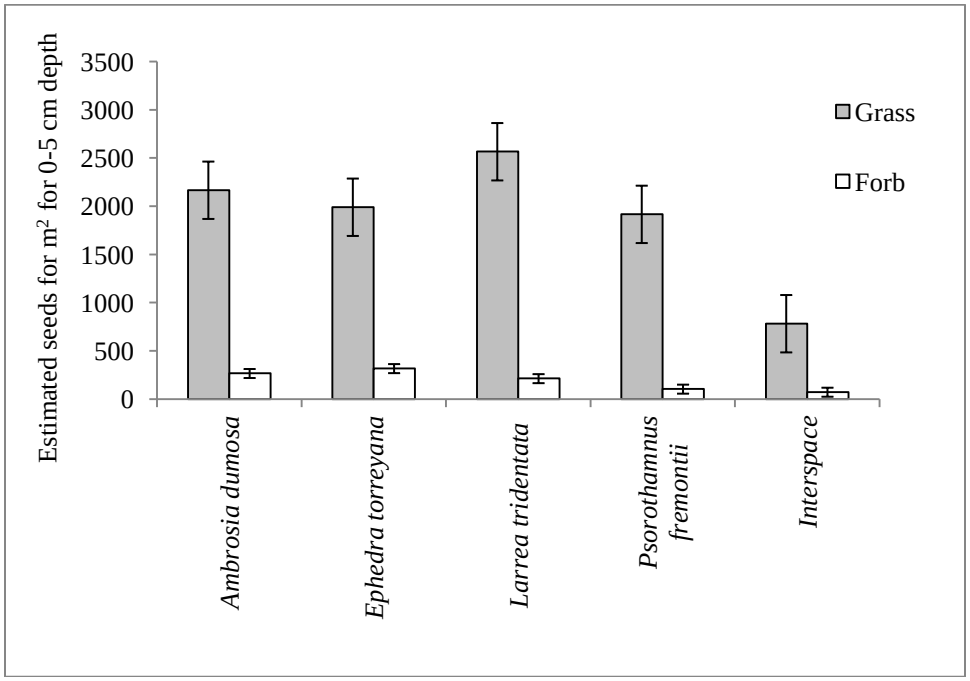


Figure 58 Mean with standard error estimated seed emergence for grass and forb seeds/m^2 for 0-5 cm soil depth across microsites shown on the x-axis for gypsiferous soil sites along Northshore Rd, between mile posts 27-48, in Lake Mead National Recreation Area Lake Mead National Recreation Area, Mojave Desert.

SYNTHESIS DISCUSSION

The objectives of this synthesis included developing a general gypsum management plan following a utilitarian approach for examining the existing landscape to guide the development of revegetation treatments in disturbed areas with the goal to return disturbed gypsum communities to a stable trajectory which does not require additional active manipulation or external assistance. Natural, undisturbed gypsiferous soil communities provide a baseline or reference conditions for designing site- and soil-specific design for restoration activities. The surveys included in this synthesis identified vegetation density and diversity existing within known soil taxonomic units used by soil scientists and also identified vegetation more generally by parent material (associated to soil suborders) to isolate and identify the plant species within gypsum-rich soils and surrounding soil communities across soil taxonomic hierarchical levels to determine which species will most likely successfully establish within disturbed soils.

Additionally, soil sampling and analysis provide macro- and micro- nutrient concentrations and physical soil property information specific to different soil groups and also link these properties with species presence-absence within elevation and soil taxonomic units or categories. However, during a disturbance event, surface soil horizons may blend non-uniformly. Ranges of soil properties were also included to provide a potential guide for identifying within a disturbed mixed soil matrix what species may most likely be successful at establishing, which may differ from existing undisturbed soil communities. Instead of a strict model with narrowly delineated criteria, our restoration model provides for adaptive strategies which can be determined per site and per project. Several laboratory tests can determine if the current disturbance has resulted in greater variation of soil parameters that are characteristic of the undisturbed soil type. In our study, we found that several soil properties were highly correlated (attached Excel spreadsheet matrix) and may assist in limiting the extent of necessary laboratory analyses. Limited analyses, such as bulk density analysis (a known indicator of soil compaction) which can be easily done with limited equipment, soil texture characterization in the field or derived from bulk density analysis (Figure 59; for the soil texture triangle hydraulic properties calculator for bulk densities http://hydrolab.arsusda.gov/soilwater/Index.htm**),** measuring pH with a pH meter in the field or in a laboratory setting, electroconductivity measured with a field meter or in a laboratory setting, or total C, N, and S measured under the same protocols decribed in the methods section can likely be an initial guide for determining site characteristics.

The following sections within this report include studies which evaluate natural recovery versus active restoration activities, including observations of disturbed treated and untreated gypsiferous soil communities, revegetation and biocrust treatments.

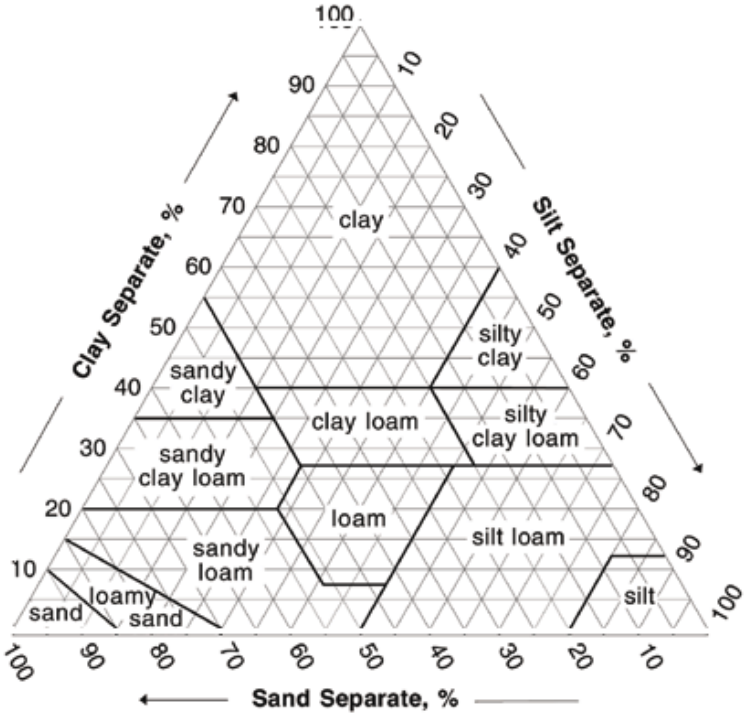


Figure 59 Example of a soil texture triangle hydraulic properties calculator for bulk densities (Saxton et al. 1986).

SECTION II. THE LAS VEGAS BEARPOPPY (*ARCTOMECON CALIFORNICA*) IN LAKE MEAD NATIONAL RECREATION AREA, EASTERN MOJAVE DESERT



Las Vegas bearpoppy adult flowering plant from Lake Mead National Recreation Area, eastern Mojave Desert (2010). Photo credit: Lindsay Chiquoine, University of Nevada, Las Vegas.

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

Las Vegas Bearpoppy Distribution

- Most of the bearpoppy populations in Lake Mead National Recreation Area are found in soils with gypsum-derived parent material
- Few populations are found in other soil types

Bearpoppy Site Seed Bank Analysis

- Extraction detected orders of magnitude greater seed densities than either emergence method and most of the differences between were statistically significant across microsites
- Shrubs occupied the most cover followed by perennial forbs
- Annual plants overall were most abundant in "fertile island" microsites below canopies of perennial plants
- Soil parameters P, K, Mn, and Sr had a wide range across bearpoppy sites
- Analysis of seed bank suggested that: (i) capturing microsite variation is important for efficiently estimating site-level desert seed banks; (ii) method comparisons hinged on the scale of analysis for some measures like species richness, as differences in species detection between methods diminished when increasing resolution from the sample to the regional scale (all 10 sites); (iii) combining data from all seed bank methods provided the strongest correlation with vegetation; and (iv) improving knowledge of germination ecology is critical for improvements to both seed bank methods, to enhance detection through emergence but also to ensure that seeds detected through extraction are viable, an under-appreciated limitation of this method which our viability tests were not able to resolve.

Bearpoppy Germination

- More work is required to elucidate methods for germinating bearpoppy
- A protocol to ensure survival of any germinated seeds still needs to be developed

Effects of Fluctuations in Precipitation on Bearpoppy Populations

- Lag precipitation and same-year precipitation were significant for predicting whether of plant was alive or dead within a population; however, the number of living plants was dependent on lag precipitation.

Text box 3:

Las Vegas bearpoppy

The Las Vegas bearpoppy is an endemic rare plant found on soils derived from Gypsids and Calcids in southern Nevada and adjacent areas of Arizona within Lake Mead National Recreation Area. It is almost exclusively found in east-central Clark County, Nevada. As of 2005 about 108 populations were identified and 4 sites have been documented in Mohave County, Arizona (Bangle 2005). The Las Vegas bearpoppy is globally and nationally ranked as vulnerable. This species is currently listed by the State of Nevada as vulnerable with a rank of S3 and by the State of Arizona as imperiled with a rank of S2. However, it has not been listed as federally endangered.

Introduction

One of the major concerns of disturbance in Lake Mead National Recreation Area (LMNRA) is the destruction of rare and endangered plant species habitat and the reduction of populations and individuals, including the reduction of species genetic diversity. With the increase in human habitation within the Las Vegas Valley and region, the potential area for the Las Vegas bearpoppy (*Arctomecon californica* Torrey & Fremont) has dwindled (see text box 3). The purposes of this project were to identify and evaluate aspects of the bearpoppy habitat in and around LMNRA, including the above-ground vegetation and seed bank, and to test feasible techniques for augmenting the bearpoppy distributions and populations.

This section is in four parts. Based on current bearpoppy information and population distribution, potential habitat areas that may support bearpoppy populations within LMNRA were identified in Part I. Currently known populations were mapped and overlaid with coinciding soil associations to obtain a potential distribution and identify potential suitable habitat and soil types. The following section, Part II, includes site assessments conducted on 10 long-term monitoring plots within and around LMNRA to identify vegetation assemblages associated with known populations and compare two types of emergence methods (immediately germinating samples versus storing them) and the extraction method for estimating soil seed bank characteristics across microsites in relation to vegetation aboveground. Site assessments provide a picture of species assemblage and identify co-occurring species within the same soil habitat. Additionally, quantify the persistent seed bank assists with identifying the habitat capacity for conservation, the regeneration capacity after potential disturbance, or the capacity for the vegetation community to response after unsuitable conditions, such as reduced precipitation, fire, or non-native invasive species introduction and/or removal (Baskin and Baskin 1998). A seed bank analysis data is presented comparing multiple assay methodologies. A photo archive was developed from the extracted seeds from the bearpoppy seed bank samples and is found in Appendix B. The bearpoppy seed ecology is poorly understood and therefore, in Part III, seed germination trials conducted with different and commonly used germination techniques with the goal of germinating bearpoppy and transplanting populations to identified supportable habitat are presented. Since bearpoppy populations

are known to fluctuate year to year. In Part IV population estimates from permanent and long-term monitoring sites within LMNRA were analyzed against published weather data to obtain an idea of population fluctuations based on precipitation variability.

PART 1. *Assessing Bearpoppy Population Distribution and Extent*



Potential Las Vegas bearpoppy habitat in Lake Mead National Recreation Area (UTM E 716877, N 4012140 (NAD 83, Zone 11 N) with soils containing 50% *Typic Haplocalcids* and 20% *Leptic Haplogypsids* within Lake Mead National Recreation Area, along the Northshore Rd corridor, which currently does not support a bearpoppy population.

Project Purpose

Due to the destruction of bearpoppy habitat within its known range, there is an interest in assessing the feasibility of establishing new and extending current known populations of the Las Vegas bearpoppy in LMNRA. We identify potential bearpoppy habitat in and around LMNRA by overlaying existing and previously existing bearpoppy locations with current soil maps to identify which soils poppy most occupied and identify the extent of soils to which bearpoppy inhabit. Additionally, a working GIS database was developed to display existing populations within identified soil mapping units and the extent of these units which currently do not contain poppy. This database is a workable database that can be adapted with new survey information.

INTRODUCTION

The Las Vegas bearpoppy is associated with Gypsids or Calcids soils with low bulk density, and mostly occurs in high gypsum content soils, with 36 % to 69 % gypsum at some sites (Meyer 1986) or high carbonate soils (Mistretta et at. 1995). There have been several hypotheses as to why poppy inhabits these soils. One may be the higher moisture retention of gypsum near the soil surface (Meyer et al. 1992; Sheldon 1994; Belnap 2001). In many of these sites, biotic crust is also well developed, which increases water absorption and retention and has a direct influence on nutrient cycling in the upper most soil layer (Barger et al. 2005; Belnap 2001); however, Megill et al. (2011) did not find a direct correlation between biocrust and poppy presence. These habitats have low vegetation density area with reduced competition and also a specific soil environment for seed germination and plant growth.

Early in bearpoppy research, the bearpoppy was believed to be a gypsophile; however, that has more recently been disputed. Soil composition, in particular, may play a major role in the presence of bearpoppy, and several studies have investigated the link between bearpoppy presence-absence in relation to gypsiferous soil composition. Sheldon and Smith (1994) found that the bearpoppy occupied sites with higher levels

of sulfur, calcium, and soluble salts than comparative sites that did not support bearpoppy. Drohan et al. (2006) suggested that gypsum is not a controlling factor in the presence or absence of bearpoppy; X-ray diffraction analysis showed that there was a lack of gypsum in the surface soil and gypsum found subsurface at different locations and sulfur was not accumulated in the leaves of plants. Pedologic analyses present evidence that site characteristics affecting potential soil water content, such as topographic relief, soil particle size, depth to horizons perching water, and soil chemistry and mineralogy, are more important to the plant's success for establishment and growth (Drohan and Merkler 2009). Drohan and Merkler (2009) concluded that bearpoppy was likely an extremophile and gypsovag (species that can occur on soil with or without gypsum), mostly inhabiting gypsum soils. Bangle et al. (2011) identified "high" density bearpoppy areas as correlated with greater soil EC, SO_4, Fe, Ca, Co, and Ni. These studies have concluded that bearpoppy is not a gypsophile, but more likely an extremophile. Despite not fully comprehending the presence of bearpoppy on these particular soil types, studies and reports on bearpoppy provide site soil provide a profile which may be applied to identifying potential habitat which is not currently inhabited by bearpoppy.

METHODS

Using the report, "Report on *Arctomecon californica* (Las Vegas bearpoppy) Monitoring, Lake Mead National Recreation Area" (Bangle 2005), updated population location information from LMNRA, current NPS-related reports, and publications on bearpoppy, we identified the current known populations of bearpoppy within LMNRA and visited the existing populations in spring 2010 and spring 2011 to verify current establishment. In spring 2010 we walked parallel transects through areas which were identified as potential bearpoppy areas that did not have existing populations, or formerly supported bearpoppy, that in recent years there was no evidence of a population. New populations were revisited in spring 2011 to observe the occurrence of adult plants. Population points were defined as a continuous land areas containing bearpoppy, with topographical features, such as a large washes or cliffs, and main roads defining area boundaries. Several of these features included gypsum outcrops. Using the Clark County, Nevada (Lato 2006) and Central Mohave County, Arizona (Strait 2006) soil surveys, we identified regions within LMNRA in Nevada and Arizona that contain bearpoppy populations to identify soil types where bearpoppy inhabits. Population locations were juxtaposed with existing soil maps and areas identified as supporting existing bearpoppy populations, formerly supporting populations and potentially supporting populations.

RESULTS

Known bearpoppy populations occupied multiple soil associations, including areas formerly under lake level that are now exposed. Most of the currently identified populations occur in Gypsids or Calcids soils or another soil type that is in association with Gypsids or Calcids (Table 59). Most of the populations occurred in Typic Haplocalcids, Durinodic Haplocalcids, Typic Petrogypsids, and Leptic Haplogypsids (Table 62). Individuals within populations and population groups appear to be generally clustered across the

landscape. Within individual soil units which were occupied by populations, there were areas of large extent within the same unit without a population (example Figure 60). Across the region, the same soil mapping units were indentified that did not contain known populations, encompassing (Figure 61 & 62, highlighted in green) but may support unmapped or unidentified populations or future populations. A large area along the eastern edge of Lake Mead contains soil types which may support bearpoppy. Since this area is difficult to access, the current status of potential populations is unknown (Figure 61). However, anecdotal evidence suggests that there are bearpoppy populations within these areas (Carrie Norman, LMNRA, National Park Service, personal communication). Additionally, soil units along the western side of Lake Mohave share soil characteristics with bearpoppy habitat, although there are no known current populations mapped (Figure 62). Also, with fluctuating lake levels during the year of poppy observations, populations were observed below the former lake level at Rogers Bay, Blue Point Bay and Stewarts Bay (Figure 60 & 61). This habitat was noted as unusual by the Park Service during surveys due to the dense vegetation population and rocky and gravelly substrate; however, poppy has been located in naturally gravelly soils which include a Calcids or Gypsids component, such as the Anniversary Narrows area. The disturbed area at Lakeshore Rd and Northshore Rd intersection was suspected of potentially being a place for introduction of bearpoppy. However, of the known populations, only two small populations (< 10 plants) inhabit this same soil association (Cheme-Huevi association) within other individual mapping units elsewhere in this region and have remained small throughout the NPS monitoring period. Low populations may be due to several factors including the soil profile itself, the soil component properties may not be ideal to support the germination and emergence of bearpoppy, lack of a primary seed source, or lack of pollinators.

DISCUSSION

Most of the poppy populations are found in soils with gypsum-derived parent material around Lake Mead (Figure 61, red colored areas). Few populations are found in other soil types (highlighted in green). In situations where bearpoppy is observed in non-gypsum-derived parent material, such as in Calcids soils, these individuals are often in close proximity to gypsum soils or in areas where the soil unit is not well defined. It is not clear that bearpoppy will inhabit or establish within these soil units. Additional research is necessary to determine if bearpoppy will establish a resident population within these soil types. However, due to limitations with enhancing germination potential and transplanting individuals, this may be difficult. Part 3 of this section includes a description of germination experiments in soils that support large populations of poppy to obtain the best techniques for assisting establishment of populations.

Table 62 Soil taxonomic suborder and subgroups which existing Las Vegas bearpoppy reside within Lake Mead National Recreation Area, Mojave Desert and the number of population points located within that soil unit.

Soil Suborder	Subgroups	Populations
	Formerly under lake water line (unclassified; near Gypsids)	17
Argids	Typic Calciargids	8
Calcids	Typic Haplocalcids	47
	Typic Haplocalcids, Calcic Petrocalcids	50
	Durinodic Haplocalcids	12
	Durinodic Haplocalcids, Leptic Haplogypsids	3
Calcids and Orthents	Lithic Haplocalcids, Lithic Torriorthents	33
	Durinodic Haplocalcids, Leptic Haplogypsids	3
Gypsids	Typic Petrogypsids	32
	Leptic Haplogypsids	59
Gypsids and Calcids	Leptic Haplogypsids, Typic Calcigypsids	1
	Leptic Haplogypsids, Typic Haplocalcids	1
Gypsids and Orthents	Lithic Torriorthents, Leptic Haplogypsids	9
Orthents	Lithic Torriorthents	6
	Lithic and Typic Torriorthents	3

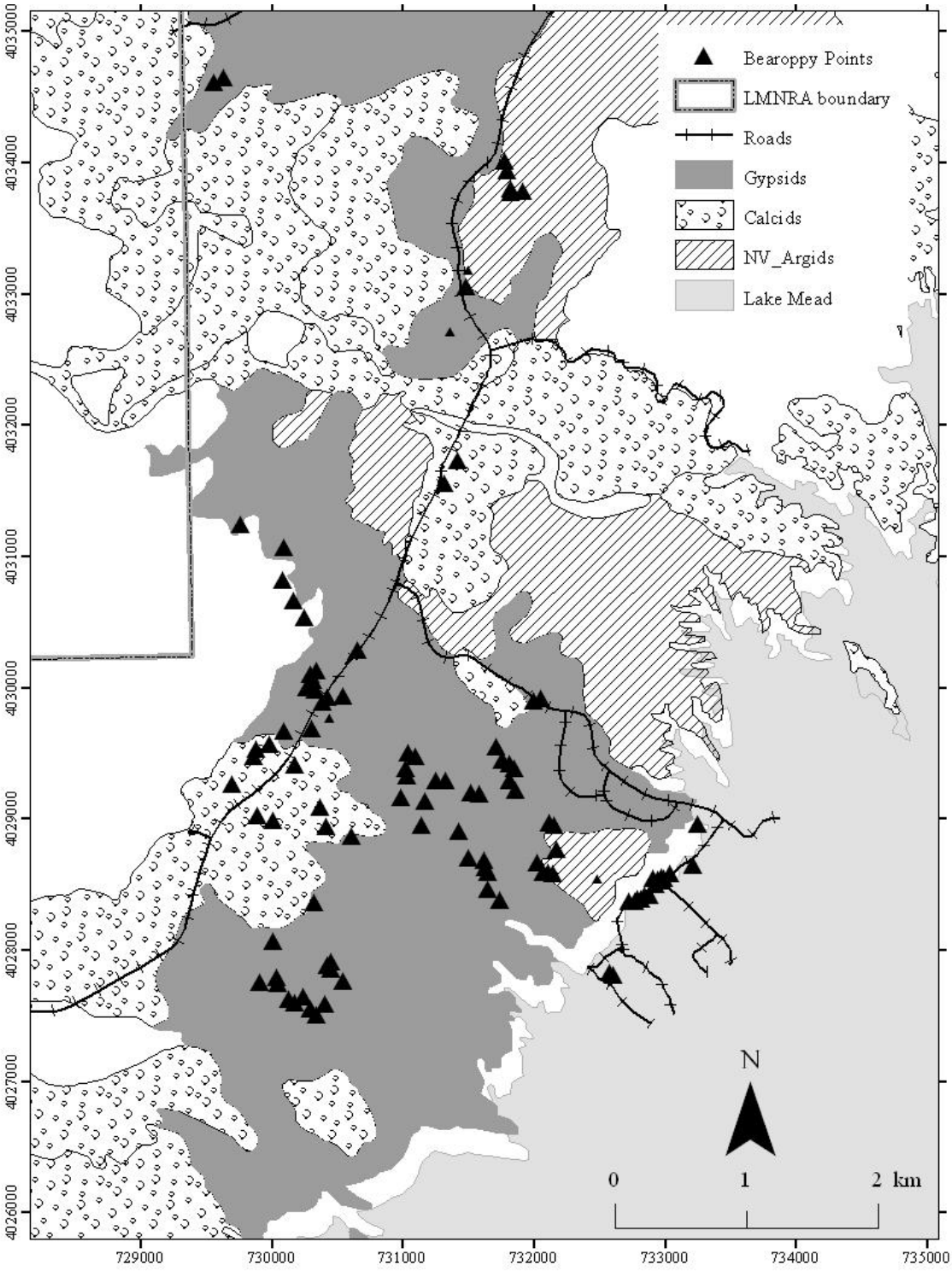


Figure 60 Map showing clustering of bearpoppy populations within soil units identified to the soil taxonomic suborder in the Stewart Spring and Blue Point Spring region along Northshore Rd within Lake Mead National Area, Mojave Desert.

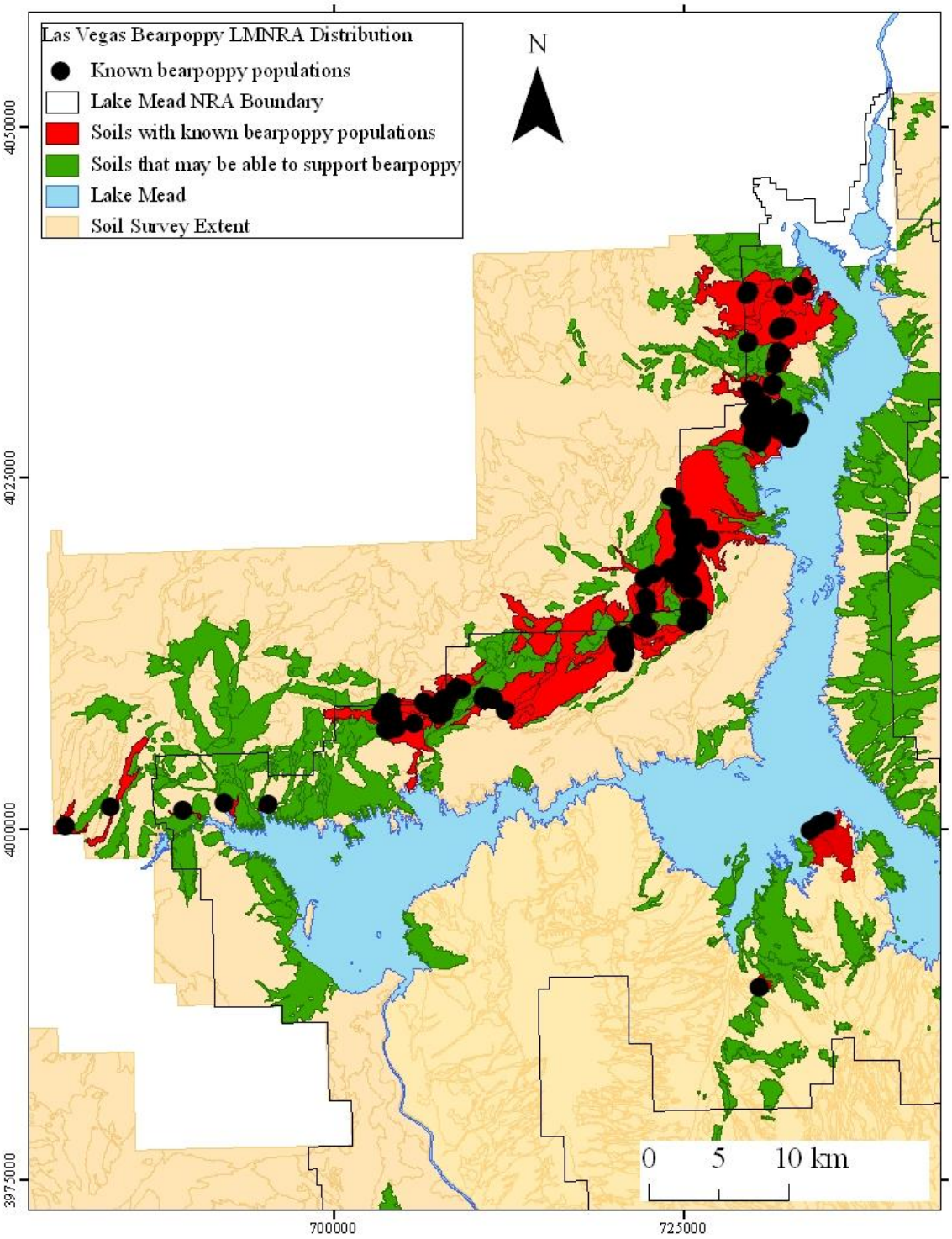


Figure 61 Known bearpoppy populations (black dots) around Lake Mead in Lake Mead National Recreation Area, Mojave Desert , with current soil mapping units identified with known bearpoppy populations (in red) and similar soil types without known populations (in green).UTM NAD 83 Zone 11N.

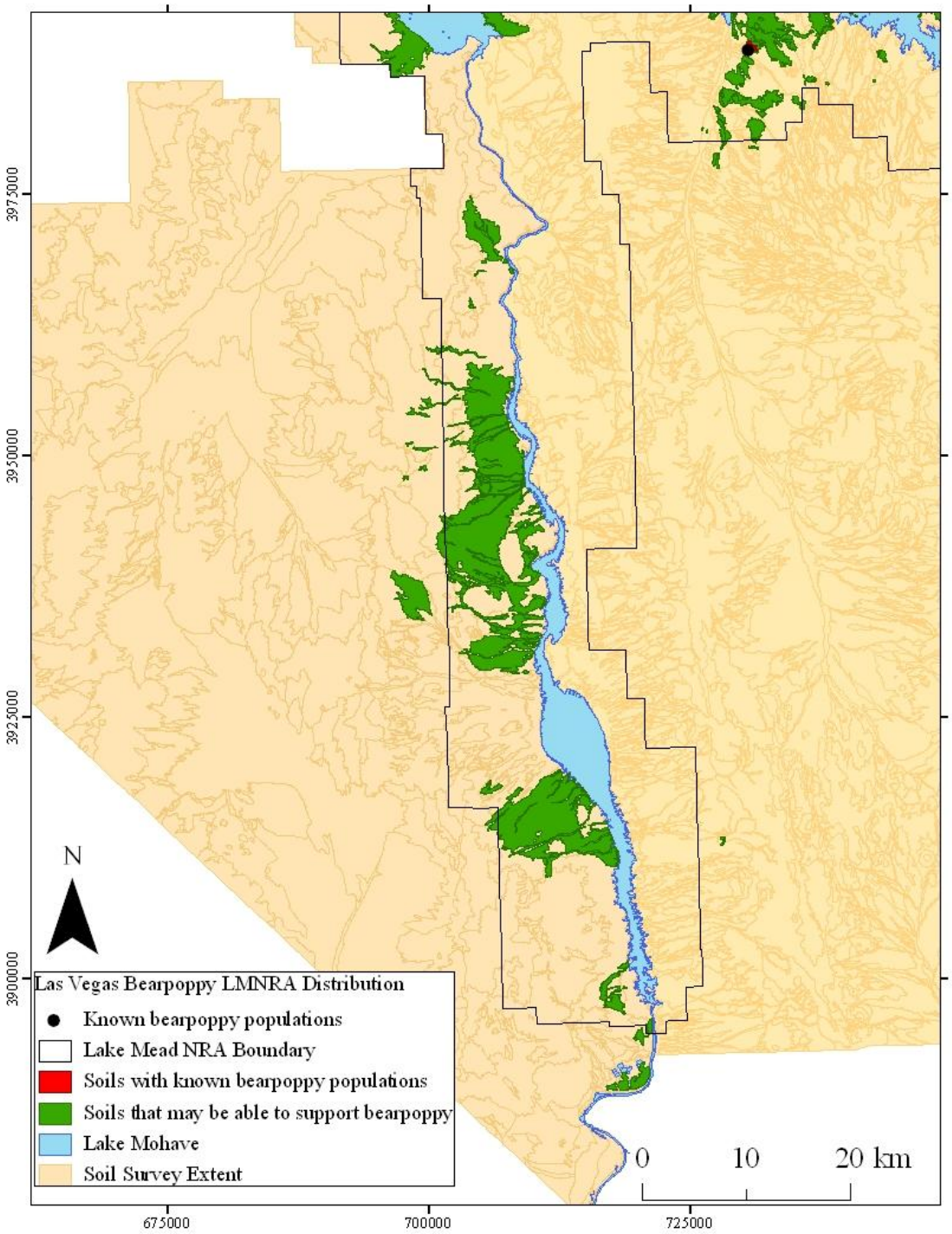


Figure 62 Known bearpoppy populations (black dots) in the southern portion of Lake Mead National Recreation Area, Mojave Desert, with current soil mapping units identified with known bearpoppy populations (in red) and similar soil types without known populations (in green). No populations have been recorded around Lake Mohave. UTM NAD 83 Zone 11N.

Part 2. L*as Vegas Bearpoppy Sites Vegetation, Seed Bank, and Soil Communities*



Characterizing soil seed banks and relationships to plant communities in Las Vegas bearpoppy (*Arctomecon californica*) habitat

Contributed by Cheryl H. Vanier and Lindsay P. Chiquoine

Project Purpose

The purposes of these site assessments are to provide a picture of species assemblage, to identify co-occurring species with the rare and endangered species Las Vegas bearpoppy (*Arctomecon californica*), and to quantify the persistent seed bank as defined by Baskin & Baskin (1998). Our goal was to elucidate how closely the seed bank composition correlated with above-ground vegetation in the growing season following seed bank sampling. Soil analysis also provided chemical properties for soils known to support these populations. Bangle et al. (2011) observed that Las Vegas bearpoppy population density varied due to soil composition in the A horizon. They also observed that Ni, Zn, Ca, and electrical conductivity (EC) were the strongest soil chemistry predictors of bearpoppy abundance and bulk density was not, and that "high" density bearpoppy areas were correlated with greater soil EC, SO_4, Fe, Ca, Co, Ni, soil texture, and pH. Evaluating the soil seed bank, either through an emergence assay, extraction, or both, assists with identifying the habitat capacity for conservation, the regeneration capacity after potential disturbance, or the capacity for the vegetation community to response after unsuitable conditions, such as reduced precipitation, fire, or non-native invasive species introduction and/or removal (Baskin and Baskin 1998). Known bearpoppy locations were used to concentrate specifically on bearpoppy habitat and the influence of microsite (under plant canopy and in interspaces) on the vegetation structure on the seed bank. Multiple seed bank assessment techniques were used to assess the bearpoppy seed bank to contribute to analyzing the methodology regarding assessment of seed banks in arid systems.

SUMMARY

1. Estimates of soil seed banks are useful for many ecological investigations, monitoring programs, and conservation plans. However, uncertainty remains about the relative performance of the two main methods (emergence and extraction) for characterising seed banks and relationships to vegetation, and whether method interacts with sample microsites (e.g., below different perennial plants) in ecosystems such as deserts with high spatial seed bank variation.
2. The goal of this study was to compare two types of emergence methods (immediately germinating samples versus storing them) and the extraction method for estimating soil seed bank characteristics across microsites in relation to vegetation aboveground and soil environment.
3. We collected 0-5 cm seed bank samples and measured vegetation in six microsite types (below different perennial plant species and interspaces) at 10 replicate sites in the Mojave Desert, USA.
4. Extraction detected 4.5-fold more species/360 cm^3 sample and orders of magnitude greater seed density than the emergence methods, which differed little from each other. However, considering all sites, species detection was not as dissimilar between methods: 21 taxa for emergence and 28 for extraction. Species composition differed among microsites and between emergence and extraction methods, with a conservation-priority rare species, *Arctomecon californica*, detected only through extraction.
5. This analysis suggested that: (i) capturing microsite variation is important for efficiently estimating site-level desert seed banks; (ii) method comparisons hinged on the scale of analysis for some measures like species richness, as differences in species detection between methods diminished when increasing resolution from the sample to the regional scale (all 10 sites); (iii) combining data from all seed bank methods provided the strongest correlation with vegetation; and (iv) improving knowledge of germination ecology is critical for improvements to both seed bank methods, to enhance detection through emergence but also to ensure that seeds detected through extraction are viable, an under-appreciated limitation of this method which our viability tests were not able to resolve.
6. Results revealed complexity in tradeoffs between emergence and extraction methods and provided equations to estimate seed bank characteristics derived from either method. These relationships likely need to be established by ecosystem to help reconcile differences between seed bank characterisation methods.

INTRODUCTION

Soil seed banks have been part of ecological theories on species evolution, traits, food webs, and succession since Darwin (1859) made among the first recorded observations of seed banks when he noted the presence of seeds stored in the soil of pond ecosystems. Reliable estimates of seed banks also are needed for many practical purposes, including evaluating plant regeneration potential, resources available to seed-eating organisms, site history (e.g., evidence of past disturbance), and comparisons of which species in the vegetation form seed banks (Roberts 1981; Warr, Thompson, & Kent 1993; Bakker et al. 1996). Knowledge of seed banks is useful for conservation applications, such as for managing rare species that rely on seed banks for maintaining their populations or for detecting exotic plant species that threaten indigenous ecosystems (van der Valk & Pederson 1989). An ideal seed bank characterisation method would detect all species and accurately estimate the density of viable seeds while being as easy as possible to implement. However, characterising seed banks is recognized as one of the more challenging measurements of the plant community (Warr, Thompson, & Kent 1993). Consequently, methods comparisons constitute an active field of research (e.g., Ishikawa-Goto & Tsuyuzaki 2004; Bernhardt et al. 2008; Price et al. 2010).

The two main categories of methods for characterising seeds in soil samples are emergence and extraction (Baskin & Baskin 1998). Both have advantages and disadvantages. In the emergence method, soil samples are placed in pots or flats in greenhouses or similar environments and seedlings that emerge from the soil are identified and counted as an estimate of seeds in the seed bank. The advantages of the method are that all seeds detected are known to be viable, it is generally easier to taxonomically identify plants than seeds, and no separation procedure of seed from soil is necessary so that the method is not subject to non-detection bias due to seed size, shape, or color (Roberts 1981). Disadvantages are that not all seeds will necessarily germinate under the greenhouse conditions, samples must be maintained for multiple months to allow as many seeds as possible to emerge, and greenhouse space and resources (e.g., water) are required to maintain samples.

In the extraction method, seeds are separated from soil and other particles by flotation techniques (Roberts 1981), then isolated and identified. The principal advantages of the method are that results can be available more quickly than for the emergence method because time for emergence is not required, and seeds varying in germination requirements can be detected (Warr, Thompson, & Kent 1993). The major disadvantages are that the detectability of seeds is not uniform across species (e.g., detecting small-seeded species can be difficult), identifying seeds to species can be challenging especially considering the ‘weathering’ of seeds in soil, and determining viability of seeds commonly is not straightforward, such as in deserts where many species have small seeds or deep dormancy and are not amendable to standard tetrazolium tests (Guo, Rundel, & Goodall 1998).

Several authors have noted that seed bank estimates obtained by the two methods, and consequently our impression of the composition of seed banks, can sharply differ between the methods (Forcella 1992; Ishikawa-Goto & Tsuyuzaki 2004; Bernhardt et al. 2008). Also significant is that upon close inspection of the literature as a whole, method comparison studies have found conflicting results. For example, it is often assumed that extraction detects more seeds than emergence, but some studies have found that seed densities or species richness are within 10% between methods or even significantly greater by emergence (Gross 1990; Cardina & Sparrow 1996; Price et al. 2010). These observations suggest that the relative performances of these methods remains debatable among ecosystems, and there is also a need for studies that calibrate the methods against each other to help make studies using different methods more comparable. For instance, species richness between the methods could be related using regression, and species prone to be 'missed' by a method could be identified.

The performance of seed bank methods is poorly known in deserts, a particularly important knowledge gap given that deserts are considered among the ecosystems most dependent on seed banks for plant community maintenance (Baskin & Baskin 1998). Owing to harsh and highly unpredictable environments in deserts, annual and many perennial plants rely on seed banks for regeneration during windows of environmental conditions favorable for plant establishment (Pake & Venable 1996). In reviewing seed bank research in the Mojave and Sonoran Deserts of the North American Southwest, for example, studies have only employed the extraction method (e.g., Nelson & Chew 1977; Pake & Venable 1996; Guo, Rundel, & Goodall 1998) until recent applications of the emergence method (Abella et al. 2009; DeFalco et al. 2009; Esque, Young, & Tracy 2010). These studies have not compared the two methods, however. Additionally, the spatial variation of seed banks within desert sites (e.g., below perennial plants versus interspaces between perennials) can be substantial (Nelson & Chew 1977; Reichman 1984). This variation is an important sampling consideration and could interact with seed bank characterisation method. The objectives of this study were to compare two variations of the emergence method and the extraction method for characterising seed banks across perennial plant microsites and sites, relate the emergence and extraction methods to each other (e.g., relating seed density through regression), and evaluate how closely each of the methods corresponded to vegetation aboveground. We conducted the study within a desert landscape of conservation significance containing rare native plant species, where estimates of seed bank composition are desired to help understand regeneration strategies of native species and the presence of exotic species that could threaten indigenous ecosystems.

METHODS

Study Area

We sampled 10 sites in the eastern Mojave Desert in Lake Mead National Recreation and adjacent Bureau of Land Management lands in southern Nevada, southwestern USA (Table 63). We selected these sites because they are long-term sites maintained by the National Park Service for monitoring rare plant habitat and spanned an extent of

59 km with a mean ± SD distance between sites of 21 ± 17 km. Located in the study area at an elevation of 768 m, the Boulder City, Nevada weather station has recorded the following averages: daily high July temperature of 39°C, daily low January temperature of 4°C, and 14 cm/yr of precipitation (1931-2004 records; WRCC 2011). On average, 73% of annual precipitation is received during the September through April growing season for annual plants, with peak blooms typically occurring in March-May depending on adequate timing and amounts of rainfall beginning the previous September (Beatley 1974).

Sites were established in 2007. The ten sites were 10 m x 10 m (0.01 ha) containing six 1 m x 1 m subplots placed at 0.5, 5, and 9.5 m along the southern and northern boundaries of the 100-m^2 site In the southwest corners of each plot, location was recorded (Universal Transverse Mercator [UTM] coordinates, using a global positioning system). Elevation (measured with a Geographical Information System [GIS]), slope aspect (compass), and slope gradient (clinometers) were recorded across the entire site. All sites were generally located along the Northshore Rd corridor (Rte 169), but were not located along roadsides (Figure MAP). The elevation of sample sites ranged from 383-634 m, and topography was flat to undulating with slope gradients < 10%. Soils were on or associated with Gypsids or Calcids parent material and were classified as Typic Petrogypsids, Lithic and Typic Haplocalcids, Leptic Haplogypsids, and Typic Calciargids (Lato 2006). Physiognomy was typical of Mojave Desert communities, which included scattered perennial plants separated by interspaces containing mostly bare soil or annual plants in moist years (Meyer 1986). Annual plants overall were most abundant in the "fertile island" microsites below the canopies of perennial plants (Meyer 1986). At least two perennial species (*Arctomecon californica* and *Anulocaulis leiosolenus*), covered under a conservation plan of the U.S. Endangered Species Act, occupied some sites (Table 63).

Seed Bank Sampling

We conducted sampling in March 2007, prior to the emergence of new seedlings, to measure the persistent seed bank as defined by Baskin & Baskin (1998). This also was a dry year, with only 49% of average precipitation for September through March prior to sampling (Las Vegas, Nevada weather station, 1937-2010 records; WRCC [2011]), exhibiting little to no annual plant emergence at the study sites which also helped to isolate the persistent seed bank. Within an area of 1 ha centered at each site, we established a 50-m transect. Along transects, we collected seed bank samples from three individuals each of six microsite types: below the perennials *Ambrosia dumosa*, *Anulocaulis leiosolenus*, *Arctomecon californica*, *Ephedra torreyana*, *Psorothamnus fremontii*, and in interspaces (defined as ≥ 1 m from the nearest perennial plant). We sampled these microsites because they were most common among sites and allowed sampling to capture different below-perennial and interspace microsites that can influence desert seed banks (Reichman 1984). We selected the largest perennial plants and interspaces for sampling that were within 5 m of either side of transects. We collected samples from three points equally spaced around each perennial plant halfway between the main stem and canopy drip line. In interspaces, we collected samples from three equally

spaced points within an area of 1 m^2. We collected samples as cores 7 cm in diameter from a depth of 0-5 cm (200 cm^3), which could include litter (typically < 0.5 cm thick, if present). Guo et al. (1998) reported that the 0-5 cm depth contains 97% of seeds in Mojave Desert seed banks. We composited samples from each individual microsite and further composited these samples by microsite type at each site, for a sample volume of 1200 cm^3.

Seed Bank Assay

For emergence method 1, within one week of sample collection, we placed 360 cm^3 of seed bank soil in a 2-cm thick layer on top of potting soil (Black Gold cactus mix, Sun Gro Horticulture Distribution, Inc., Bellevue, Washington, USA) in a 3.8-L, 15-cm diameter pot for each microsite type at each site. We randomly arranged pots on a bench in an unheated greenhouse maintained with natural lighting. We watered samples daily with an automated misting system delivering 1.5 cm of water/day. We checked samples at least every two days, counted and pulled identified seedlings every two weeks, and allowed for a 9-month emergence period. S*chismus* and *Typha* spp. were not reliably identified to species without mature reproductive structures, and since not all of the seedlings matured, we grouped these seedlings to genus. Nomenclature follows NRCS (2011).

For emergence method 2, we placed 360 cm^3 of soil from each microsite in a nylon mesh bag and stored the samples outdoors within a fenced greenhouse complex on a wooden shelf raised 10 cm above the ground and covered with a 1-m^2 wooden roof so the samples were not exposed to rainfall. After storing the samples for 12 months, we established them in the greenhouse using the same methods as for emergence 1.

Seeds were extracted from soil (360 cm^3/sample) using a water flotation technique (e.g., Gross 1990; Pake & Venable 1996; Bernhardt et al. 2008). Each soil sample was placed in a beaker, tap water was added, and the suspension was filtered through a stainless steel sieve with openings 0.18 mm in diameter. After the suspension air dried, seeds were visually separated from other material under microscopes with ≥ 10× magnification. To assess extraction recovery efficiency, we spiked three randomly selected samples with *Penstemon palmeri*, which has brown seeds averaging 1 mg air dry (Royal Botanic Gardens, Kew, United Kingdom) and is not known to occur at the study sites (Meyer 1986). Recovery occurred only in spiked samples and was 70%. We identified extracted seeds to the finest taxonomic level possible (species for 76% of 41 taxa, genus for 20%, and family or higher for 5%) using local floras and seed illustrations (e.g., Baldwin et al. 2002), comparing to local seed collections (e.g., Lake Mead National Recreation Area plant nursery, Boulder City, Nevada, USA) or seeds on plants at study sites, or germinating the seeds and identifying the seedlings. We photographed and weighed extracted seeds. We followed procedures for estimating viability used in previous seed bank studies in deserts (e.g., Pake & Venable 1996) and other ecosystems (e.g., Price et al. 2010) by visually scoring a seed as viable if an embryo was fleshy and intact. Not all seeds, including in deserts, are amenable to tetrazolium testing for viability because of their small size, dormancy stage, or other factors (Pake & Venable 1996). We further attempted to assess germinability by sowing seeds in pots

established in the same manner as for the emergence methods.

Vegetation Surveys

To elucidate how closely seed bank composition correlated with vegetation the growing season following seed bank sampling, we measured vascular plant species in May 2008 at each microsite where seed bank samples were collected. This was considered an average year for annual plants, with > 68% of average September through April precipitation (Las Vegas, Nevada weather station, WRCC [2011]). Sampling was conducted using a 1 × 1 m quadrat centered on the perennial plant or interspace for each microsite. Areal cover of each plant species (including of the focal perennial plant in perennial microsites) rooted in each quadrat was visually categorized using Peet et al.'s (1998) classes: 1 = trace (assigned 0.1%), 2 = 0-1%, 3 = 1-2%, 4 = 2-5%, 5 = 5-10%, 6 = 10-25%, 7 = 25-50%, 8 = 50-75%, 9 = 75-95%, and 10 = 95-100%.

Soil Sampling

Soils were samples across each site; 2 samples of 360cm^3 at 0-5 cm depth were acquired and composited to encompass soils across the entire 0.01ha site. Soil samples from the Las Vegas Bearpoppy were sampled from the 0.01 ha sites in 2007. Soil samples were air dried, sieved through a 2-mm sieve, and analyzed for texture (hydrometer method following Tan (2005)); pH (1:1 soil:water); total C, N, and S (dry combustion, CNS analyzer); P and K (LECO), the water-soluble concentrations of Al, Ca, Fe, K, Mg, Na, P, and B, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sr, Zn (method following Burt 2004).

DATA ANALYSIS

Seed Bank Analysis

We expressed seed densities as seeds/m^2, the common measure for seed bank studies (Baskin & Baskin 1998), corresponding to the 0-5 cm sampled soil depth. Seed density and species richness/360 cm^3 sample were analyzed as a partially hierarchical design containing the fixed effects of microsite (6 microsite types of 5 perennial plant species and interspaces, tested over the interaction between microsite and site), method (emergence 1 and 2 and extraction, tested over the interaction between method and individual soil sample), and the interaction between microsite and method (tested over the residual term). Species richness was Poisson distributed, so a generalized linear model assuming a Poisson distribution was fit using PROC GLIMMIX in SAS software version 9.2 (SAS Institute, Cary, North Carolina, USA). Effect sizes were estimated from the minimum adequate model determined by *P*-values ($\alpha = 0.10$). Seed density and species composition (based on relative seed density, calculated as the proportion of seeds a given a species contributed to the total seed of all species within a sampling unit) were analyzed using permutational multivariate analysis of variance (Anderson 2001) in DISTLM software (Anderson 2004). The distance matrix was based on the Sørensen index and *P*-values on 999 permutations by soil sample for the microsite effect and soil sample by method for the method effect. Contrasts using the same permutation method were conducted when *P*-values were < 0.05. To compare site-level seed bank species richness (based on the total species detected across microsites within a site) among methods, we used a general linear model

with Poisson error and a fixed effect of method (tested over the residual) and a random effect of site. We related seed density and species richness at microsite and site scales between seed bank methods using simple linear regression. We graphically displayed species composition (relative seed density) among methods with non-metric multidimensional scaling ordination using PC-ORD's "slow and thorough" autopilot setting with Sørensen distance (McCune and Mefford 2006).

Vegetation Analysis

Total mean cover and richness was calculated at the microsite level for annuals and the site level for perennial species. We related seed bank and vegetation species richness at the microsite and site scales using simple linear regression. To evaluate congruence in species composition between seed bank methods (and all methods combined) and vegetation at microsite and site scales, we used Mantel tests. The Mantel test (Mantel 1967) evaluates a null hypothesis of no relationship between matrices and produces a standardized Mantel statistic (*r*) ranging from -1 to 1, analogous in interpretation to a correlation coefficient. The matrices, which used presence/absence data and included 53 rows corresponding to all microsites at the microsite scale and 10 rows corresponding to the sites at the site scale, were converted to Jaccard distance matrices on which Mantel tests were performed. Significance of Mantel statistics was determined by permutation (999 permutations), and the tests were run in R 2.8.1 (R Development Core Team 2008) with the 'vegan' package (Oksanen et al. 2009).

Soil Analysis

Only soil analysis results that had actual numerical results were included. Across all bearpoppy sites, the mean of soil parameters was calculated. A principal components analysis (PCA) was run using PC-ORD (MJM Software Design 2006) with correlations as a distance-based biplot, with randomization tests, on 2 site parameters (elevation, transformed aspect following Beers et al. 1966) and 18 soil variables.

RESULTS

Seed Density

Overall, extraction detected orders of magnitude greater seed densities than either emergence method and most of the differences between were statistically significant across microsites (Table 64; Figure 63). Microsite also affected seed density estimates and interacted with method. None of the microsites differed from each other within the extraction method, but the *Anulocaulis leiosolenus* and *Arctomecon californica* microsites in extraction did not differ from all microsites of the emergence method and some microsites within emergence methods differed from each other (Figure 63). *Ambrosia dumosa* microsites contained significantly greater seed densities than *Anulocaulis leiosolenus* microsites in emergence 1, and in emergence 2, *Ambrosia dumosa* and *Ephedra torreyana* microsites had significantly more seeds than open microsites. In relating methods to each other for average seed density, the emergence methods were more strongly correlated in their estimates of seed density than were emergence and extraction (Table 65).

Seed Bank Species Richness

Microsite and method did not interact but were significant main effects influencing seed bank species/sample (Table 64). At the site scale with all microsites combined, method significantly affected richness/site ($F_{2, 18} = 25.8$, $P < 0.001$). The same pattern of multiple comparisons occurred at both the sample and site scales: richness did not differ between emergence methods and extraction detected more species than either emergence method (Figure 64). A total of 41 taxa were detected in all seed bank samples, with detection ranging from 13 taxa in emergence 1, to 28 in extraction (Table 66). In relating methods to each other, estimates of richness/site were similarly correlated (r = 0.42-0.48) between methods (Table 65).

Seed Bank Species Composition

The effect of seed bank method on recorded species composition of the sample depended on microsite (Table 64). The ordination revealed a clear separation in species composition between emergence and extraction methods and similarity in composition between emergence methods (Figure 65). *Typha* was correlated with the emergence methods because these taxa exhibited higher relative seed density in emergence compared to extraction.

In contrast, a variety of species such as *Ambrosia dumosa* and *Arctomecon californica* were correlated with the extraction method. Extraction detected the most taxa unique to only its method, with 20 taxa, compared to 4 taxa for emergence 1 and 7 taxa for emergence 2. Six general categories of taxa appeared evident: taxa detected by all methods and also occurring in the vegetation, taxa detected only by emergence and also in vegetation, taxa detected only by extraction and also in vegetation, taxa only in the seed bank and not in vegetation at the sites, taxa only in vegetation and not detected in the seed bank, and rare taxa detected only once (Table 63). The three exotic taxa (*Bromus rubens*, *Malcolmia africana*, and *Schismus* spp.) were detected both by emergence and extraction. Considering the two rare species with conservation status, *Arctomecon californica* was only detected by extraction while *Anulocaulis leiosolenus* was not detected in the seed bank.

Seed Bank:Vegetation Relationships

The correlation coefficients between seed bank and vegetation species richness for individual seed bank methods ranged from 0.33-0.51 at the microsite scale and from 0.14-0.46 at the site scale. There were no consistent patterns for higher or lower correlations with respect to seed bank methods, and combining species richness from all methods provided the strongest correlations with vegetation richness at both scales. The trend for species composition was similar, in that no particular seed bank method was consistently correlated with the vegetation, whereas combing seed bank methods into one compositional estimate resulted in significant Mantel tests at both scales (Table 67).

Soil

Some soil parameters, such as P, K, Mn, and Sr, had a wide range across all sites. PCA ordination identified % Fe (r^2 = 0.98), % Al (r^2 = 0.96), % K (r^2 = 0.91), Mn (mg/kg; r^2 = 0.95), and elevation (m; r^2 = 0.87) as significant variables characterizing plot

distribution (Table 68; Figure 66). However, there were few correlating factors. Soil variables examine in multiple regression showed that PCA scores were most influenced by % Fe (partial r^2 = 0.95, P<0.001) and elevation (partial r^2 = 0.87, P<0.001).

Vegetation Aboveground Cover

Annual plants overall were most abundant in "fertile island" microsites below canopies of perennial plants. Two rare perennial species (*Arctomecon californica* and *Anulocaulis leiosolenus*), protected under a regional conservation plan, occupied some sites (Table 63). Shrubs occupied the most cover with a mean of 5 % across all microsites and sites (Table 69), followed by perennial forbs 0.81 % (Table 69), while native annuls only had a mean cover of 0.011 % (Table 70). The non-native annual grasses *Schismus* spp. and *Bromus rubens* had a mean cover of only 0.08 across all microsites and across all sites (Table 70).

DISCUSSION

General Patterns

A general expectation is that extraction detects more seeds and species than emergence (Roberts 1981), but a close inspection reveals that the literature is mixed (Gross 1990; Cardina & Sparrow 1996; Price et al. 2010). Our results, among the first methodological comparisons in an arid environment, support studies in other habitats (e.g., conifer forests, Brown [1992]; and deciduous forests, Ishikawa-Goto & Tsuyuzaki [2004]) that have found that extraction detects greater seed densities and species richness and portrays a different species composition than emergence. It is not clear whether method performance is correlated with ecosystem type, and variation might result from many factors such as successional status within habitats. Further work is needed to assess whether generalizeable patterns exist to account for when a particular method might be more effective in different habitats.

Microsite Influences

Given the significant influences of microsite on seed bank measures, sampling by microsite can likely increase sampling efficiency when whole-site seed bank estimates are desired. These whole-site estimates might be useful for understanding the full regeneration potential of the seed bank, such as if topsoil is to be salvaged for later land reclamation or if disturbance homogenizes the spatial arrangement of surface soils (DeFalco et al. 2009). Our finding of greater seed densities below perennial plants, especially of larger perennial species, is consistent with studies in other arid environments (Guo, Rundel, & Goodall 1998). Several mechanisms, likely providing valuable insight into seed bank formation if their importance were to be experimentally untangled, might explain the observed greater seed densities below perennial plants. These mechanisms include seed production of the perennial itself; microclimate amelioration and increased soil fertility below the perennial, in turn fostering annual plant communities and their seed production; trapping of seeds via wind deposition of dust or surface movement of soil; soils of low bulk density below perennials facilitating seed penetration into the soil; the presence of surface litter able to trap seeds; and greater animal activity near perennial plants (Reichman 1984). While perennial plant microsites occupy only small

portions of desert landscapes (often < 10%), they contain a disproportionate amount and species richness of seeds, a source of variation important to capture for efficient site-level seed bank sampling.

Species Specifics and Germination Ecology

A general model for identifying species detectable by one or the other seed bank methods could help reconcile differences between methods and help understand which species go undetected by a particular method but that are likely in seed banks. Seed size could be a useful characteristic, as especially small seeds might be difficult to detect via extraction (Thompson, Band, & Hodgson 1993). However, our data revealed no clear overall trend with seed size and detectability, as some small-seeded (< 1 mg) and some large-seeded (≥ 1 mg) species were detected by both extraction and emergence. For example, small-seeded *Typha* (0.04 mg) and *Schismus* spp. (0.1 mg) were detected by both methods, similar to the large-seeded *Plantago ovata* (1.1 mg) and *Bromus rubens* (2.9 mg). Some important large-seeded species in the vegetation were only detected by extraction (e.g., 7.0 mg *Ambrosia dumosa*, 1.6 mg *Arctomecon californica*), implying that emergence requirements of these species were not met by emergence methods given that these seeds exhibited characteristics (e.g., hardness) consistent with being viable (Megill et al. 2011).

An improvement to the effectiveness of both methods could be to increase our understanding of germination requirements of species to help meet these requirements for detecting seeds through emergence and estimating germinability/viability of seeds recovered by extraction. This is especially important in ecosystems such as deserts where germination ecology is not well understood nor are viability tests (e.g., tetrazolium) well developed for species exhibiting specialized dormancies for the desert climate (Pake & Venable 1996). It is important to recognize that germination of freshly collected seed or seed stored in the lab is not necessarily the same as for seeds that have resided in soil seed banks (Baskin & Baskin 1998). Similarly, the process of extraction could change seed dormancy in ways that have been little documented, complicating germinability and viability estimates that should be part of the extraction method. This highlights a need to understand both the basic germination ecology of individual seed species as well as for the overall seed bank including treatments to seed bank samples that can increase emergence. Our study suggests that there is no advantage of storing desert soils in outdoor conditions to increase emergence, as stored samples even exhibited slightly lower seed densities than samples not stored. Example treatments in other regions that have enhanced seed bank detection include treating soils of semi-arid Arizona *Pinus ponderosa* forests east of our study area with liquid smoke (21% increase in detected seed density; Abella et al. 2007), and heating in Australian *Eucalyptus* woodlands (79% increase; Enright et al. 1997). Esque et al. (2010) described a procedure of wetting/drying and gibberellic acid treatments for Mojave Desert seed banks, and comparing these treatments with other or no treatments could provide valuable methods insight. Treatments increase the labor, materials, and time required to assay samples, but developing effective treatment regimes is apparently required if emergence is to detect some important species such as *Arctomecon californica*.

Vegetation

Many studies have compared seed bank with vegetation composition (e.g., Olano et al. 2005), but few studies have examined how different seed bank methods correspond to vegetation (Cardina & Sparrow 1996). Practical value of accurately estimating seed bank:vegetation relationships includes understanding seed bank potential for regenerating current species composition versus other species if disturbance occurs (van der Valk & Pederson 1989). Seed bank formation by species of the current vegetation promotes high seed bank:vegetation similarity, whereas seed bank persistence from past vegetation, seed bank formation from off-site seed dispersal of different species, and lack of seed bank formation by current on-site vegetation all promote low seed bank:vegetation similarity. From the standpoint of selecting a seed bank method, it would be desirable to select a method that represents the seed bank:vegetation relationship as accurately as possible, including when the seed bank and vegetation are not closely related. Because some species were present in the seed bank but not vegetation and vice versa, which varied by seed bank methods, we did not find that a particular seed bank method was consistently most strongly correlated with vegetation. In fact, combining data from seed bank methods resulted in the strongest correlations with vegetation, likely because this more thoroughly represented full seed bank composition. Both methods also detected a major seed bank taxa (*Typha* spp.) not present in the vegetation (reducing seed bank:vegetation similarity). *Typha*, a wetland taxa, is not known to occur in vegetation of gypsum soils (Meyer 1986; Megill et al. 2011), and seeds likely dispersed from springs or nearby Lake Mead or some type of past depositional event.

Practical Considerations

This study revealed several practical considerations about seed bank methods depending on the purpose of the characterisation. For example, detecting exotic species could be an important purpose of seed bank assays, especially when the key exotic plants are annuals that may not be evident in the vegetation for several years (Pake & Venable 1996). The three main exotic plants within the study area – *Schismus* spp., *Bromus rubens*, and *Malcolmia africana* – were detectable by all of the methods, suggesting that any method could be used to meet this purpose. To detect conservation-priority native species, in contrast, only extraction appears viable for *Arctomecon californica*, unless improving knowledge of its germination ecology can enhance effectiveness of the emergence method. None of the methods detected the other conservation-priority species, *Anulocaulis leiosolenus*, and it is unclear whether seed banks of this species actually are sparse or methodological improvements are needed for its detection. When comparing seed banks to vegetation is a study goal, combining data from both seed bank methods to provide the most comprehensive seed bank estimate likely is most accurate. If a general inventory of the seed bank is desired, results suggested that extraction detects more seeds and species than emergence, recognizing, however, that seed viability/germinability assessment for extraction was not straightforward and emergence did detect some species that went undetected by extraction. Other tradeoffs, such as availability of greenhouse space for emergence and seed reference collections

for extraction, also warrant consideration (Warr, Thompson, & Kent 1993). Our results further suggest that when developing site-level seed bank estimates is desired, sampling by microsite (e.g., different perennial plants and interspaces) may enhance sampling efficiency given the orders of magnitude variation in seed density between microsites in desert soils. Improving knowledge of seed and seed bank germination ecology will likely be linked with future improvements in seed bank characterisation methods.

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Table 63 Characteristics of study sites for seed bank sampling of Las Vegas bearpoppy sites in the Mojave Desert, USA.

	Site									
	1	2	3	4	5	6	7	8	9	10
Geography										
UTM-*x* (m)[a]	730433	731351	725083	709067	720723	732470	731489	731984	683973	722515
UTM-*y* (m)	4029759	4032711	4020333	4010099	4013458	4028535	4033178	4035767	4001684	4019182
Elevation (m)	456	424	465	546	634	383	431	425	598	544
Slope gradient (%)	3	4	6	3	0	12	2	1	0	4
Soil (0-5 cm)[b]										
Texture	SL[c]	L	SL	SL	L	SL	SL	SL	L	L
pH (1:1 soil:water)	7.6	8	7.5	7.7	7.4	7.7	7.7	7.7	7.6	7.5
P (mg kg^{-1}, Olsen method)	9.6	4.0	<0.1	<0.1	<0.1	2.4	4.1	4.3	1.3	4.0
Total C (%)	1.3	1.5	1.6	4.1	3.9	2.7	1.0	1.2	3.5	1.7
Total N (%)	0.029	<0.01	<0.01	<0.01	0.038	<0.01	0.012	<0.01	<0.01	<0.01
Total S (%)	3.2	2.1	5.7	2.4	4.3	1.0	2.6	2.1	2.0	3.5
Plant density (ha^{-1} [d])										
Ambrosia dumosa	300	600	0	<20	<20	100	60	200	<20	0
Anulocaulis leiosolenus	0	0	500	0	300	<20	0	0	200	100
Arctomecon californica	100	100	<20	300	900	<20	100	500	300	200
Ephedra torreyana	20	25	100	200	100	100	200	300	100	25
Psorothamnus fremontii	500	100	600	0	200	600	400	500	200	200

[a] Universal Transverse Mercator, North American Datum, Zone 11
[b] Sampling was conducted in interspaces between perennial plants
[c] SL = sandy loam, L = loam
[d] Perennial species below which soil seed bank samples were collected

Table 64 Statistical results for the influences of microsite (five perennial plant species and interspaces), seed bank characterization method (two types of emergence and extraction) and their interaction on characteristics of soil seed bank samples of the Mojave Desert, USA

	— Species richness —			——— Density ———			– Species composition –		
Effect	*df*[a]	*F*	*p*	*Df*	*F*	*p*	*df*	*F*	*p*
Microsite	5, 47	3.3	0.013	5, 10	1.9	0.060	5, 45	1.8	0.006
Method	2, 94	58.3	<0.001	2, 104	20.7	0.001	2, 104	12.5	0.001
Microsite × method	10, 94	0.7	0.751	10, 104	1.8	0.016	10, 104	1.05	0.010

[a] Numerator, denominator degrees of freedom

Table 65 Regression parameters relating seed bank methods and vegetation in the Mojave Desert, USA.

	——— Comparing seed bank methods ———					
	Seeds/m^2			Site species richness		
	m	*B*	*r*	*m*	*b*	*r*
Emergence 1 : emergence 2	0.63	6	0.77	0.51	1	0.48
Emergence 1 : extraction	11.06	2959	0.40	0.82	7	0.42
Emergence 2 : extraction	19.62	2760	0.57	0.82	7	0.45
	– Comparing seed bank and vegetation richness –					
	Microsite scale			Site scale		
Emergence 1 : vegetation	0.74	2	0.33	0.39	9	0.14
Emergence 2 : vegetation	1.16	2	0.51	1.05	8	0.39
Extraction : vegetation	0.50	1	0.47	0.68	4	0.46
All combined: vegetation	0.49	1	0.54	0.59	4	0.50

Table 66 Comparison of individual taxa detected by three different seed bank methods and in the vegetation aboveground at 10 sites in the Mojave Desert, USA. Values are the number out of 10 sites in which a taxon was detected, except in the Rare and Total taxa categories at the bottom of the table which represent numbers of taxa. Dashes denote absences. Taxa with asterisks are exotic.

Species	Emergence 1	Emergence 2	Extraction	Vegetation
Seedbank/vegetation				
*Bromus rubens**	2	3	2	4
Phacelia palmeri	5	2	7	1
Plantago ovata	4	1	6	6
Schismus spp.*	6	5	10	5
Vulpia octoflora	4	2	7	2
Emergence/vegetation				
Dasyochloa pulchella	—	1	—	1
Mentzelia albicaulis	—	1	—	2
Extraction/vegetation				
Ambrosia dumosa	—	—	7	8
Arctomecon californica	—	—	9	9
Atriplex confertifolia	—	—	1	4
Cryptantha utahensis	—	—	1	2
Enceliopsis argophylla	—	—	4	3
Ephedra torreyana	—	—	1	10
Lepidium fremontii	—	—	1	1
Phacelia spp.	—	—	1	1
Sphaeralcea ambigua	—	—	3	2
Seedbank only				
Atriplex canescens	—	—	2	—
Atriplex elegans	—	—	2	—
Atriplex spp.	—	—	2	—
Camissonia claviformis	1	1	—	—
Chenopodium spp.	—	—	2	—
Cryptantha holoptera	—	1	2	—
Lesquerella tenella	—	—	2	—
*Malcolmia africana**	1	—	1	—
Mentzelia pterosperma	—	—	3	—
Mimulus spp.	—	—	4	—
Phacelia pulchella	1	—	9	—
Typha spp.	9	9	8	—
Vegetation only				
Anulocaulis leiosolenus	—	—	—	5
Camissonia multijuga	—	—	—	3
Cryptantha nevadensis	—	—	—	3
Eriogonum inflatum	—	—	—	6
Eriogonum maculatum	—	—	—	2
Phacelia crenulata	—	—	—	2
Plantago patagonica	—	—	—	2
Psorothamnus fremontii	—	—	—	10
Rare				
Various species	4 species	6 species	5 species	14 species
Total taxa	13	15	28	38

Table 67 Relationships of species composition between seed bank methods and vegetation aboveground at microsite (five perennial plant species and interspaces) and site scales (all microsites combined) in the Mojave Desert, USA. Values are *r* (*P* value) from Mantel tests.

Seed bank method	Microsite scale	Site scale
Emergence 1	0.14 (0.227)	-0.15 (0.764)
Emergence 2	-0.01 (0.400)	-0.20 (0.846)
Extraction	**0.19 (0.003)**	0.18 (0.167)
All combined	**0.22 (0.002)**	**0.43 (0.005)**

All combined represents the cumulative seed bank composition from all methods.

Table 68 Principle component analysis (PCA) results for the 10 Las Vegas bearpoppy sites in the Mojave Desert, USA, soil and site variables for a 2-dimensional solution. Eigenvectors, scaled to unit length, are coordinates used for a distance-based biplot, where the distances among objects approximately their Euclidean distances. Correlation coefficients between scores for rows in the main matrix and the volume variables are the same as the PCA of a correlation matrix with Eigenvectors each scaled to its standard deviation. The coefficient of determination of site and soil variables represents the degree to which each variable explains plot distribution.

Site or soil		Eigenvectors		Coefficient of determination	
variable	axis	1	2	1	2
Elevation (m)		-0.0293	0.4479	0.008	0.875
% Total C		-0.0114	0.3939	0.001	0.677
% Al		0.3178	-0.0432	0.915	0.008
% Fe		0.3241	0.0402	0.952	0.007
% K		0.3026	-0.059	0.829	0.015
Mn (mg/kg)		0.3167	0.0468	0.909	0.010

Table 69 Native perennial plant species mean cover (with standard error) across all microsites and all of the 10 Las Vegas bearpoppy sites in the Mohave Desert, USA.

Nativity	Growth Form	Species	Mean % Cover	SE
Native			2.80	
	Forb		0.81	
		Amsonia tomentosa	0.04	0.14
		Anulocaulis leiosolenus	1.66	3.22
		Arctomecon californica	2.98	2.39
		Enceliopsis argophylla	0.19	0.39
		Sphaeralcea ambigua	0.01	0.02
	Grass		0.01	
		Dasyochloa pulchella	0.01	0.03
	Shrub		5.00	
		Ambrosia dumosa	11.93	8.25
		Atriplex confertifolia	0.68	0.97
		Atriplex hymenelytra	0.25	0.79
		Ephedra nevedensis	22.93	10.60
		Gutierrezia sarothrae	0.05	0.16
		Lepidium fremontii	0.25	0.79
		Psorothamnus fremontii	18.54	8.60
		Salazaria mexicana	0.25	0.79

Table 70 Native and non-native annual species mean % cover across all microsites and all of the 10 Las Vegas bearpoppy sites in the Mojave Desert, USA.

Nativity	Growth Form	Species	Mean % Cover	SE
Native			0.11	
	Forb		0.05	
		Unidentified	0.01	0.01
		Camissonia brevipes	<0.01	<0.01
		Camissonia multijuga	0.03	0.09
		Chaenactis fremontii	<0.01	0.01
		Chorizanthe rigida	<0.01	0.01
		Cryptantha nevadensis	0.06	0.16
		Cryptantha spp.	<0.01	0.01
		Cryptantha recurvata	0.01	0.02
		Cryptantha utahensi	0.06	0.16
		Eriogonum inflatum	0.69	1.87
		Eriogonum maculatum	0.01	0.03
		Eriogonum spp.	<0.01	0.01
		Eriogonum pusillum	<0.01	<0.01
		Eriogonum trichopes	0.24	0.72
		Eucrypta micrantha	<0.01	0.01
		Mentzelia albicaulis	0.01	0.02
		Phacelia crenulata	<0.01	0.01
		Phacelia pulchella	<0.01	0.01
		Phacelia palmeri	<0.01	<0.01
		Plantago ovate	0.16	0.40
		Plantago patagonica	<0.01	<0.01
	Grass		0.06	
		Unidentified	0.05	0.02
		Vulpia octoflora	0.01	0.01
Non-Native			0.08	
	Grass		0.08	
		Bromus rubens	0.05	0.16
		Schismus spp	0.03	0.06

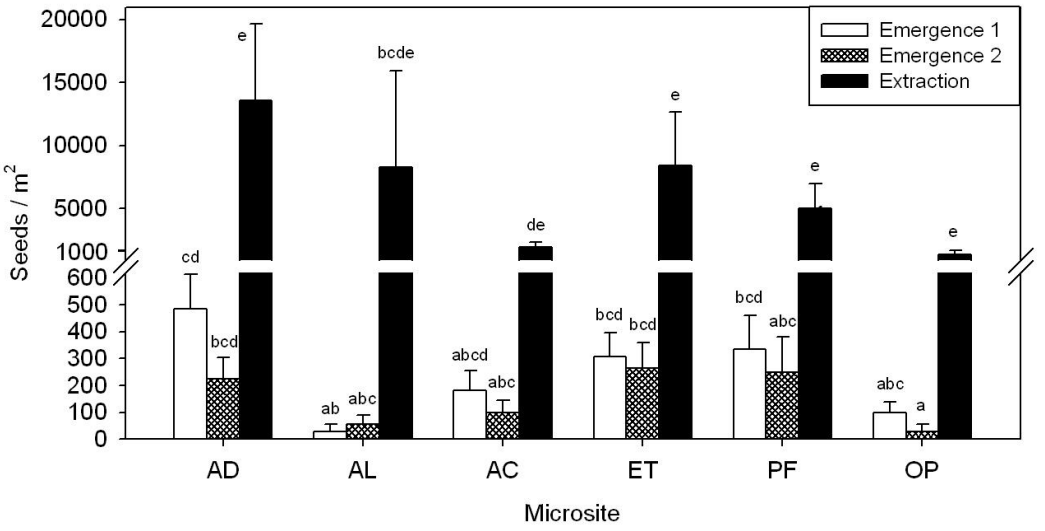


Figure 63 Mean seed density by seed bank characterization method and sampling microsite in the Mojave Desert, USA. Means without shared letters differ at $P < 0.05$ and error bars are standard errors of means. Microsites include interspace (OP, openings between perennial plants) and below the canopy of the perennial plants *Ambrosia dumosa* (AD), *Anulocaulis leiosolenus* (AL), *Arctomecon californica* (AC), *Ephedra torreyana* (ET), and *Psorothamnus fremontii* (PS).

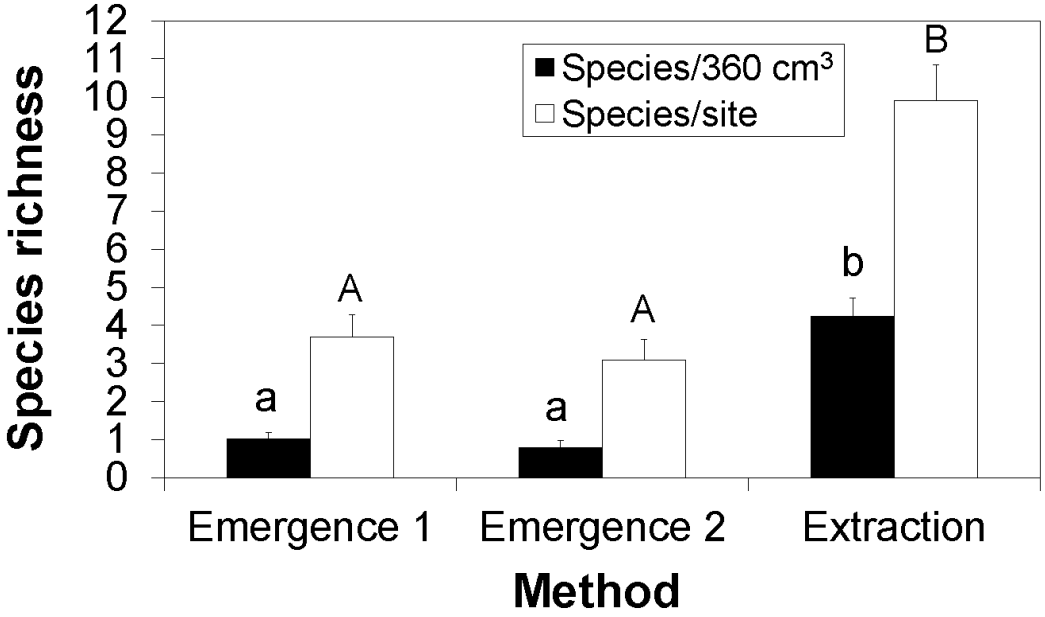


Figure 64 Mean species richness at two scales compared across characterization method for soil seed banks of the Mojave Desert, USA. Means within a scale (differentiated by uppercase and lowercase letters) without shared letters differ at $P < 0.05$. Error bars are standard errors of means.

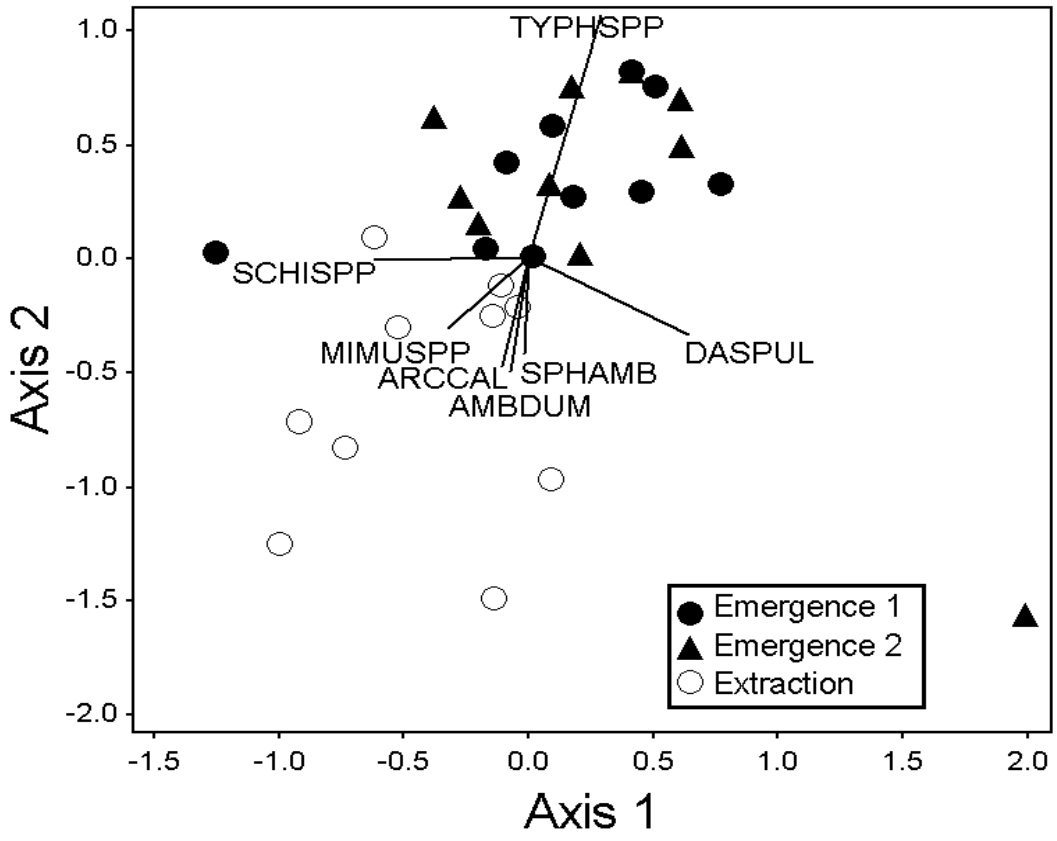


Figure 65 Nonmetric multidimensional scaling ordination of species composition (relative seed density) among seed bank characterization methods for the Mojave Desert, USA. Vectors display species that have correlations (r2) ≥ 0.25 and are abbreviated as: AMBDUM, *Ambrosia dumosa*; ARCCAL, *Arctomecon californica*; DASPUL, *Dasyochloa pulchella*; MIMUSPP, *Mimulus* spp.; SCHISPP, *Schismus* spp.; SPHAMB, *Sphaeralcea ambigua*; and TYPHSPP, *Typha* spp.

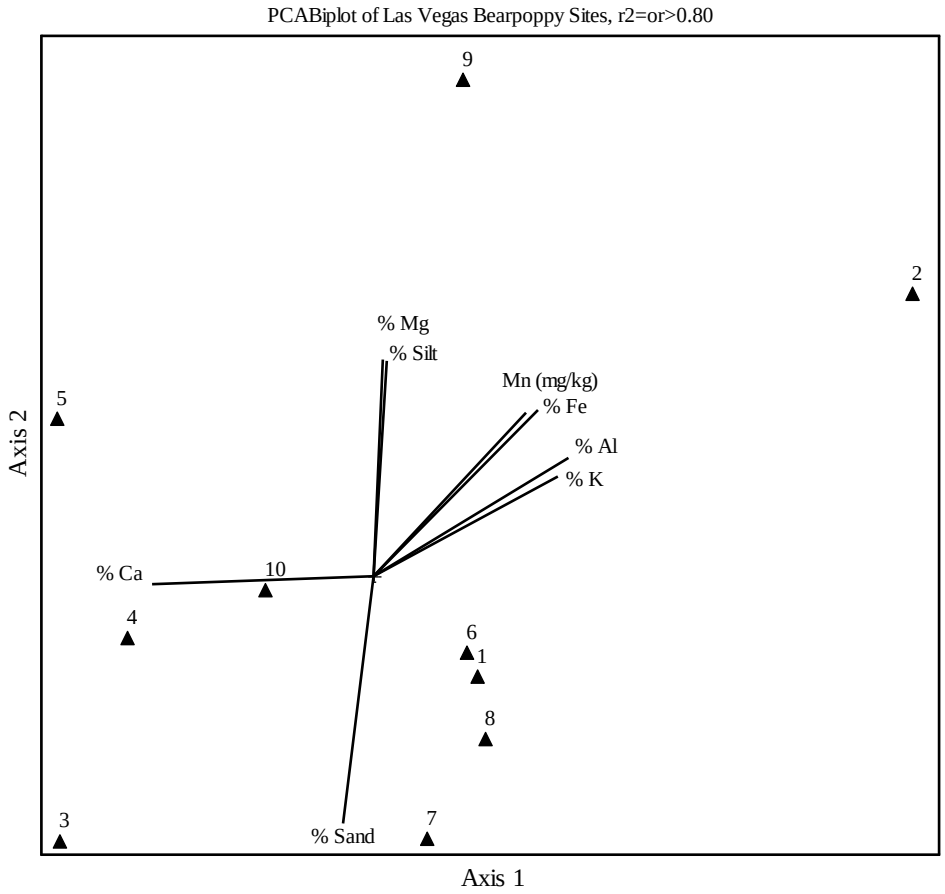


Figure 66 Principle component analysis ordination (PCA) biplot of the site and soil variables from the 10 Las Vegas bearpoppy sites in the Mojave Desert, USA. Vectors display site and soil variables that have $r^2 \geq 0.80$ with axes.

Part 3. *Las Vegas Bearpoppy Seed Germination Trials*



Las Vegas bearpoppy flower (right), seedling (left) and seeds (front) from Lake Mead National Recreation Area, Mojave Desert, USA. Photo credit: Lindsay Chiquoine, University of Nevada, Las Vegas.

Contributed by Lindsay P. Chiquoine and Heidi McMaster (undergraduate), University of Nevada, Las Vegas.

Project Purpose

Augmenting the current Las Vegas bearpoppy populations is a management concern. Efforts to increase the population through restoration activities have been largely unsuccessful (Science Applications International Corporation 2001), and plant salvage of this species (Winkel 2004) remains difficult. The purpose of this project was to examine different seed treatments to force germinate bearpoppy seed.

Introduction

Populations appear to be reliant on long-lived seed banks, and large germination events occur after adequate precipitation (Meyer 1986; 1996), causing fluctuations in adult plant populations. Megill et al. (2011) found that in a North Vegas population, 60% of the poppy seed found were in the top 2 cm of soil and 40% in 2-4 cm. Only 33.3% of the seed was viable (tested by 2, 3, 5-triphenyl tetrazolium chloride solution), resulting in 0.651 viable seed/m^2 (Megill et al 2011).

Previous attempts have occurred to try to force germinate bearpoppy. Meyer (1996) exposed dry stored seed for varying periods of time to intermediate-high temperatures, followed by moist chilling treatments and subsequently incubated at moderately cool temperatures, which resulted in an 11% germination success. Nevada Division of Forestry, with seeds collected from 2003-2005 from Bureau of Land Management,

found that with a half a minute soak in high concentration of sulfuric acid had a minimal germination (Amy Dunn, Las Vegas Nursery Manager, personal communication December 2012). However, seedlings did not survive over 3 months. Currently, there have been no successful seed germinations with transplant recorded to date (based on available data). Song (2001) completed a seed germination study in 2001 and according to his preliminary report to NPS, only 25% of the seeds germinated which is more than any other test. However, transplant of the seeds from petri dishes with germination paper to native soils resulted in 100% mortality rate (Song 2001).

This section includes a summary of the seed germination testing done at the University of Nevada, Las Vegas, and in field sites in LMNRA in soils that are known to support bearpoppy populations, however are not currently inhabited by bearpoppy. The intention of these laboratory and field tests were to identify and test different treatments on the seed (e.g., watering, protecting seeds from predation using cages, soaking in gibberellic acid or water, scarification) to germinate bearpoppy for propagation in the laboratory and field setting.

METHODS

Field Study

For current populations of bearpoppy in the Park as spring 2010, populations were visited in May and June 2010. From 10 sites with adequate populations (>10 estimated seed producing plants per 100-m^2 area) 10 individuals were selected for seed collection. Approximately 50-100 seeds were collected per individual. Seeds were composited per site and be used for environmentally controlled study and field germination studies. Sites and dates of collection were recorded for each composite sample and samples. Additionally, we requested to use bearpoppy seeds collected LMNRA staff from 2008 and 2009.

Field studies were conducted along closed RD 108 in the Park to control for soil variables, such as soil components, except those variables influenced by disturbance. Along the closed road, the first 250-m segment was ripped. Along this segment, 5 sites were randomly selected to include in testing seed germination under field conditions. In each selected ripped road segment a 30 m long by 3 m wide site was established and was paired with the same size site in an undisturbed area parallel to the road segment and 10 m from the edge of the disturbed roadbed. Within each sampling unit, 7 randomly placed subplots were established which included different seed treatments with 12 seeds/subplot: (1) soaking in water only for 24 hours, (2) soaking in 1000 ppm gibberillic acid solution for 24 hours, (3) scarifying only, (4) scarifying then soaking in water only for 24 hours, (5) scarifying and soaking in 1000 ppm gibberillic acid solution for 24 hours, (6) no treatment, and (7) no seeding. From the 2010 seeds, 200 seeds/site were composited to ensure a random sample for seed germination treatments. The 2010 seeds used for the field study were kept in paper envelopes and covered and placed in the *Percival* model GL-36VL Intellus Environmental Controller set on a diurnal setting with night/day temperatures at 15°C/25°C for 3 months until site establishment in October of 2010. Each subplot was enclosed by a 0.5 m high chicken wire cage.

Laboratory

Laboratory tests were conducted between July 2010 and July 2011. The environmentally controlled aspect included a combination of treatments using 21 seeds and 5 replicates per treatment type for the three years of bearpoppy seeds (3 rounds). Treatments include: (1) soaking in water only for 24 hours, (2) soaking in 1000 ppm gibberillic acid solution for 24 hours, (3) scarifying only, (4) scarifying then soaking in water only for 24 hours, (5) scarifying and soaking in 1000 ppm gibberillic acid solution for 24 hours, prior to planting individual seeds in its own 1.5-cm-radius cell on a tray with a 7 x 15 cell arrangement. Soaking took place overnight in petri dishes at room temperature in the laboratory. Scarifying involved gently rubbing seeds between fine sandpaper sheets to mimic seed scaring in soils. From the 2010 seeds, 100 seeds/site were composited to ensure a random sample for seed germination treatments. Five replicates of 21 seeds each were dry sown directly into soil as a control. Since bearpoppy is found mostly in gypsum-dominated soils, we used salvaged topsoil from topsoil stockpiles at the Northshore Rd realignment locations after asking permission of the Park Vegetation Manager. Soils were homogenized for 20 minutes in a cement mixer then autoclaved at the UNLV laboratory. Flats were placed in a *Percival* model GL-36VL Intellus Environmental Controller (Percival Scientific, Inc. Perry, IA) with a light irradiance at 80 μmol m^{-2} s^{-1} and set on a diurnal setting with night/day temperatures at 15°C/25°C for 8 weeks each run and rotated every two days in the environmental controller. All flats were gently watered to maintain a constant moist soil environment. This method was repeated a second time for 2010 seeds.

Additionally, for 2010 seeds temperature stratification pre-treatment was conducted on an additional set of seeds with the same water, gibberellic acid, and scarification combination treatments already described. The 2010 seeds were either placed in the cold at a mean temperature of 4°C for 4 days then in the oven at 35°C for 4 days prior to seed treatment or placed in the cold at a mean temperature of 4°C for 8 days then in the oven at 35°C for 8 days prior to seed treatment. Prior to these treatments, seeds were kept dry and in a sealed container in the environmental controller on a diurnal setting with night/day temperatures at 15°C/25°C.

RESULTS

Laboratory and Field Seed Germination Test

For all of the 6 germination tests run on the 2008, 2009, and 2010 poppy seeds collections, no seeds had evidence of germination. As of fall 2012, there was no evidence of emergence in any of the field sites. Continued monitoring of field sites is recommended since germination requirements of bearpoppy are unknown and because of the seasonal variability in precipitation since the field study establishment.

Part 4. *An Examination of Las Vegas Bearpoppy Population Dynamics: Fluctuations in precipitation*



Contributed by Heidi A. McMaster, Bachelor of Arts, University of Nevada, Las Vegas (2010)

Project Purpose

Starting in 1998, the contracted botanist for NPS, LMNRA conducted partial surveys on the bearpoppy population as a preliminary assessment of its range and density. The final report concluded that the bearpoppy appears to remain present at some sites over many years with the potential to disappear and reappear at several sites (Bangle 2005). This phenomenon may be linked to incidental precipitation (Mistretta et al. 1996), the dormancy of populations (Bangle 2005), the fluctuation of the presence pollinators (Tepedino and Hickerson 1996), and the intensity of impacts, if present. Years of sufficient rainfall are required for the establishment of bearpoppy seedlings (Meyer 1986; Bangle 2005). The seeds of the bearpoppy can remain dormant for at least three years or longer (Bangle 2005), remaining dormant until adequate soil moisture is achieved. Since the poppy flowers require cross-pollination to produce fruits and seeds, pollinators are required (Tepedino and Hickerson 1996), and long, active populations may be important for the survival of pollinators (Powell 1999). Pollinators are much higher in un-fragmented sites in LMNRA, than in fragmented sites in Las Vegas Valley (Tepedino and Hickerson 1996). In areas that are currently considered feasible habitat in LMNRA, the presence of required pollinators is unknown, but some information may be supplied by an invertebrate assessment sponsored by LMNRA. Monitoring data of *A. californica* was obtained from LMNRA to develop a possible correlation between recorded annual precipitation and yearly population fluctuations between the years 1998 and 2005. Regression analysis was used to test whether the bearpoppy populations are

significantly related to annual precipitation. Results of the regression analysis suggest there significant relationship between annual precipitation as well as lag precipitation.

ABTRACT

Las Vegas Bearpoppy (*Artomecon californica*) is a rare plant species found only in the Mojave Desert, specifically to the Southeast Clark County and Northwest Arizona area around Lake Mead National Recreation Area (LMNRA) and Las Vegas. National Park Service data from the LMNRA monitoring of *A. californica* was used to develop a possible correlation between recorded annual precipitation and yearly population fluctuations between the years 1998 and 2005. The regression analysis is used to test whether the bearpoppy populations are related significantly to annual precipitation. Results of the regression analysis validated the alternative hypothesis showing there is a significant relationship between annual precipitation as well as lag precipitation.

INTRODUCTION

There are three distinct species in the *Papaveraceae* (Poppy) family, genus *Arctomecon*: *A. californica* (Yellow Bear Poppy), *A. humilis Coville* (Dwarf Bear Claw Poppy) and *A. merriamii Coville* (Great Bear Poppy) (Thompson et al 1997). Not many studies have been completed on *A. californica* but recent studies have focused on understanding this disappearing perennial desert wildflower. The State of Nevada currently lists *A. californica* as Critically Endangered, and is also a

Physical Characteristics

Category 2 species under review with the Federal government (Sheldon 1994). *A. californica*, first described by John C. Fremont in 1887 (Mistretta et al. 1996), has had very little research done on specific characteristics associated with population dynamics and seed germination. This species was described and categorized when southern Nevada was still a part of California, however, no populations of *A. californica* are found in California.

Not much is understood about the relationship between annual precipitation and annual population variations. Data suggest that such volatile cycles are primarily the result of a relatively short life span (individuals surviving the first year may be expected to live an average of 4-5 years) coupled with irregular occurrence of germination events (Thompson et al. 1997). The first year is strictly a vegetative growth period and if there is adequate rainfall in that year, the next year yields flowers (Thompson et al. 1997). Years with sufficient winter rainfall to assure significant establishment of the seedlings may occur up to nine years apart (Mistretta et al. 1996). Hence the species appears to rely on high reproductive output and the maintenance of a large reservoir of long lived seed in the soil in order to persist including annual replenishment of the seed bank (Mistretta et al. 1996, Sheldon et al. 1997). Data collected by the NPS at LMNRA and annual precipitation recordings by the National Weather Service, may assist to elucidate the relationship between precipitation and yearly fluctuations of *A. californica* populations and the role it plays in seed germination.

Arctomecon californica is a short lived perennial forb (wildflower) with a basal

rosette of leaves that have long shaggy white hairs. Each rosette produces a single flowering stem with multiple flowers per stem (Sheldon 1994). The plant has a taproot that grows down into heavy clay horizons where water moisture is retained at greater levels than the sandy surface layer (Mistretta et al. 1996). Below the sandy layer toward the surface, the spring deposit offers a water barrier that could assist with retaining water closer to the surface during the winter and spring months (Drohan and Merkler 2009).

The plants produce bright yellow flowers yearly between March and June making this plant a beautiful addition in the Mojave Desert. The flowers produce a fruit capsule between May and June containing roughly 100 seeds. The seeds are shiny black and tiny, which are then windblown and mechanically dispersed roughly 2 feet from the parent plant (Sheldon 1994). First year seedlings found in early spring do not flower the first year of growth as mentioned previously. Buds that mature earlier in the season have a lower abort rate than those that mature later in the season (Thompson et al. 1997). Arctomecon habitat sites are dominated by perennial forbs whereas non habitat sites are primarily shrubs and grasses. Thompson observed fewer vascular plants on habitat versus non habitat (Thompson et al. 1997). Vegetation is similar at all *A. californica* sites, even at great distances apart (Thompson et al. 1997), which could indicate a niche in the ecology that the plant has adapted to resulting in the belief of plant endemism to gypsum (Drohan and Merkler 2009).

Distribution

This species is found to occur in southeastern Nevada and northwest Arizona; from Temple Bar in LMNRA to the Grand Canyon (Phillips and Phillips 1988) in Arizona; and Las Vegas north to Apex to areas near Gold Butte. This geographical area is within the Mojave Desert which has temperature extremes from -5°C (23°F) to 49°C (120.2°F) (Thompson et al 1997). The surveyed populations have been found to occur at elevations between 1060 and 3150 feet (Mistretta et al. 1996). Most surveys have concluded *A. californica* to be a gypsophile; only living in soils with 36 percent to 69 percent gypsum (Mistretta 1996). However, Meyer (1986) considered that *A. californica* may occur on other substrates but primarily occurs in gypsum; a gypsocline. Powell (2003) also supports the theory that populations may occur on other soil types, but found primarily in gypsum. Research conducted by Drohan and Merkler (2009) suggested further that *A. californica* may be a gypsovag (species that occurs in or outside of the gypsum habitat). Limited research has shown that high levels of sodium and sulfur typify the species habitat (Sheldon 1994). A hypothesis also offered in 1976 by Parsons suggested that sulfur may be a factor in establishment and overall success of species on gypsum soils (Parsons 1976). It is unknown whether other minerals found in the soils may be better indicators for possible poppy habitat. A study conducted by Sheila Thompson Sheldon showed higher levels of sulfur, calcium and salts in the areas where *A. californica* populations are located, than areas that do not have *A. californica* populations (Thompson et al. 1997). The last major review of the species showed a global population of

approximately 830,000 plants in 39,500 acres divided by 99 populations 91 in east-central Clark County and eight in adjacent northwestern Mojave County (Mistretta et al. 1996). The survey by Mistretta et al. (1996) also anticipates the true total population was no more than 25% larger than originally documented.

Populations are currently located on BLM, NPS, State of Nevada, County and private lands. Locations within Las Vegas city limits are at the Las Vegas Valley Water District, North Las Vegas Airport, and Nellis Air Force Base. The Las Vegas bearpoppy (*Arctomecon californica*) Habitat Management Plan states 45,750 acres for conservation on BLM land, which contains 80% of poppy surveyed on BLM land and over 95% of the richest populations (BLM-unpublished 1998). The map in Figure 67 shows the locations of where the extirpated sites are located as well as current surviving locations (Clark County information only; Nevada Natural Heritage Program 2000).

Problems with Habitat

Current contributors to habitat destruction and population declines of *A. californica* include development on gypsum outcrops, dumping and off-road vehicle use, construction of utility lines, mining (particularly gypsum mining), habitat degradation from livestock and feral horse and burro, and specimen collecting. Pollinators, which include species of bees and beetles, are also seen as a problem since developed areas see fewer pollinators due to habitat fragmentation, which influences the number of seeds produced. This is supported by a study conducted by Thompson et al. (1997), indicating plants that relied on self pollination only had significantly less seeds and had more seeds aborted prior to maturation. Habitat fragmentation of the western populations is causing genetic diversity loss which could pose a long term threat of extinction (Mistretta et al. 1996). *A. californica* has shown, through preliminary breeding studies, that it depends on insect pollinators for successful reproduction and pollinator effectiveness has been significantly impacted in at least one Las Vegas valley site (Mistretta et al. 1996). Specific studies on specific insect pollinators have not been completed and therefore, more detailed information regarding pollination of the Las Vegas bearpoppy is unavailable.

HYPOTHESIS

H_o: Precipitation has no effect on mean living and flowering plants.

H_a: Precipitation has a positive effect on mean living and flowering plants.

METHODS

Raw data collected by the NPS at LMNRA was put into a spreadsheet (59 total observations). The data reflects monitoring efforts at permanent transect locations at Bitter Springs, Blue Point Springs, Calville Wash, Road 100, Rainbow Gardens, North Las Vegas Airport, Sunrise Hills, and Stewarts Point (not shown on map) (Figure 68). The monitoring years were 1998 through 2005 with incomplete data for the 2005 year. Each site had population numbers for each year of the monitoring. Stewarts Point was added to the monitoring study in 2003; there were only 3 years of monitoring data for that location. In addition to the data supplied by LMNRA, precipitation data was taken from the

National Weather Service in order to test the hypothesis that precipitation has a positive effect on the number of living and flowering plants. A regression analysis will test any possible significance between the observations collected and the precipitation data.

RESULTS

The mean precipitation for the monitoring period (1998-2005) was 13.64 cm. This is consistent with Las Vegas average precipitation values. The mean number of living individual plants for all monitoring sites was 63.19 individuals. The mean number of flowering plants was 9.68 individuals. On average, there was twice as many individuals within size class 1 (0-5 cm) than any other size class category. Regression results show that both lag precipitation ($P = 0.0091$) and same-year precipitation ($P = 0.0466$) were significant for predicting whether of plant was alive or dead within a population; however, the number of living plants was dependent on lag precipitation more, which reflects the increase in the number of living plants seen the following spring (Figure 69). The years 2003, 2004 and 2005 had above average precipitation resulting in a significant growth in bearpoppy populations at all monitoring locations. Flowering was a significant predictor of individuals falling into size classes categories 2 through 6; however, the classes were not distinguished (Table 71). Figure 70 enhances the observation that precipitation is related to population. This rejects the null hypothesis. Figure 70 reports an unanticipated result showing that the size of the bearpoppy plant is related to the number of flowering plants. Size class 1 (0-5 cm) do not flower, therefore, years of significantly higher size class 1 have smaller amounts of plants that are flowering.

DISCUSSION

The Size class 1 being twice as large as any other Size class category supports the observation by Thompson et al. (1997) that the seedling phase of growth is the most critical in survivability and also has the greatest mortality rate (60-87%). Also a significant observation is the fact that the previous year precipitation directly affects the next spring's population numbers. Years with continually above average rainfall exhibit positive plant recruitment year to year. This supports the fact that seeds drop in the summer and hold in the soil through a hot dry period and then a cold wet period to emerge in the early spring of the next year. Thompson et al. (1997) also observed that the older plants had greater reproduction potential loss and seed abortion which can also explain population fluctuation observed by the NPS. The years with high numbers of older plants may have reached the end of their life cycle and the use of the seeds of the seed bank to replenish populations was needed but this relies on annual precipitation to stimulate germination. Habitat degradation and loss affects the ability of plants to cross pollinate, due to the island effect (Hickerson et al. 1998). This supports observation of population within the Las Vegas valley that have seen continued decline in populations. Fewer plants to cross pollinate with means they are restricted to self-pollination which yields the highest abort rate and fewest seed production.

Pollinators could be a significant variable in correlating between high flowering years and subsequent years with high plant recruitment. Declining numbers of

pollinators negatively affect plant reproduction and recent studies have shown that the species is not reaching its full potential, making it susceptible to anthropogenic disturbance (Childers 2004). However, since this variable was not observed during the monitoring study conducted by LMNRA, fluctuations in data may not be explained with the limited observations.

Another issue involved, raising questions about particular site recruitment being higher or lower than another, is soil characteristics. It is not known what specific soil chemistry and composition exists at each site of transect monitoring locations. The only known factor of each site being considered gypsum is the Clark County Soil Survey conducted in 2006. Soil horizons are unknown across the transect locations. A study conducted by Childers (2004) indicated some *A. californica* numbers to be located on Limestone deposits. Future studies could benefit from knowing specific soil horizon details to ensure that these factors do not limit or enhance populations in these areas. Areas with cryptogamic crusts have shown to increase nutrient levels at the surface as well as protect against wind erosion (Harper et al. 1993). Transect location with higher disturbance or lower cryptogamic crusts may have influences in population numbers but is outside the scope of this report. In a contrasting report by Meyer et al. (1992), gypsum areas with high crust area could inhibit germination and overall plant establishment. Areas with lower crust cover or at least weaker crust formation were seen to have higher populations of *A. californica* (Saxena 2005). This could indicate that some crust formation is important for nutrient retention but an over abundance of crusts could inhibit growth. Further research of these factors could provide a more in depth knowledge about how cryptogamic crusts factor into *A. californica* population dynamics.

Suggestions for further population surveys should include a detailed soil analysis of each monitoring location as well as pollinator observations being recorded if possible. It is recommended that a percent cover of cryptogamic crust be observed in order to test for variances in populations based on crust population. These variables may help explain some of the population changes over long periods of time and could be a better predictor of future population changes.

CONCLUSION

Studies which have had germination have had 0% success in transplant, indicating other aspects should be considered when attempting germination of the seeds. A protocol to ensure survival of any germinated seeds needs to be developed. Song (2001) suggests that one such protocol might be to place the pots in a shallow saucer of water to keep the top layer of soil very moist. All of the early-germinated seeds planted in a sand layer over the greenhouse mix died (Song 2001).

It is difficult to determine which soil types *A. californica* may grow in since recent studies have shown the plant to not be a gypsophile but possibly a gypsocline or gypsovag. The current soil survey maps are not detailed enough to make any comparisons (Powell 2003). More detailed soil analyses should be carried out in years with high populations to better understand

how soil characteristics influence where *A. californica* occurs.

Climate, parent material, and topography all interact to determine species distribution (Kruckeburg 1991). Areas where no *A. californica* species are located but have potential habitat could be an indicator of future population sites or previously inhabited sites (Thompson et al. 1997). Current areas for habitat protection by the BLM do not expressly account for possible future population sites; therefore, these areas should be included in future protected areas (Thompson et al. 1997). Expanding the protected area is necessary since the normal measures of revegetation are not viable at this time.

The climate of the Mojave Desert indicates there are freezing and heat stresses that the seeds are exposed to which could be possible determinants of seed germination each year (Thompson et al. 1997). Further investigation into climate variables is needed to test for more specific conditions that the seeds germinate under. While this report provided some significant results regarding precipitation relationships, it also provides areas of further investigation that may help future germination studies be more successful. Recommendation is the interim include public education about this species in order to reduce the amount of plants taken from the native habitats; fencing off current habitat where possible in order to keep mammals from trampling or otherwise disturbing the habitat; increase efforts of study so revegetation techniques may be used to assist conservation efforts; and also continue mitigation efforts by mining and construction prospectors to reduce the amount of land disturbed by these activities. With habitat decline, species must be restricted in growth possibilities and is species isolation from each other which affects dispersal and species richness over time (Hickerson et al. 1998). Each of these could assist scientists and other government officials in maintaining current populations while also studying how to supplement efforts of population restoring to a non-critical level, reducing the need to place the species on the Endangered Species list.

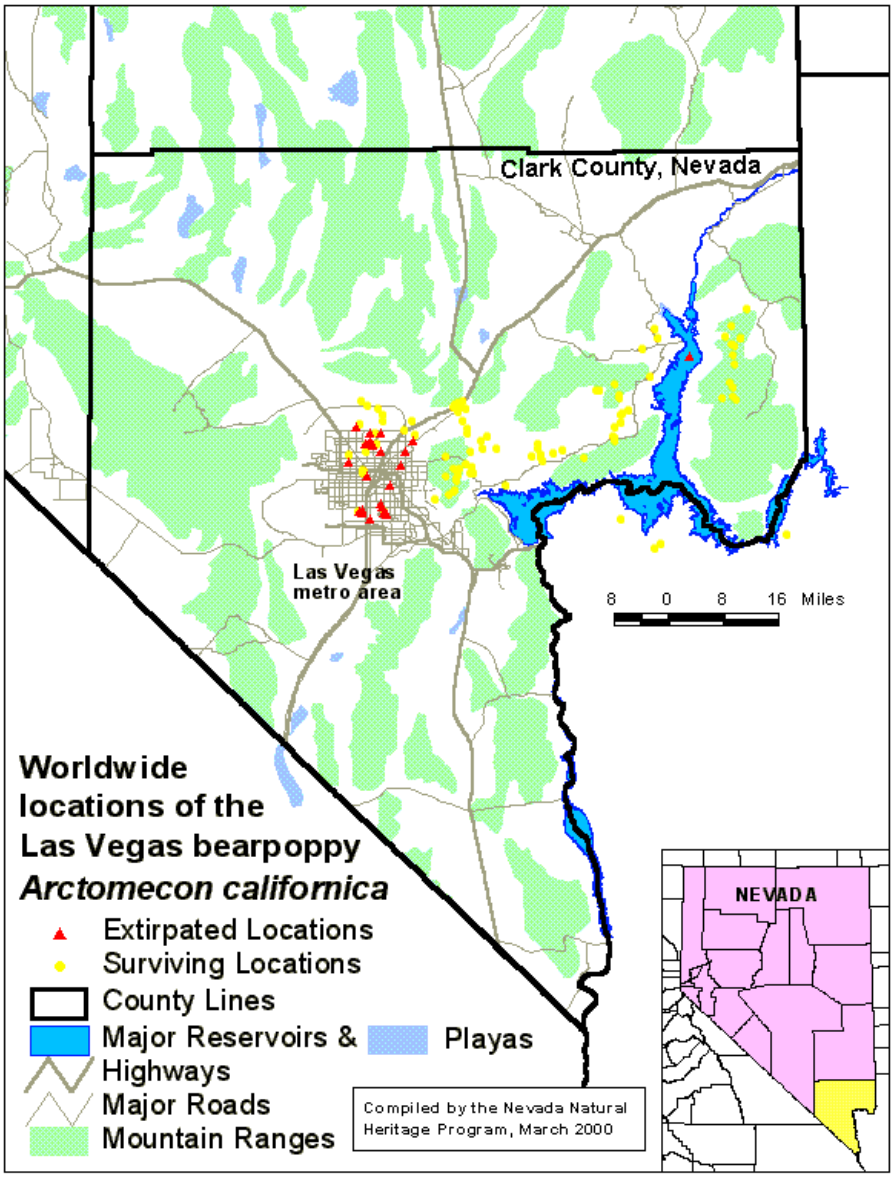


Figure 67 Locations of the Las Vegas bearpoppy *Arctomecon californica* in southern Nevada; Natural Heritage Program, March 2000.

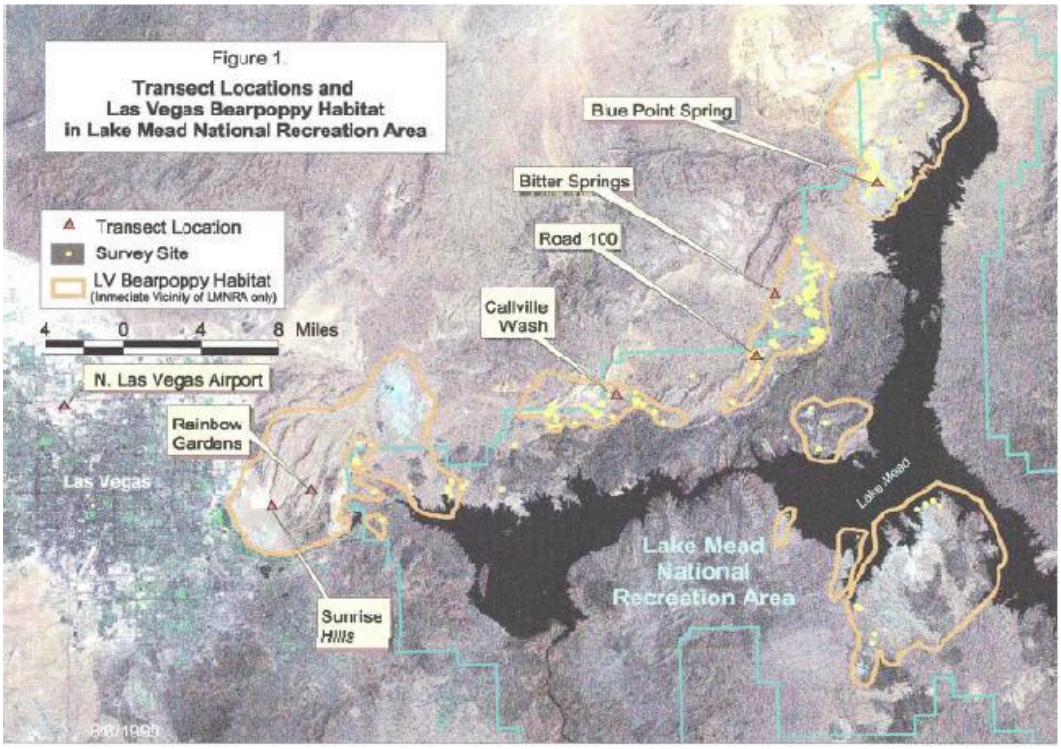
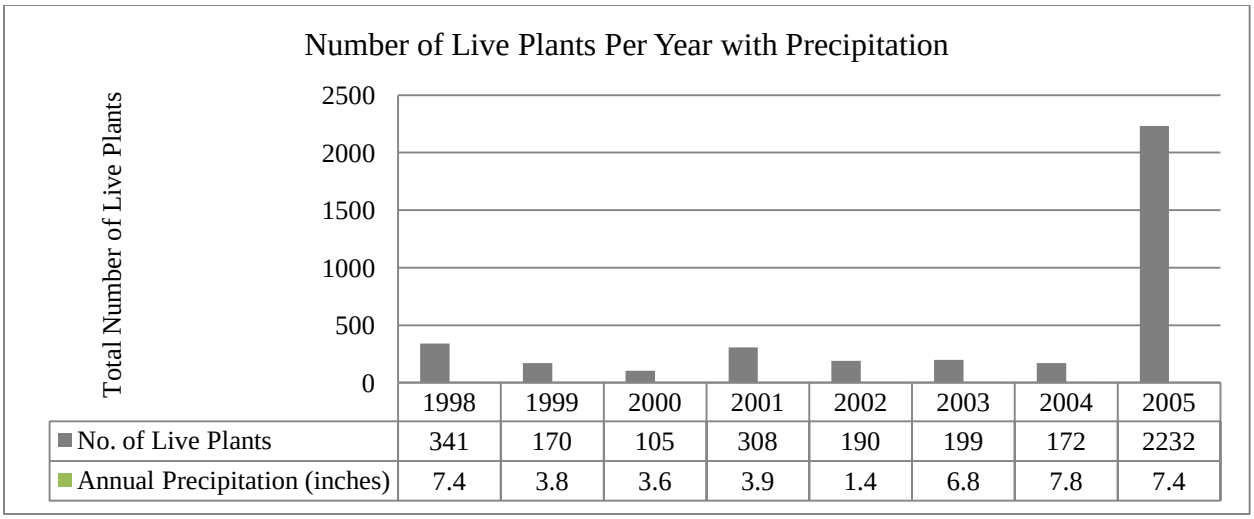


Figure 68 Transect locations and Las Vegas bearpoppy habitat in Lake Mead National Recreation Area and on Bureau of Land Management-administered lands (Bangle 2005). Stewarts Point site (established 2003) is not shown but is located to the northeast of Blue Point Spring.

Table 71 Significant variables estimating phenological stage of bearpoppy in the eastern Mojave Desert.

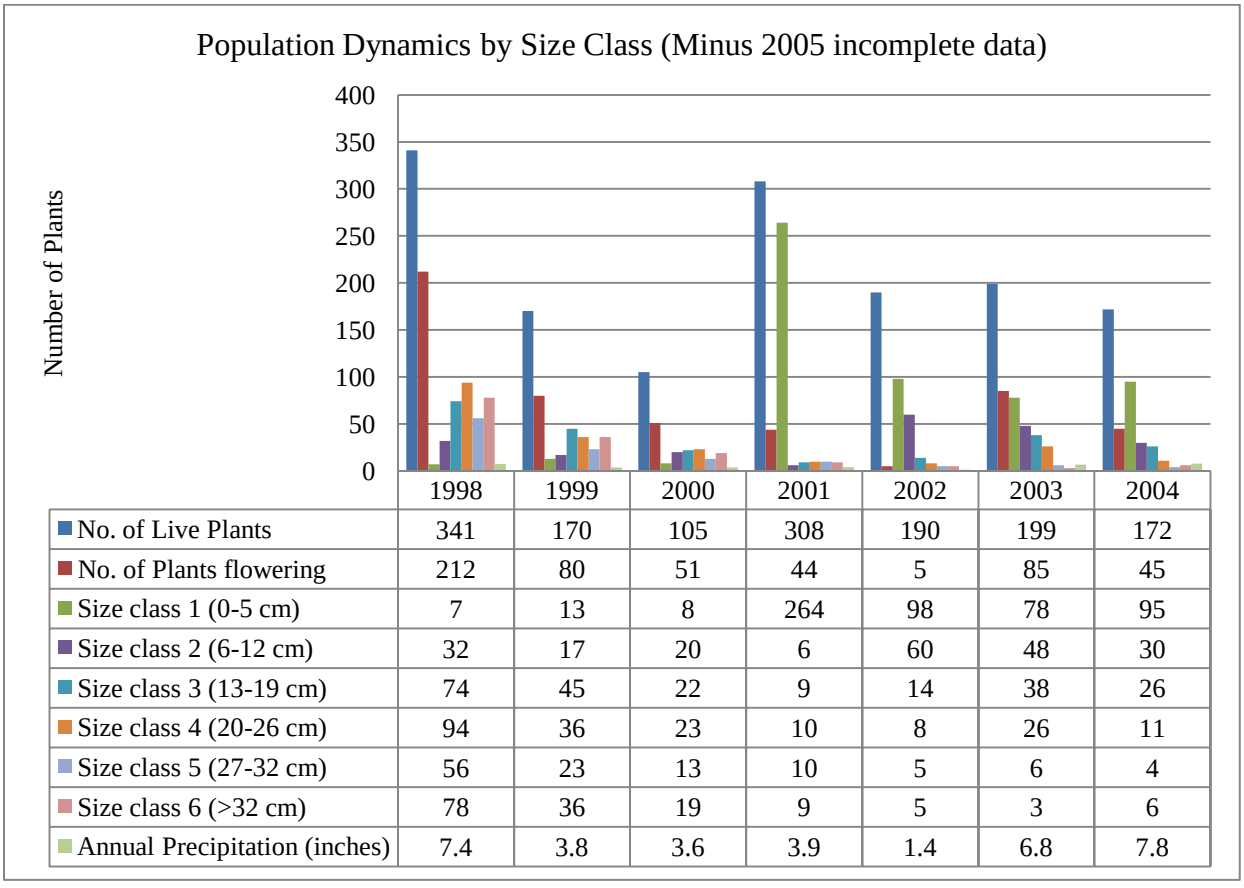
Regression Analysis Summary

Live/Dead or Phenology stage	Predictor	Estimate	SE	*t* value	Pr > |t|
Living	Lag Precipitation	21.24811	7.85645	2.7	0.0091
	Precipitation	16.57234	8.13901	2.04	0.0466
Size 2	Flowering	0.14267	0.06417	2.22	0.031
Size 3	Flowering	0.24208	0.05342	4.53	<.0001
Size 4	Flowering	0.23422	0.05037	4.65	<.0001
Size 5	Flowering	0.08781	0.03487	2.52	0.0152
Size 6	Flowering	0.14857	0.05548	2.68	0.0102



	1998	1999	2000	2001	2002	2003	2004	2005
No. of Live Plants	341	170	105	308	190	199	172	2232
Annual Precipitation (inches)	7.4	3.8	3.6	3.9	1.4	6.8	7.8	7.4

Figure 69 Relationship between annual precipitation and number of living bearpoppy indivudals plants from 1998 – 2005, eastern Mojave Desert.



	1998	1999	2000	2001	2002	2003	2004
No. of Live Plants	341	170	105	308	190	199	172
No. of Plants flowering	212	80	51	44	5	85	45
Size class 1 (0-5 cm)	7	13	8	264	98	78	95
Size class 2 (6-12 cm)	32	17	20	6	60	48	30
Size class 3 (13-19 cm)	74	45	22	9	14	38	26
Size class 4 (20-26 cm)	94	36	23	10	8	26	11
Size class 5 (27-32 cm)	56	23	13	10	5	6	4
Size class 6 (>32 cm)	78	36	19	9	5	3	6
Annual Precipitation (inches)	7.4	3.8	3.6	3.9	1.4	6.8	7.8

Figure 70 Bearpoppy population dynamics for 1998-2004, showing live and live flowing plants within the overall population as well as number of individuals grouped into size classes and the annual precipitation (inches).

SECTION III. IMPACTS OF DISTURBANCE TO GYPSIFEROUS HABITAT VEGETATION AND SOIL COMMUNITIES AND NATURAL RECOVERY

Case Study Closed Road 108
Lake Mead National Recreation Area



Not Ripped | Ripped | Undisturbed

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

Road Ripping

- There was not a significant divergence in overall composition between ripped and not ripped road sites and between all road sites and undisturbed sites
- Results suggest there was a treatment effect on composition and richness of perennial plants but not on annual plants; perennials in not ripped road sites had lower overall cover and reduced species richness
- Not ripped road sites had significantly less species richness and total cover when annuals and perennials were combine compared to undisturbed sites, and ripped road sites were not significantly different from either not ripped or undisturbed sites
- Ripped road site soils were more similar to undisturbed sites than not ripped were to undisturbed sites due to several soil properties; most physical soil characteristics did not differ significantly
- There were significant treatment differences in some soil macronutrients and micronutrients

Project Purpose

Rd 108 was closed in 2002 with portions of the road ripped or not ripped to test the effectiveness of ripping on natural revegetation and effect on soil properties. In 2009, soil and above-ground vegetation surveys were conducted. The purpose of this project was to quantify the effectiveness of road ripping in gypsum-rich soils in Lake Mead National Recreation Area (LMNRA).

INTRODUCTION

Disturbance to aridland systems can cause disruption of native ecological functioning. Compaction of soil materials alters the surface soil environment by increasing soil density and altering particle size distribution (Webb 1982), reducing soil macropore size (Shestak and Busse 2005), with particle size related to rate of compaction (e.g. Greacen and Sands 1980), reducing time for water to penetrate into soil surface and reducing storage capacity, altering gas and water transport properties within the soil subsurface (Hamamoto et al. 2009; Shestak and Busse 2005; Santruckova et al. 1993), decreasing seed infiltration into surface soil, as well as root movement and penetration (Greacen and Sands 1980), and increasing the potential for erosion events that lead to increased water and surface soil runoff, a reduction of surface area capable of capturing seeds or airborne fine particulates containing bioessential nutrients in dust and a reduction in the ability for development of protective soil biota, which not only stabilize the soil surface but also increase size of soil pores, increase water retention, and increase carbon and nitrogen in the surface soil. Additionally, disturbance in soils with high levels of gypsum results in the development physical crust cover which limits seed infiltration and seedling emergence and vegetation development (Belnap 2001; Smith and Robertson 1962).

Long-term disturbance provides an opportunity to examine how disturbance affects native systems and examine restoration activity effectiveness. Closed Rd 108 in the Blue Point Spring/Roger Spring LMNRA provides an opportunity to examine the effects of long-term disturbance to a sensitive desert vegetation and soil system, which contains rare plant communities, including the Las Vegas bearpoppy (*Arctomecon californica*) and southwest ringstem (*Anulocaulis leiosolenus*), and unique biocrust communities with a high level of organism diversity. The old road bed was observed to be heavily disturbed and "the damage [was] so severe that all the topsoil [was] eroded away leaving exposed bedrock," which resulted in visitors "choosing to drive off road to avoid the undesirable designated path" (disturbance assessment information provided by LMNRA, 2009). As a result frequent violations could be observed in areas adjacent to the main roadbed, which infringed upon highly developed biocrusts and rare plant species habitat. LMNRA resource management decided to close Rd 108 due to poor road conditions, the increase in the number disturbances adjacent to the road resulting in erosion damage and damage to rare species habitat, and due to recommendations by geologists that the gypsum road bed will continue to degrade.

METHODS

Study Area

Closed Rd 108 was an unpaved dirt road located off of Northshore Rd (mile post 41) approximately across of Blue Point Spring in Lake Mead National Recreation Area (Figure 71). Elevation of the road area ranges from 375 m closer lake end to 458 m on the Northshore Rd end. The entire closed road is within Drygyp-Bluegyp soil association composed of loamy, gypsic, hyperthermic, shallow Typic Petrogypsids and coarse-loamy, gypsic, hyperthermic Leptic Haplogypsids (Lato 2006). After road closure, a 300-m road segment closest to Northshore Rd, between Northshore Rd and a utility access road, were ripped to reduce the visibility of the former road segment. Along the remaining path of the road south of the utility access road to the lake, approximately every 0.1 mi (~150-160 m) segments were ripped or left not ripped (Figure 73). Additionally, a trail was established which follows the edge of the former road path to Lake Mead.

In spring 2009, areas along closed Rd 108 were identified as ripped or not ripped in the field with assistance a sketch drawing (Figure 72). Within the 150-m segments identified as ripped and not ripped, twelve and six, respectively, 33.3 m x 3 m sites containing six 1 m x 1 m subplots centered at 0.5, 6, 12, 18, 24, 30 m along the southwestern site boundary were established and 12 undisturbed sites of the same size were established parallel to the closed road (Figure 73).

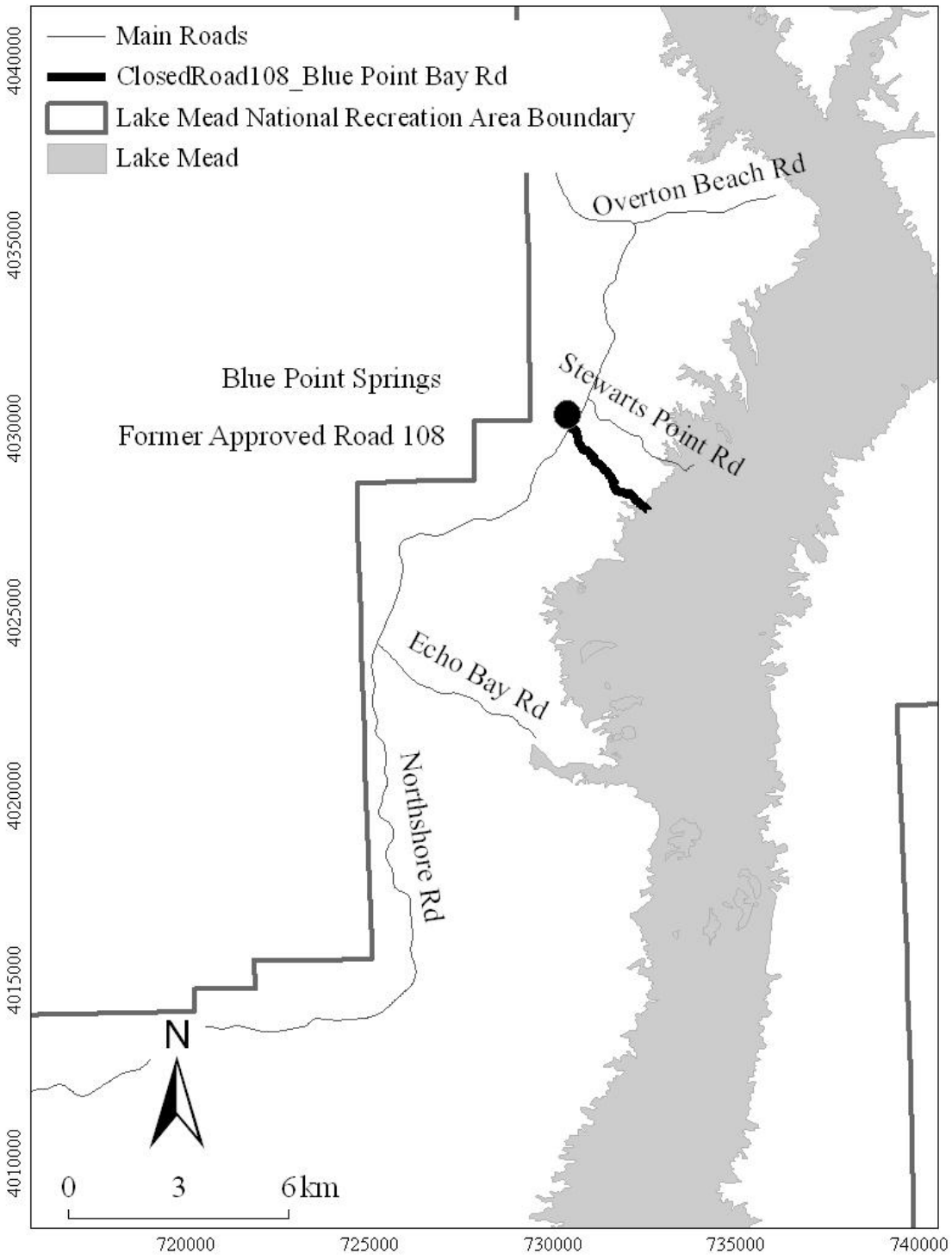


Figure 71 Former approved road 108 (bold black line) in Lake Mead National Recreation Area, eastern Mojave Desert, closed in 2002 with portions ripped and not ripped. The former road path is highlighted in bold.

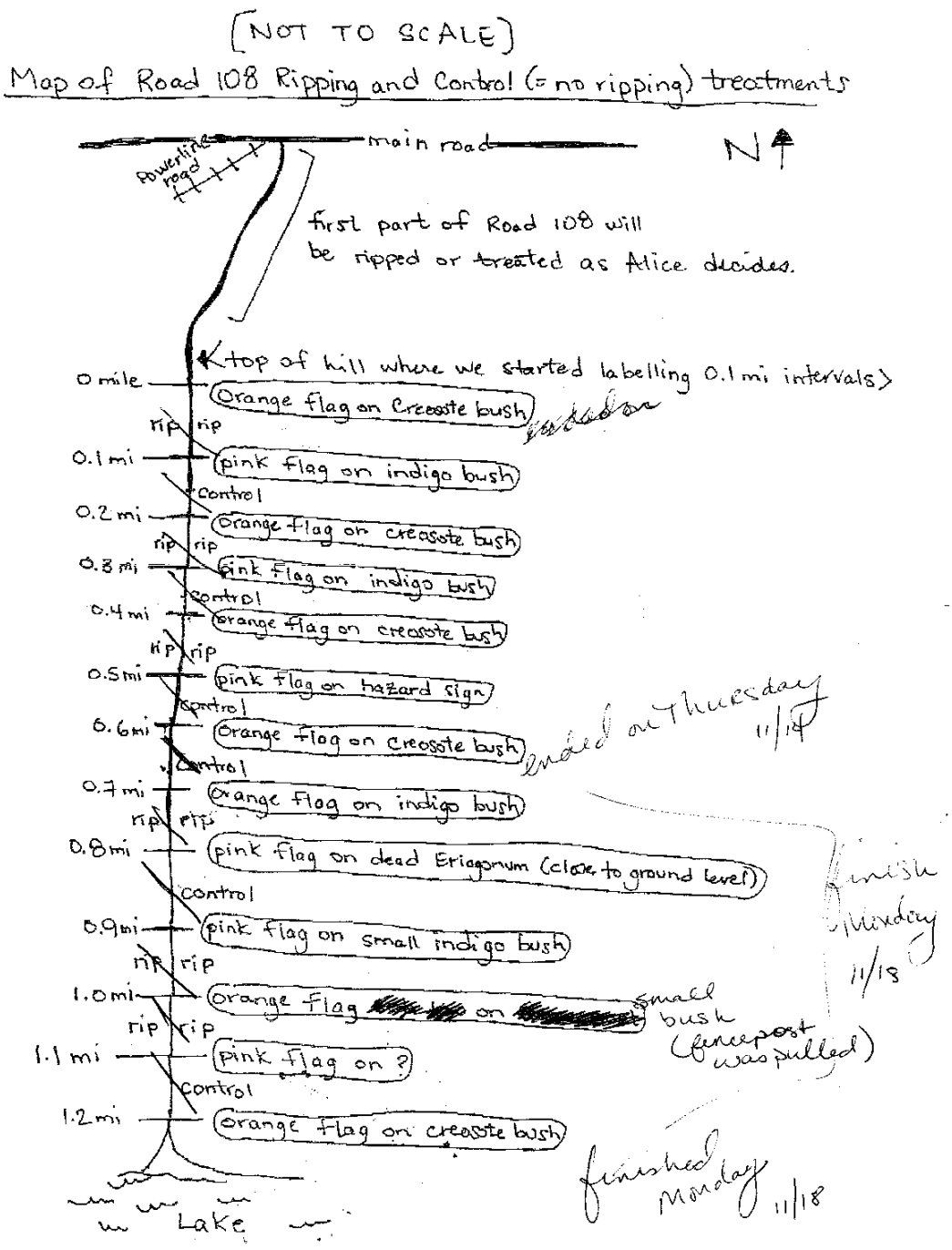


Figure 72 Sketch of ripped and not ripped treatment road segments of closed road 108 in Lake National Recreation Area, eastern Mojave Desert, from 2002 showing the approximate ripped and not ripped sections.

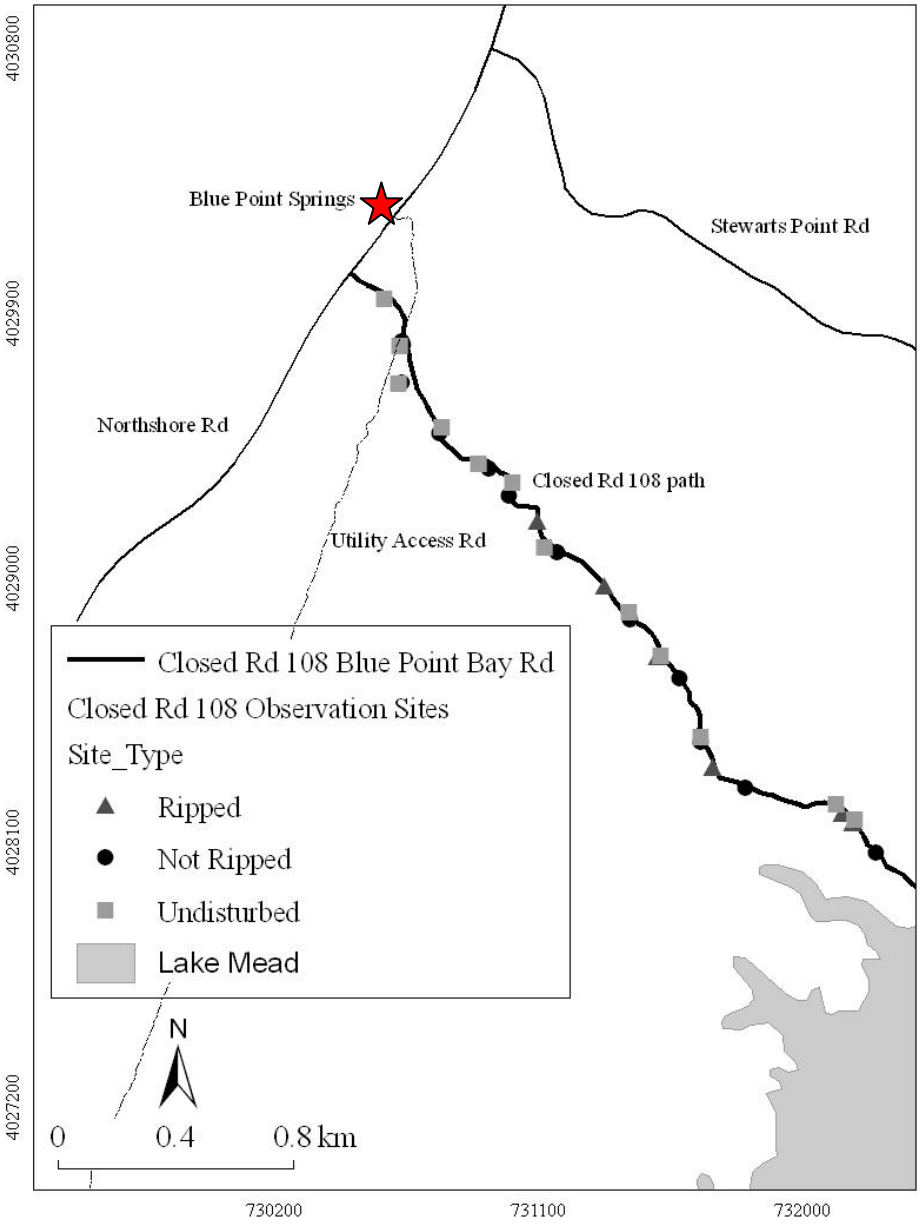


Figure 73 Locations of monitoring sites along the extent of closed road 108 in Lake Mead National Recreation Area, which was closed in 2002 with segments ripped or left not ripped.

Data Collection

In the northwest corners of the sites, location was recorded (Universal Transverse Mercator [UTM] coordinates, using a global

positioning system). Elevation (measured with a GPS), slope aspect (compass) and slope gradient (clinometers) were recorded across the entire site. Vegetation sites were established in 2009 and mean cover for perennial and plant species was estimated across the subplots, and if not present within the subplots, across the entire 1000-m^2 site using cover class categories from Peet et al. (1998): 1 = trace (assigned 0.1), 2 = 0 - 1%, 3 = 1 - 2%, 4 = 2 - 5%, 5 = 5 - 10%, 6 = 10 - 25%, 7 = 25 - 50 %, 8 = 50 - 75%, 9 = 75 - 95% and 10 = > 95%. Cover was represented as the average cover (in %, represented by the midpoints of the cover classes used) from subplots and whole site cover from species not in subplots and averaged across all subplots and whole site cover. Additionally, all perennial plants were identified to species within the whole site, individuals counted and each individual plant's mean horizontal diameter was estimated (average of shortest and widest width of horizontal plant structure) to approximate horizontal spatial cover and average height to estimate 3 dimensional spatial cover and size per species per site.

From the northwestern and southwestern site corners in intersected ≥ 1 m away from the nearest perennial plant, soil samples were collected from the top 0-5 cm depth of surface soil and composited to represent entire site. Additionally bulk density samples were collected separately in the same manner 0-5 cm depth at 7-cm diameter for a 400-cm^3 soil sample from each site. Soil samples were air dried, sieved through a 2-mm sieve, and analyzed for texture (hydrometer method following Tan (2005)); pH and EC (1:3 soil:water); P (Olsen sodium-bicarbonate extraction)l total N and organic C (dry combustion, CNS analyzer); SO4, Cl, and NO3 (ion chromatography); and water-soluble concentrations of Ca, B, Cd, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, and Zn (1:3 soil:water extracts, inductively coupled plasma mass spectroscopy) following Burt (2004). Bulk density was estimated for the bulk density by sieving soil samples through a 2-mm sieve and oven drying samples at 105°C for 24 hours. Bulk density of the <2-mm fraction was then calculated with the volume (estimated by water displacement) of coarse fragments ≥ 2 mm included (Burt 2004). All nutrient concentrations were converted to volume contents at g/m^2 at 5 cm depth using bulk density.

DATA ANALYSIS

Vegetation

A matrix, 30 sites x 39 plant species representing species detected on sites, of relative cover calculated as the proportion of cover each species contributed to the summed cover of all species on each site (summed cover average 21 ± 28% [±SD] among all sites). Using the software PC-PRD (MJM Software Design 2006) a nonmetric multidimensional scaling (NMS) analysis on autopilot slow and thorough was used to estimate the number of axes to use for ordination followed by a manual NMS run using a correlation distance measure, 2 axes with 250 runs with real data, 25 iterations to evaluate stability, a stability criterion of 0.00001 and random starting coordinates and with randomization tests was used to evaluate plant structure differences across treatments.

For the statistical model, treatments were considered nested within sites; therefore, the effects of treatment were tested over the interaction between site and treatment. Some dependent variables, including total, annual,

and perennial plant species richness, and total , annual, and perennial mean cover were analyzed individually in a mixed effects analysis of variance (ANOVA). Cover variables and annual species richness were $\log_{10}$+1 transformed to reduce the influence of one or a few large observations. Species composition changes with treatment were estimated separately for annual plants, herbaceous perennials and perennial shrubs, as well as for three groups of soil variables corresponding to physical variables, macronutrients, and micronutrients in a multivariable ANOVA (MANOVA).

Data for examining individual plant size by species per treatment group were unreliable due to high variation among individuals and small sample size; however, this data may be useful for guiding future research. Species per treatment combinations were limited to species with at least two individuals, and only sites with had a species for at least two treatments were considered in order to avoid biasing conclusions concerning treatment effects. For the species that fit these criteria, the cover for each site and treatment was divided by the number of individuals. The average plant cover per individual for each species was analyzed in a mixed effects ANOVA with treatment as a fixed effect (tested over the residual) and site as the random effect. Significant effects were explored using Bonferroni post-hoc tests. Data for *Eriogonum inflatum* and *Psorothamnus fremontii* were $\log_{10}$+1 transformed in order to meet assumptions of the analysis. Back-transformed means and standard errors are reported.

Soil

A matrix of 31 soil parameters was calculated to use for a principle component analysis (PCA) with a correlation cross-product matrix and a distance-based biplot for calculated scores with randomized tests and 999 number seeds. For the multivariate analyses, EC, organic carbon, particle size (texture), nitrate, and all of the soil micronutrient variables were $\log_{10}$ (+1, when zeroes were present) transformed prior to analysis, and soil and plant variables were scaled by their range prior to multivariate analysis. For all analyses, the Bray-Curtis index was used to derive a distance matrix, and significant differences among treatments were determined by 999 permutations (Anderson 2001, McArdle and Anderson 2001) in distlm software (Anderson, M.J. 2004. DISTLM v.5: a FORTRAN computer program to calculate a distance-based multivariate analysis for a linear model. Department of Statistics, University of Auckland, New Zealand). Significant treatment differences were further explored by Bonferroni pairwise comparisons based on p-values from 999 permutations. Since half of the sites did not include the disturbed but not ripped treatment, the pairwise comparisons with not ripped treatments used only the values from the six sites which had both treatments involved in the comparison. Significant treatment effects in MANOVAs led to univariate ANOVAs. Univariate ANOVAs for reasonably normal dependent variables (transformed as stated above) were estimated in SAS PROC MIXED (SAS Institute. 2002-2008. Cary, NC).

RESULTS

Vegetation

NMS ordination did not show a significant divergence in overall composition between not ripped, ripped, and undisturbed sites (Figure 74). Treatments affected the composition and richness of perennials but did not have the same influence on annual plants; disturbance and ripping treatment did not significantly affect annual plant cover (Table 72). Plant cover was overall low across all sites, regardless of treatment, for both annual and perennial plants. Most of the plant cover was from perennial species, with an averaged cover of less than 4% for the undisturbed sites and much less for the road treatments (Table 73). When annuals and perennials were considered together, species richness and total plant cover in not ripped sites was significantly less than species richness in undisturbed sites; ripped site species richness was not significantly different from not ripped or undisturbed treatments (Table 73).

The composition of perennial forb cover and perennial shrub cover significantly varied by treatment (Table 72); however, given the extremely small amount of cover and the high variation among sites, particularly for large species, very little can be reliably stated about changes in species composition from a statistical perspective. Individual ANOVAs were considered for evaluating species composition differences, but the small sample size and extremely high variation relative to the mean may result in unreliable univariate analyses.

Qualitatively, annuals made up a larger percentage of total cover in the undisturbed and ripped sites compared to not ripped sites; annual cover in all treatments was dominated by *Plantago ovata*. The ripped sites had substantially less perennial shrub cover than not ripped or undisturbed sites (Table 72); however this appears due to a minority of not ripped sites having much greater cover compared to overall the sites within the treatment. Ripped site plant cover was every low and consisted mostly of perennial forbs, dominated by *Camissonia multijuga, Lepidium fremontii, Stephanomeria pauciflora, Suaeda moquinii,* and *Tiquilia latior*. The perennial shrubs in ripped sites were similar in species composition to undisturbed sites, which were dominated by *Atriplex confertifolia* and *Psorothamnus fremontii*. Perennials in not ripped sites had lower overall cover and reduced species richness (Table 73), with a barely equal mix of shrubs dominated by *Ambrosia dumosa* and *Larrea tridentata* and perennial forbs dominated by *Sphaeralcea ambigua* and *Tiquilia latior*. The non-ripped sites also had higher perennial forb cover than undisturbed sites, but forb cover in non-ripped sites consisted mostly of *Eriogonum inflatum* and *Tiquilia latior*. For perennial shrub cover, not ripped sites had great cover of *Ambrosia dumosa* and *Larrea tridentata* and less cover of *Atriplex confertifolia,* than undisturbed and ripped sites. Compared to undisturbed sites, the ripped sites had far less perennial shrub cover relative to other cover types, but species composition was similar, dominated by *Psorothamnus fremontii*, *Atriplex confertifolia*, and *Petalonyx parryi.*

An analysis of individual plant size was conducted, but results were unreliable due to high variation among individuals and small sample size (Table 74). For individual size of plants per species per treatment, most species did not show a treatment response due to the small amount of cover per individual plant. There were two exceptions to this general trend with *Ambrosia dumosa* and *Stephanomeria pauciflora* (Table 74).

There were one or two extremely large *Ambrosia* in one of the not ripped sites (Site 1). Since this was the only site used to estimate plant size for not ripped treatment group *Ambrosia*, the results indicate a dramatic different between *Ambrosia* in not ripped (4.46±0.02%) and ripped (0.05±0.01%) and undisturbed (0.01±0.01) sites. The results for *Stephanomeria* followed the same trend, although the differences were not as large. The not ripped *Stephanomeria* mean plant size (0.045±0.004%) was significantly larger than ripped (0.014±0.003%) or undisturbed (0.017±0.003%). Since only one site was included in the not ripped plants for this analysis, these results are unreliable and require further study.

Soil

Overall ripped soil treatment sites were more similar to undisturbed sites than not ripped were to undisturbed sites due to several sol properties (Table 75 & 76; Figure 75). Only about 23% of the variability between sites is explained by Mg, total S, $CaCO_3$, inorganic C, total C, Ni and Fe. Between the two road treatments, ripped versus not ripped, compared to undisturbed sites, most physical soil characteristics did not differ significantly (pH, EC, organic C, bulk density), although some texture characteristics did differ (Table 76). The texture of soils in undisturbed sites was intermediate between not ripped sites, which had smaller amounts of sand and larger (but still small) amounts of clay and ripped sites, which had more sandy soils (Table 77). Ripped sites were intermediate to the small particle size found in undisturbed sites and the larger particles observed for not ripped sites..

For macronutrients, there were no treatment differences in total nitrogen, nitrate, sulfate, or calcium (Table 76). However, there were significant treatment differences in some soil macronutrients and micronutrients (Table 76 & 77). Sites which were not ripped and undisturbed sites were alike in having lower total S, higher P and higher K than ripped sites, although significance varied (Tables 76 & 77). For most of the macronutrients and the micronutrient Mg, ripped treatment sites were more similar to undisturbed sites than not ripped was to undisturbed sites. Sites which were not ripped were significantly higher in Mg than ripped or undisturbed sites. Inorganic carbon, which was highly correlated to total C and $CaCO_3$, was higher in non-ripped and undisturbed sites than in ripped sites. For micronutrients, Cl, Pb and Zn did not significantly vary among treatments (Table 75). Not ripped sites were higher than ripped sites for all other micronutrients, although ripped and undisturbed sites were more similar. Undisturbed and ripped sites were alike in having lower levels of Cd, Co, Fe, Mo, Na, and Ni than not ripped sites (Table 77). Undisturbed sites had levels of B which were intermediate to levels in ripped and non-ripped sites, although only ripped and not ripped sites statistically differed. Undisturbed sites also had levels of Cu which were intermediate to levels in ripped and non-ripped sites, and ripped sites were significantly different than both not ripped and undisturbed, but not ripped did not differ from undisturbed sites. Undisturbed sites also had levels of Mn which were intermediate to levels in ripped and non-ripped sites, and, ripped sites were not statistically different from undisturbed sites while not ripped sites did differ with both ripped and undisturbed sites.

DISCUSSION

Road ripping with subsoilers or other machines is used for increasing the infiltration capacity of formerly highly compacted surface soils. Road ripping directly impacts the potential for water infiltration, reducing erosion by creating a textured soil surface, and stabilizing slopes, as well as the recovery of vegetation. The effectiveness of ripping may be measured based on the restoration goal. In this case, the goal was to restore the natural recovery trajectory for vegetation cover and increase the visual consistency of the landscape by blending the former road area into the surrounding landscape and creating a soil environment conducive to plant establishment, while reducing the visibility and further use of the road. Maintaining or recovering the natural soil structure was not a primary goal, although the differences in soil properties between treatments were examined primarily to obtain the relationships between the soil environment and vegetation diversity and cover within the road treatments. Ripping treatment resulted in possibly earlier soil developmental characteristics with higher % sand and lower % clay that would allow for water and root penetration and plant establishment.

Bulk density between road treatments (ripped vs. not ripped) and between the road treatments and undisturbed sites did not differ significantly; therefore other factors are possibly influencing vegetative differences. Compaction of soil materials altered the surface soil environment by increasing soil density and altering particle size distribution (sand vs. clay) as shown between not ripped and undisturbed sites. Compaction likely resulted in a reduction of macropore size, water and gas storage and exchange capacities, as well as impacted seed infiltration and root development of any new species. Compaction was reduced in ripped sites (greater sand; although bulk density was not significant) which may have allowed increased rates of seed infiltration and germination and emergence of perennial forbs. The not ripped sites were highly compacted, while the undisturbed sites had shallow soils on top of an undisturbed caliche layers with high biocrust cover which creates a selective soil environment preferential to certain species. Biocrusts have a direct impact on the top surface soil environment, although biocrusts were not quantified across all treatments. However, there was no evidence of macroscale biocrust organism presence in either ripped or not ripped sites, while mean cover in undisturbed sites ranged between 30-40% (not reported). This may be due to several factors including soil surface compaction, erosion potential, low soil pore density, and time for recovery.

The macronutrients that were not significantly different may not have differed due to their relative stability and inactivity within the soil profile, such as Ca and SO_4 that have concentrations contributed by gypsum, which has a low dissolution rate that decreases in higher temperatures. Additionally, calcium carbonate solubility decreases with gypsum present due to the common ion effect (Ca^{2+}). Those soil variables which appear to influence site distribution and clustering in the PCA were not necessarily explained by differences in soil variables. Ripped and undisturbed sites appear to cluster more greatly with themselves and each other compared to not ripped sites, which appear to have greater spread. Those soil parameters which appear

to most correlate with not ripped sites, including K and inorganic C, are more similar to undisturbed sites than undisturbed sites are to ripped sites. Total S appears to be slightly correlated with undisturbed and ripped site clustering, although within these two site groups total S was statistically different. Total S in ripped sites was also statistically different from not ripped, which may show the dissimilarity between ripped versus not ripped site clusters. Micronutrient differences may have had a great effect on soil and vegetation differences.

Road treatment did not impact overall vegetation cover; however it did impact the number of individuals per species constituting the cover. Ripped sites were more similar to undisturbed sites in overall composition. Cover across all sites was very low, which is characteristic for this soil type and this area in LMNRA, although this made analyses difficult. Annual cover and richness were not significantly different; however qualitatively, annuals made up a larger percentage of total cover in the undisturbed and ripped sites compared to not ripped sites also showing that the ripped site conditions are a step between the not ripped and undisturbed site conditions. Winter 2008-2009 was a higher than average precipitation season. Annual cover may have to be examined further to incorporate seasonal differences. For those plant community variables which were significantly different, ripped sites were between not ripped and undisturbed sites, specifically for the perennial species cover and richness potentially indicating a vegetative successional trajectory that may be similar to natural succession, where short lived perennial shrubs inhabit soils that are less developed. Ripped sites were mostly perennial forbs, while not ripped sites contained higher cover of shrubs, yet with fewer individual shrubs than undisturbed sites and with single individuals within only a few sites creating possible outliers. Most species did not show a treatment response related to shrub size except *Ambrosia dumosa* and *Stephanomeria pauciflora*, although only within a single site each species. The exaggerated size of these individuals may be due to several factors including pooling of water on the surface, lack of competition, less soil compaction, and/or disturbance of subsurface layers or different type or developmental stage of subsurface layers which may allow for greater root development.

CONCLUSION

The goals of restoration should be defined prior to restoration activities. For this case study, ripping appears to have the advantage of increasing the above-ground cover, although species richness differed from undisturbed sites. The not ripped treatment sites had very low overall cover with large spatial gaps between vegetation, which created inconsistencies in the visual landscape. The soil environment varied between all three site groups, although it appears ripped and undisturbed sites are more physically similar. And the resulting soil environment within the ripped sites provided an environment more conducive to natural plant establishment, even with lower macronutrients P, K, and Mg and micronutrients B, Cd, Cu, Fe, and Mn, likely due to reduced compaction and physical crust cover.

Table 72 MANOVA and ANOVA results for total, annual, and perennial plant species composition, cover, and richness or species found in sites along closed Rd 108, Lake Mead National Recreation Area, for each treatment group (not ripped, ripped and undisturbed). Significance $\alpha = 0.05$ results are in bold and $\alpha = 0.10$ in italics.

Source	F	P
Composition of Annual Cover	1.09	0.392
Total Annual Cover	0.93	0.480
Annual Richness	1.22	0.312
Composition of Perennial Forbs	1.87	**0.028**
Composition of Perennial Shrubs	1.86	**0.029**
Total Perennial Cover	2.26	*0.072*
Perennial Richness	18.73	**0.001**
Total Cover	3.18	**0.029**
Total Richness	6.43	**0.013**

Table 73 Mean and standard error (SE) for total, annul and perennial plant species richness and total, annual, and perennial plant cover for species found in sites along closed Rd 108, Lake Mead National Recreation Area, for each treatment group (not ripped, ripped and undisturbed). Significance between treatments at $\alpha = 0.05$ displayed by letters.

	Not ripped (1-6)		Ripped (1-12)		Undisturbed (1-12)		
	Mean	SE	Mean	SE	Mean	SE	Significance
Total Richness	4.17	1.29	7.25	0.91	9.83	0.91	a ab b
Total Annual Cover	0.12	0.12	0.06	0.08	0.23	0.09	
Annual Richness	0.78	0.67	1.03	0.51	1.77	0.70	
Total Perennial Cover	0.66	0.45	1.41	0.45	2.54	0.66	
Perennial Richness	2.50	0.70	5.75	0.50	7.17	0.50	a b b
Total Cover	0.69	0.46	1.48	0.46	3.12	0.77	a ab b

Table 74 ANOVA results for treatment effects on individual plant size for closed Rd 108 sites in Lake Mead National Recreation Area, based on ripped, not ripped and undisturbed treatment groups. Significance $\alpha = 0.05$ results are in bold.

Species	NumDF	DenDF	F Value	*P*
Ambrosia dumosa	2	2	22101.21	**0.000**
Atriplex confertifolia	2	2	0.04	0.964
Eriogonum inflatum	2	6	0.48	0.642
Lepidium fremontii	2	1	2.08	0.441
Psorothamnus fremontii	2	9	0.72	0.514
Stephanomeria pauciflora	2	2	33.33	**0.029**
Tiquilia latior	2	7	3.00	0.114

Table 75 MANOVA and ANOVA results for soil variables from an adjacent undisturbed control and road segments treated with ripping or not ripping, compared along closed Rd 108 in Lake Mead National Recreation Area, Mojave Desert. F (ANOVA) or pseudo-F (MANOVA) results are shown, as well as p-values. Significance alpha=0.05 results are in bold.

Source	F	P
Macronutrients	7.72	**0.002**
Micronutrients	6.03	**0.002**
Physical Soil Variables	5.14	**0.003**

Table 76 ANOVA results for treatment effects on soil variables found in sites along closed Rd 108, Lake Mead National Recreation Area, for each treatment group (not ripped, ripped and undisturbed). Significance $\alpha = 0.05$ results are in bold and $\alpha = 0.10$ in italics.

Source	Variable	F	P
Macronutrients	Total N	2.75	**0.094**
	Total S	7.83	**0.004**
	NO3	2.28	0.134
	SO4	1.11	0.354
	P	15.49	**0.000**
	Ca	3.24	*0.066*
	K	7.57	**0.005**
	Mg	11.58	**0.001**
Micronutrients	B	4.96	**0.021**
	Cd	6.42	**0.009**
	Cl	0.77	0.481
	Co	10.53	**0.001**
	Cu	8.85	**0.003**
	Fe	7.27	**0.006**
	Mn	9.47	**0.002**
	Mo	7.63	**0.005**
	Na	8.91	**0.003**
	Ni	6.38	**0.009**
	Pb	3.06	*0.075*
	Zn	1.25	0.314
Physical Soil	pH	1.16	0.338
	EC	2.41	0.121
	Organic C	0.13	0.876
	Inorganic C	10.51	**0.001**
	Sand	7.03	**0.006**
	Clay	3.51	*0.054*
	Bulk Density	1.26	0.311
	Particle size	5.99	**0.011**

Table 77 Mean and standard error (SE) for soil variables for each treatment of road segment along closed Rd 108 in Lake Mead National Recreation Area, Mojave Desert. Mean difference are indicated by different letters in the 'Significance' column.

		Not ripped (1-6)		Ripped (1-12)		Undisturbed (1-12)		
		Mean	SE	Mean	SE	Mean	SE	Significance
Physical	pH	7.42	0.06	7.26	0.04	7.31	0.04	
	EC µS/cm	2069.1	379.4	1754.1	221.8	1353.2	171.1	
	Organic C	0.40	0.14	0.34	0.08	0.38	0.09	
	Inorganic C	2.72	0.83	0.62	0.13	1.72	0.36	b ab a
	% Sand	65.0	2.9	77.2	2.0	69.9	2.0	b ab a
	% Clay	0.47	0.09	0.16	0.06	0.27	0.06	a a
	Bulk Density	1.14	0.05	1.19	0.03	1.12	0.03	
	Particle Size	23.7	14.0	9.7	4.0	3.0	1.5	a a
Macronutrients	Total N	29.02	6.07	24.52	4.29	38.76	4.29	
	Total S	1.51	0.70	4.68	0.50	2.12	0.50	b ab a
	NO_3	66.62	45.56	264.15	117.67	128.64	57.31	
	SO_4	0.68	0.09	0.81	0.06	0.67	0.06	
	P	1.05	0.11	0.31	0.08	0.74	0.08	bc ac ab
	Ca	0.38	0.03	0.38	0.02	0.31	0.02	
	K	2.15	0.38	0.30	0.27	1.38	0.27	b ab a
	Mg	2.37	0.33	0.32	0.23	0.76	0.23	ab a b
Micronutrients	B	1.19	0.64	0.23	0.08	0.49	0.18	a a
	Cd	3.45	2.02	0.30	0.12	0.78	0.30	ab b a
	Cl	1.91	1.91	0.98	0.62	0.67	0.42	
	Co	126.79	41.16	27.53	6.06	33.81	7.44	ab b a
	Cu	0.62	0.14	0.19	0.03	0.35	0.05	b ab a
	Fe	0.31	0.11	0.08	0.02	0.09	0.02	ab b a
	Mn	1.63	0.68	0.27	0.08	0.69	0.19	ab b a
	Mo	0.34	0.21	0.03	0.01	0.07	0.03	b a a
	Na	4.09	2.85	0.21	0.09	0.25	0.12	ab b a
	Ni	2.38	0.74	0.75	0.16	0.88	0.19	ab b a
	Pb	1.02	0.31	1.28	0.26	2.05	0.42	
	Zn	0.34	0.07	0.32	0.04	0.24	0.03	

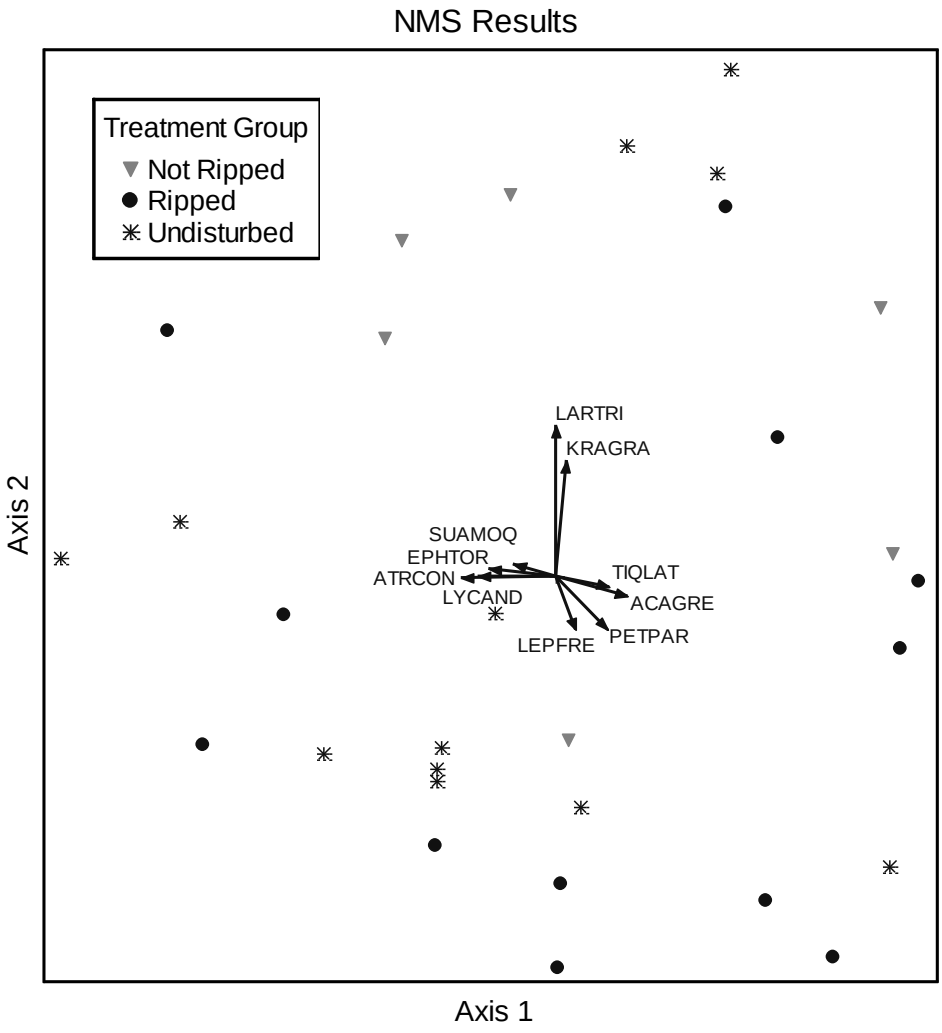


Figure 74 Nonmetric multidimensional scaling results using plant mean cover from treatment sites along closed Rd 108 treatments, Lake Mead National Recreation Area, with treatments not ripped, ripped, and undisturbed sites.

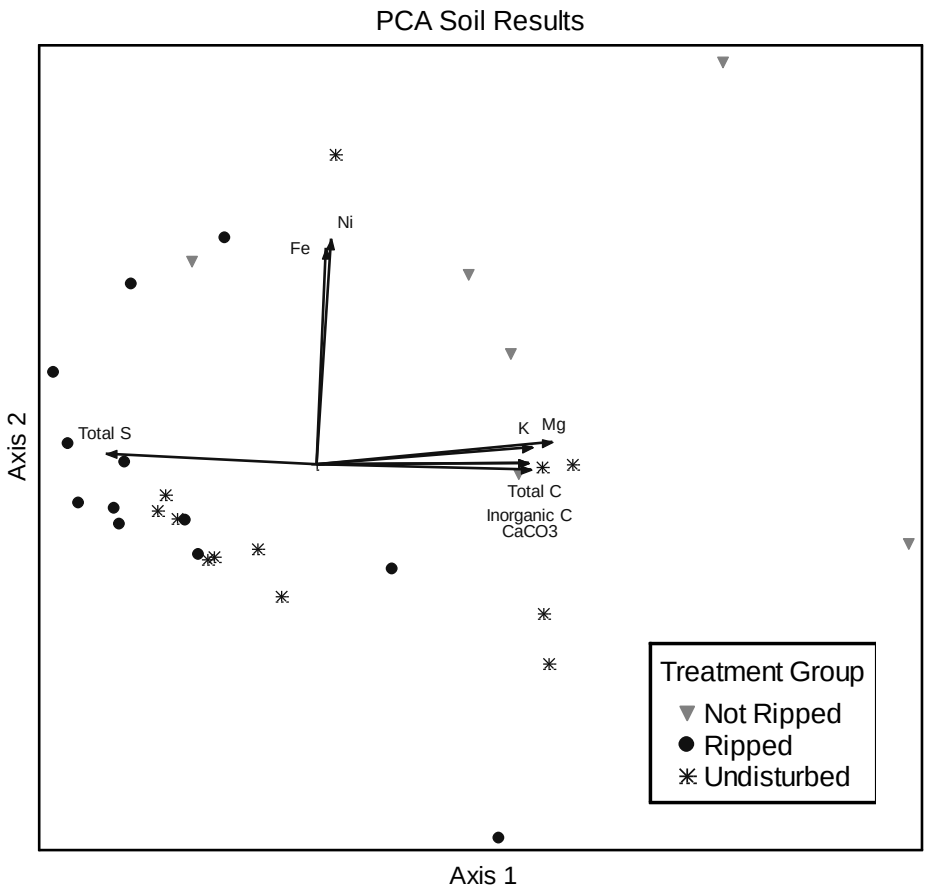


Figure 75 Principle component analysis results of soil parameters with treatment groups from closed Rd 108 sites in Lake Mead National Recreation Area, with axis one explained mostly by Mg, S, $CaCO_3$, inorganic C, and total C and axis two explained by Ni and Fe; with soil vector overlay cutoff $r^2 \geq 0.70$ and 23% of the percent of variance in distance matrix explained.

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

Northshore Rd Salvage/Outplanting, Federal Highway Administration Project

- Overall salvage survival was 46% and outplanting survival was 49%
- Additional treatment of perennial plants during salvage did not impact overall survival; qualitative response to treatments was species specific
- Salvage survival ranged from 14-69% and depended on species; the species *Ambrosia dumosa*, *Larrea tridentata*, and *Sphaeralcea ambigua* exhibited the greatest survival in salvage
- After three months, outplanting survival was 90%, but decreased to 60% after year 1 and to 49% by year two, indicating that the first year of treatment is crucial
- Topsoil increased overall success of outplanting survival by 20%
- Watering plants throughout the maintenance period significantly increased outplanting survival
- Overall, watering treatment increased survival by 16%, with DriWater improving survival by 12% and hand watering by 21%. These benefits of DriWater and hand watering should be weighed against the added effort and cost of simply planting more plants
- *Ambrosia dumosa*, *Sphaeralcea ambigua*, and *Stephanomeria pauciflora* exhibited the greatest survival in outplanting and are recommended species for revegetating gypsum soil along Northshore Road

Biocrust Restoration

- Salvaged biocrust organisms survive salvage and 2 years in storage
- Inoculation with salvaged biocrust resulted in greater biocrust cover and recovery of cyanobacteria and macro-species
- Topsoil re-application resulted in increased species richness and density of cyanobacteria species
- Biocrust inoculation increased available nitrogen and soil stability

INTRODUCTION

Lake Mead National Recreation Area (LMNRA) in southern Nevada contains gypsiferous soil types. Gypsum communities are easily damaged by mechanical equipment, illegal off-road vehicle driving, trampling and browsing from non-native mega fauna (i. e. feral cattle and burros), and other disturbances (Belnap and Warren 2002; Lovich and Bainbridge 1999; Webb 2002). Past and present legal and illegal land uses lead to the modification of these systems and can have enduring effects on the soil and vegetation communities, potentially resulting in removal and destruction of native vegetation, the introduction of and greater susceptibility to non-native invasive species, the degradation of biological and chemical soil crusts and desert pavement communities, and continued disturbance (Lovich and Bainbridge 1999). Impacted areas have variable rates of recovery depending on the type and degree of impact, the rate of soil stability and seed bank recovery, soil nutrients and fertility, the composition of the ecosystem, and the rate of natural revegetation. Other factors that contribute to slow recovery rates in Mojave ecosystems may include limited and unpredictable precipitation, herbivory and granivory, lack of source material, and continued disturbance. Precipitation may vary from year to year, creating conditions that are not always suitable for seed germination and survival. In areas that are impacted, high rates of precipitation will contribute to surface soil instability and run off. Herbivory of established plants by wildlife may kill plants, interfere with seed production, and reduce surface cover. Established shrubs create "fertile islands" that provide a vegetative structure for nutrient and moisture accumulation in soils and a surface cover for seeds from direct sun and erosion (Wallace et al. 1980). Granivory by rodents and insects may decrease the available viable seeds within a system (Nelson and Chew 1977; Brown et al. 1979). These confounding factors in conjunction with low spatial densities in arid systems contribute to a lack of source material within the natural system. In addition, it may be difficult to limit or exclude future impacts on areas that were once disturbed yet easily accessible, such as preventing illegal trespasses on closed roads (e.g. the illegal trespass of closed Rd 105 in 2010 in LMNRA).

Due to slow recovery rates, managers may feel it is necessary to institute actions that assist in ecosystem recovery, such as, prior to a known impact, salvage perennial plants, topsoil, or biocrust; or after a road closure prepare the soil surface (i.e. ripping or contouring surface soils) or inoculating the soil surface with native soil biota, and mechanically seed or transplant or outplant vegetation. Seeding may include broadcasting seeds dry or in water slurry and other material (hydro-seeding), drilling to insert seeds into the ground, or encasing seeds with soil (pelleting) (Monsen and Stevens 2004). It may be necessary to grow seedlings from local genetic sources in a greenhouse setting. In addition to planting, mechanical watering or use of a watering alternative, like DriWater application (Newton 2001), may be necessary to assist in plant re-establishment. Irrigation, such as drip systems, or creating water catchments by re-contouring land to retain rainfall, may also be necessary to supplement water during plant re-establishment. Plants may

also require protection against herbivory by use of exclosures (Bainbridge et al. 1996) or repellents (ex: Critter Out™) (Dara Scherpenisse, National Park Service, Personal e-mail correspondence, September 28, 2009). Inoculation with native soil biota reintroduces the native soil organisms which contribute to soil stability, reducing wind and water erosion, and surface texturing, as well as contribute to plant essential nutrients through carbon and nitrogen fixation or acting as dust traps that accumulate airborne dust.

In all cases, the practical application of restoration actions may depend on accessibility, availability of materials and resources, and area of impact. Not all areas that are impacted are easily accessible. Larger areas require large numbers of seeds to produce a desired density and diversity, in which case, there may not be enough seed available from local sources. National Park Service policy requires local genetic diversity to be preserved (Alice C. Newton, National Park Service, Personal e-mail correspondence, October 8, 2009). For outplanting, plants must first be grown from seed or propagated, potentially a year in advance (Janis Lee, National Park Service, Personal communication, October 8, 2009). Outplanting and transplanting, in addition to maintenance and care, are labor intensive and expensive (Bainbridge et al. 1996), require the facilities and personnel to tend to the plants, and there is potential for mortality during plant re-establishment. Species and treatment selection can dictate the success or failure of a vegetation treatment due to differences in plant drought tolerance, germination requirements, growth rates, nutrient requirements, and susceptibility to granivory or herbivory (Smith et al. 1997). Irrigation or supplemental watering may be resource- and time-consuming, depending on the scope of the project. Plant protection, such as cages, requires maintenance, and repellents require regular re-application. Due to the above factors, current restoration protocols within LMNRA vary and are site specific (Dara Scherpenisse, National Park Service, Personal e-mail correspondence, September 27, 2009). Acquisition of native biocrusts require salvage from a local population which is within similar soil types under treatment, while also causing minor disturbance to undisturbed areas or salvaging prior to a known disturbance event.

Project Background

The reconstruction and realignment of Lakeshore Rd and Northshore Rd in LMNRA began in 1993. Specific actions were required during road reconstruction to reduce the overall impact to wildlife and plant communities, including salvaging, stockpiling and reapplying topsoil. Anecdotally, this process is believed to not disrupt the soil seed bank dramatically. However, research has shown dilution of the native seed bank during this process (Scoles-Sciulla and DeFalco 2009). For Phase I along Lakeshore Road, plants were propagated and transplanted, which, if plants survived, provide additional seed sources throughout the recovery process. For the rest of the road construction only topsoil was salvaged and reapplied and no seeding or planting treatments were implemented. At these sites, lower revegetation rates were observed even after seven years following completion of construction and reapplication of topsoil and lower perennial plant cover was observed compared to surrounding undisturbed areas (Scoles-Sciulla and

DeFalco 2009). The most recent phase of the Northshore Road realignment (2008-2010) spans sensitive biocrust and desert pavement communities in association with Gypsids and Calcids soils. Topsoil was stockpiled and the first large-scale plant salvage was conducted in gypsiferous and surrounding soil types in LMNRA. Biocrust samples were also collected from the path of destruction along the new Northshore Rd designated route and stored. Once road construction was completed, specific topsoil and planting treatment were established to test outplanting methods and biocrust restoration methods. The purposes of the projects included in this section were to test salvage and outplanting techniques for vegetative specie (Part 1) and biocrusts restoration techniques (Part 2) in gypsiferous soil and surrounding soil habitats in Lake Mead National Recreation Area (LMNRA).

PART 1. *Salvage and Outplanting of Common Eastern Mojave Desert Gypsiferous Perennial Plant Species*



Project Purpose

The purposes of the salvage and outplanting projects included in this section were to test salvage and outplanting techniques for perennial plant species specifically observed in gypsiferous soil and surrounding soil habitats predominately in the northern region of Lake Mead National Recreation Area (LMNRA; Figure 76), and to identify which treatments and which treatments per species had the highest performance for both salvage and outplanting to assist in developing restoration techniques specific to the lower elevation gypsum habitats within LMNRA. This project is associated with the Federal Highway Administration Rehabilitate Northshore Rd Project (2008-2010).

METHODS

Salvage Treatments

As a part of the Northshore Project mitigation measures, in October 2008 LMNRA personnel identified areas in the new road path of destruction along Northshore Rd in the Echo Wash area, Valley of Fire Area, and the intersection of Northshore Rd and Overton Beach Rd (Figure 77), and salvaged small to medium native perennial plants, including the common perennials *Ambrosia dumosa*, *Atriplex* spp., *Baileya multiradiata*, *Encelia* spp., *Enceliopsis argophylla*, *Ephedra* spp., *Eriogonum inflatum*, *Gutierrezia sarothrae*, *Isocoma acradenia*, *Larrea tridentata*, *Pleuraphis rigida*, *Psorothamnus fremontii*, *Sphaeralcea ambigua*, and *Stephanomeria pauciflora*, *Suaeda moquinii*, and *Tidestromia oblongifolia*. Each plant was designated a tag with a unique number to monitor throughout the salvage and planting process. Plants were treated with indole-3-butyric acid (IBA; 1H-Indole-3-butanoic acid; $C_{12}H_{13}NO_2$), a root-stimulating hormone, and/or slurry (containing Watersorb ® Water Crystals, a water-absorbing gel polymer) to prevent root damage due to entanglement during transport to the plant potting area or, no treatment (roots dipped in water) and potted on site at Overton Beach Ranger housing (3-

13 miles from salvage sites). For a few of the plants, they were left sitting in water or slurry overnight (about 12-14 hours; notation: ON or ONS) before planting in pots the following morning.

All salvage plants were potted in 4-L or 19-L plastic nursery pots with a soil potting mix of 1:3 of organic mulch to sand. Plants were stored at the Overton Beach Ranger housing from October 2008 until May 2009 and watered with drip irrigation three times a day for 8 minutes per watering period. Plants were relocated to the LMNRA plant nursery due to lowering water levels within Lake Mead, which was the primary water source. The last sixty days plants were weaned off of drip irrigation by reducing the watering schedule to twice a day in November 2009 and then once a day for December 2009 until planting in January 2010. Plants were transplanted over a 2 week period in January 2010. A final salvage survival survey was conducted in late November 2009 to determine final salvage survival and determine which plants would be used for the Northshore Rd outplanting portion of the project.

Seedlings emerged throughout the nursery resident period within salvage plant pots were transplanted to their own 4-L pot with the same some potting soil mixture as the salvage plants and placed under the same watering conditions. Seedlings likely germinated from seeds in soil carried with the original plant salvaged or were seeded after the potted plants bloomed and produced seed. The seedlings were removed from the salvage data set prior to further analysis; however seedling survival was assessed prior to outplanting separately.

Outplanting Treatments

Fifteen out of 20 road segments were identified over the three main areas under reconstruction to receive outplanting treatments (south to north: Echo Wash, Valley of Fire, Overton Beach Rd intersections with Northshore Rd; Figure 77). Segments were either newly disturbed or along the former road path and now filled with native and locally salvaged subsurface soil and contoured to blend with the existing landscape. These sites were identified as either with topsoil reapplication or as newly exposed subsurface soil without topsoil reapplication.

Each plant species with enough individuals to assess outplanting treatment were split randomly between topsoil/non topsoil areas. Additionally, within each of these groups, watering treatments were randomly assigned to individuals within each species. Watering treatments included hand watering, DriWater (jellified water polymer) application, or no additional watering treatment after planting.

All planting holes will filled with water and allowed to be absorbed prior to planting. A shallow burm was built around the base of each plant the each plant received about 1-L water at planting. For plants with a DriWater treatment, the manufacturer's DriWater 7.62-cm diameter plastic tube was placed in the ground with the bottom open to the roots of the plant and the top at or just above soil surface level, as per manufacturer's instructions. DriWater gels were replaced once a month in the hotter summer months (May-September) and every 80-90 days in the cooler months (October-April). Hand watering treatment included approximately

500-mL water once a month during all seasons. All plants were caged using quarter inch mesh hardware cloth. Outplanting survival surveys took place in March 2010, March 2011, and March 2012.

Disturbed Soil Transects

Within each of the 20 road segments, a 50-m soil transect was placed in approximately the center region of the segment. A 150-mL sample at 0-5 cm depth was taken from interspaces along the transect at 0-m, 25-m, and 50-m within 10-cm of the transect line along one side. Each set of three samples were composited per transect for a 460-mL sample. Additionally, bulk density analysis samples and soil seed bank samples were acquired with the same sample methods as the soil analysis sampling. Soil analysis Samples were acquired in July 2011 and analyzed at the Environmental Soil Analysis Laboratory at the University of Nevada, Las Vegas (UNLV). Soil analysis samples were dried and sieved through a 2-mm sieve and analyzed for texture (Lazor method due to high gypsum content); pH and electrical conductivity (1:3 soil:water); available P (Olsen sodium-bicarbonate extraction); $CaCO_3$ (manometer method, Burt); total C, N and S (dry combustion, CNS analyzer); organic C (subtraction of inorganic C from total C); NO_3, SO_4, and Cl (ion chromatography); and the water-soluble concentrations of the elements Na, K, Mg, Mn, Fe, Cl, Cu, Co, B, Mo, Pb, and Cd (1:3 soil:water extracts, inductively coupled plasma mass spectroscopy) following Burt (2004).

Bulk density analysis was conducted at the University of Nevada, Las Vegas. Bulk density was estimated by oven drying samples at 100°C for at least 8 hours and sieving sample through a 2-mm sieve. The fraction of <2-mm was then calculated with the volume (estimated by water displacement) of coarse fragments (≥ 2 mm).

A seed bank emergence assay was performed on samples to represent a year post outplanting after vegetative species would have flowered and dropped seed and over wintered. Samples were obtained in May 2011. Soil samples were immediately potted in 15-cm diameter pots at 2 cm depth on top of a 1:3 soil mixture of organic mulch to sand at UNLV greenhouse facilities. Pots were placed under an automatic watering system and watered two times daily, 0.5 cm per event with environmental conditions set at a spring time day/night time temperature range of 15/25°C. Due to the development of physical crust in these soils, the soil surface was roughened every few days to disrupt the physical crust layer. At two weeks, 150-ml solution of 1000 ppm of gibberellic acid was added to pots. As species were identified, they were tallied removed from pots. Pots were observed for 6 weeks. Unidentified individuals were classified into growth habits, if they did not survive to maturity.

DATA ANALYSIS

Salvage and outplanting analysis was done in four parts: survival of seedling that germinated after salvage in pots, survival of salvaged plants (salvage), field planting survival (outplanting), and environmental correlates with survival. The salvage plant treatments, IBA, slurry, and overnight water soak treatments, were not applied in a factorial design; subsets of data were used in

the analysis to avoid biased conclusions. Salvage analysis does not include seedlings that emerged after salvage and potting.

Seedlings

Seedlings individuals did not receive any additional treatment. Since these individuals were not as well established as salvaged plants and not as large in overall size, they were not included in the salvage or outplanting analysis due to differences in nursery resident time and differences in individual salvage treatments.

Salvage

The three salvage treatment factors, leaving salvage plants in water overnight, providing them with the rooting hormone IBA, or using a slurry, were not applied in factorial fashion; the subsets of data were used to avoid biased conclusions. The overnight soak was not an intentional treatment during the staging of the salvage operation; however enough individual plants were left overnight in water prior to potting that it became a factor. Overnight soak in water was combined with IBA for only one plant, and it was never combined with slurry; therefore, the effect of soaking in water overnight before planting was analyzed on the subset of data for which there was no IBA or slurry treatment (n=467 for no water soaking, n=98 for water soaking). For individual species, there were not enough plants to analyze an effect of overnight soaking (Appendix C, Table 1). However, there were sufficient data to estimate an effect by growth habit (grass, forb, or shrub), which was estimated including only species which had representatives in both overnight soaking treatments.

Each species was summarized into two groups (soaked, not soaked) for input into the analysis to account for the different sample sizes associated with species in each growth habit group for calculating *p*-values. Means were calculated based on each plant weighted equally. The design suggests a two-way factorial design which includes growth habit and overnight water treatment and their interaction. A generalized linear model (glm) was used with binomial error in PROC GLIMMIX in SAS 9.1 (SAS Institute 2002-2008, Cary, NC), which incorporates a logit link function. The effect of water treatment within growth habit was of particular interest and was therefore estimated in *a priori* contrasts. Means and standard errors were back-transformed to linear scale in order to represent the proportion of plants surviving.

IBA and slurry were assessed using the subset of plants which excluded plants soaked in water overnight. Treatments were not applied evenly across species (Appendix C, Table 2). Subsets of species were chosen to study the effects of IBA, slurry, and, where possible, the interaction between them, relative to species and growth habit. Four separate models were run to accommodate the varying structure of each species and treatment. The first two models were two-way glms with binomial error, and they included 1) IBA and 2) species (Appendix C, Table 2 & 3, 'IBA and no slurry', 'IBA with slurry' columns) as fixed effects. The species were in separate models because in the former group we could test IBA when no slurry was applied, and in the latter we could test IBA when slurry was always applied; a potential interaction between IBA and slurry might confound the effect of IBA if both groups were placed in

the same analysis. The second two models were three-way glms with binomial error, and they included the fixed terms and all two-way and three-way interactions (all tested over the error variance) for 1) IBA, slurry, and species, and 2) IBA, slurry, and growth habit. For the growth habit analysis, each species was summarized per each treatment combination of IBA and slurry.

Outplanting

Topsoil was not applied in only two segments: one block at the Echo Wash site and one block at the Valley of Fire site. All the Overton Beach Rd intersection sites did receive topsoil reapplication after road reconstruction. The analysis testing for the effect of topsoil excluded the Overton Beach Rd intersection sites. There were no species that received all watering treatments across both topsoil and no topsoil in sufficient numbers to test topsoil and watering treatments even when watering treatments were combined to "water" and "no water" categories. Therefore, to look at the interaction between topsoil and growth habit (forb, grass, shrub) or watering, the sum of the species that had represented across topsoil x watering (yes/no) regimes was used to represent forbs and shrubs in the analysis. Grass only had two species with limited numbers of individuals. "Watered" plants with topsoil were therefore a combination of DriWater treatment and hand watering treatment plants, while the "watered" plants in non topsoil areas were almost exclusively hand watered. The effect of watering without topsoil may be biased.

A hierarchical design dictated a mixed effects analysis of variance (ANOVA) model which included topsoil (tested over road segments within each of the three main sites) and watering (included or excluded), growth habit (forb, grass, or shrub), and all two-way and three-way interactions, each tested over their respective interactions with road segments within each site, as fixed effects. Since there was low statistical power to test the interaction between watering treatments and species or growth habit, we tested the effects of watering treatments within each species or growth habit as *a priori* contrasts. Bonferroni post-hoc comparisons were used for all other contrasts.

Soil Properties and Outplanting Survival

For each of the transect samples, 30 soil variables were considered. Inorganic C, $CaCO_3$, and total C were perfectly correlated ($r = 1.0$); only inorganic C was used in the analysis. Soil variables were parsed into three biologically relevant group: physical aspects of the planting location (10 variables; Appendix C, Table 4); macronutrient levels (8 variables), and micronutrient level (8 variables). The analysis is exploratory to form the basis for further research. To meet the model assumptions relating to linearity, constant variance, and to minimize outliers for this and all other soil variable analysis, sulfur, potassium, iron, manganese, and zinc were $\log_{10}$ transformed.

Many of the soil variables within each group were highly correlated ($r > 0.78$). Specifically, within the physical variables, EC and sodium absorption ratio (SAR) were positively correlated ($r = 0.91$), sand and clay were negatively correlated ($r = -0.91$), and particle size by volume and inorganic carbon were positively correlated ($r = 0.93$).

For the macronutrient variables, sulfur and potassium were positively correlated (0.84). The micronutrients sodium, boron, and molybdenum were all positively correlated (NA-B r = 0.87, Na - Mo r = 0.78, B - Mo r = 0.88). With this sample size, even moderate correlations can cause problems in a multiple regression.

Each soil variable was first modeled in a glm with binomial error, with survival after three years as a function of water addition (yes or no), the soil variable, and their interaction to study if soil properties might interact with water to enhance survivorship of transplants. After Bonferroni adjustment within groups, there was no indication of an interaction between soil properties and water; therefore, only one survival value was used to represent each soil transect in subsequent analyses. Simple logistic regression was run on each soil variable alone, with subsequent Bonferroni adjustment within the three groups (1 = species, 2 = water yes/no; and 3 = species x water yes/no). The odds ratios and p-values resulting from that analysis do not account for any other variables in the study; the coefficients reflect only the relationship between a soil variable and transplant survival after 27 months. Following, a logistic regression with multiple predictor variables was run, one for each of three groups (1 = species, 2 = water yes/no; and 3 = species x water yes/no). The odds ratios and p-values resulting from these analyses take into account all of the other predictor variables within that group.

RESULTS

Salvage Survival

Many of the species in the study could not be used in analyses looking at effects of salvage treatments due to imbalances in treatment application or insufficient sample size. However, an overall report of salvage and outplanting survival is provided. [A summary of the proportion of surviving plants and the 95% confidence interval (calculated from 1000 bootstrap samples in R2.14.2) after salvage and then after outplanting for 27 months is provided in Appendix C, Table 5, along with statistical model results.] Seedlings had far better transplant survival after three years than salvaged and transplanted counterparts of the same species. Results suggest that seedlings had 80% or better survival rate across all species (Table 78).

Soaking plants overnight after salvage either had no effect for grasses (*Pleuraphis rigida* was the only grass represented) or reduced salvage survival, qualitatively for forbs and significantly for shrubs (Figure 78). Forbs had the same qualitative pattern as shrubs, but the difference in survival was not statistically significant. For plants which were not soaked overnight, application of IBA or slurry made no statistically significant impact on salvage survival overall, and the qualitative response to IBA or slurry application was unique to each species. When species were grouped into growth habits, plants treated with the combination of IBA and slurry and plants which received no IBA or slurry treatment had higher salvage survival than plants treated with IBA or slurry alone.

Species varied in how well they survived salvage, but there was no consistent impact of IBA treatment on salvage survival across all species (Figures 79 & 80). Estimates of error were high due to limited sample size, but qualitatively, IBA improved salvage survival in *Astragalus preussii*, *Stephanomeria pauciflora,* and *Baileya multiradiata*, while IBA decreased salvage survival in *Enceliopsis argophylla, Isocoma acradenia, Suaeda moquinii,* and *Hymenoclea salsola* (Figures 79 & 80).

Salvage survival ranged from 14% for *Ephedra torreyana* to 69% for *Ambrosia dumosa* (Figure 81). For this set of species, we observed no significant effect of IBA or slurry treatments. Qualitatively speaking, most mean values were close together for IBA x slurry treatments, but three of the species showed potentially interesting response to treatments. *Larrea tridentata* salvage survival was 18 or more percentage points higher when treated with both slurry and IBA compared to no treatment or treatment with IBA or slurry alone. Trends suggest that *Psorothamnus fremontii* salvage survival was improved by slurry alone, but was depressed by IBA. Finally, trends for *Sphaeralcea ambigua* suggest that doing nothing or both IBA and slurry resulted in higher survival compare to IBA or slurry alone.

When species were grouped into growth habits, there was an overall interaction between IBA and slurry; treatment with neither IBA nor slurry or both IBA and slurry promoted better salvage survival than slurry alone, while IBA treatment alone had intermediate salvage survival (Figure 82). Looking at treatment effects within growth habits, there were no significant differences. Qualitatively, IBA improved the survival of forbs and shrubs when plants were treated with slurry, but IBA had either no effect or even a negative effect when plants were not treated with slurry.

Outplanting Survival

Influence from Topsoil

Outplanting success was increased at least 20 percentage points by the presence of topsoil, but this difference was not statistically significant. Watering dramatically improved transplant survival in all species, but the type of water application mattered. Survival improved by at least seven percentage points for forbs and at least 25 percentage points for shrubs. There was no indication that topsoil interacted with water and/or growth habit type in some synergistic way based on the qualitative trends (Figure 83). Only the water treatment, with or without, were shown to be statistically different.

Types of watering by species

Ambrosia dumosa (62%±13%; mean±SE survival) had one of the highest survival for outplanting followed by *Stephanomeria pauciflora* (51%±16%), *Sphaeralcea ambigua* (47%±15%), and *Eriogonum inflatum* (26%±11%) (Figure 84). Across all species, on average DriWater treatment (48%) consistently improved survival compared to the no water, however the difference was not statistically significant (Figure 84). Hand watering treatment was statistically better than no water treatment; outplanting survival was 62%. Although the interaction between watering methods and species was not significant, the *a priori*

contrasts within species suggested that hand watering treatment was significantly better for outplanted *Sphaeralcea ambigua* individuals compared to DriWater or no water treatments, while these differences were not significant in the other three species that had enough individuals per species for analysis (Figure 84). It is notable that survival was qualitatively lower with no water treatments compared to DriWater or hand watering across all species.

Types of watering by growth habit

Shrubs (53%±11% surviving) had significantly better outplant survival than forbs (34%±10%). The *a priori* contrasts comparing watering techniques within growth habits indicated significant (for shrubs) and marginally significant (for forbs) differences among watering treatments. For both growth habits, hand watering promoted better survival than no water, but for shrubs, DriWater was as effective as hand watering at aiding survival, while for forbs DriWater did not improved (and qualitatively even reduced) survival after outplanting (Figure 85).

Watering treatment by species

Species comparisons suggested significantly lower outplant survival for *Baileya multiradiata* (19%±9%) and *Eriogonum inflatum* (22%±11%) compared to *Ambrosia dumosa* (59%±13%), while all others were intermediate. Watering improved survival qualitatively for every species, but this result was only marginally statistically significant (Figure 86). The most reliable gains in outplant survival due to watering involved *Ambrosia dumosa* (35% improvement in survival due to watering), *Larrea tridentata* (209% improvement in survival due to watering), *Eriogonum inflatum* (166% improvement), and *Sphaeralcea ambigua* (101% improvement). The smallest improvement in survival due to watering was for *Baileya multiradiata* (35%).

Soil variables as covariates

There were no significant differences in the relationships between transplant success and soil variables between watered and unwatered sites. Results are interpreted from the logistic regression of each soil variable alone on the grounds that the correlations among variables were poorly estimated and that these correlations have a strong impact on results (Appendix C, Tables 15-17).

Physical variables

When considered alone, the slope, aspect, amount of organic carbon, and percent of clay and sand had no impact on outplant survival. However, ions in the soil reduced survival of the transplants. A 10% increase in EC decreased survival of transplants by 12%, while a 10% increase in the SAR ratio reduced transplant survival by 9% (Appendix C, Table 15). A 10% increase in inorganic carbon was associated with 11% improved survival, while a 10% increase in the closely related percent of particles greater than 2mm by volume resulted in 19% better transplant survival. Ten percent greater bulk density decreased survival of outplants by 12%.

Macronutrients

Total nitrogen and phosphorus had no significant effect on transplant success (Appendix C, Table 16). However,

biologically available nitrogen (NH_4 and NO_3) levels were associated with lower transplant survival: 10% reduction in survival for a 10% increase in ammonium and a 14% reduction in survival associated with a 10% increase in nitrate. All other macronutrients showed the same pattern, where 10% increases in (log_{10}) sulfur, (log_{10}) potassium and magnesium were associated with 13%, 14%, and 8% reductions in transplant survival, respectively. Calcium increase was also associated with a reduction in survival, but association was not present when two extreme outliers were removed.

Micronutrients

With the exception of iron, which had no significant relationship with transplant survival, higher micronutrient levels were associated with reduced transplant survival (Appendix C, Table 17). The associated decrease in survival ranged from 6% for a 10% increase in boron to a 21% reduction in survival for a 10% increase in copper. There was one outlying data point for copper, but the relationship was the same with or without it.

Seed Bank

Out of the 20 potted transect samples, 13 produced seedlings and only three samples produced a single native annual species, all three forbs of different species. One-hundred percent of the grasses were non-native, while only 50% of the forbs were non-native across all samples (Figure 87). A majority of the samples with seedlings (64%) contained 1-2 individuals of the non-native annual grass Mediterranean grass (*Schismus* sp.), and a single sample resulted in 26 individuals of the non-native annual grass red brome (*Bromus rubens*). Two samples resulted in African mustard (*Malcolmia africana*), a non-native forb that is of growing concern, particularly in gypsum habitats. And three samples resulted in prickly Russian thistle (*Salsola tragus*) seedlings. Overall, however, germination was low, with a mean species richness of one.

DISCUSSION

Plant Salvage

Salvaging native perennial plants prior to a known disturbance event to use in restoration treatments can reduce the overall time for revegetation. Results suggest concentrating salvage on dominant species to reduce overall time-effort, particularly shrubs, which overall had the highest density and salvage survival. Treatments used in this study included a root-stimulating hormone, IBA, and slurry composed of water and a super water-absorbing product, which appears to have an interaction with the IBA; however, this was not assessed as to why in this study. Additionally, the slurry was used to avoid root entanglement, however whether this preventative measure was successful was not recorded or notes. Across plants taken as a whole, there was no improvement due to these treatments on survival. However, at an increased resolution, both treatments had different effects on growth habits of species and on specific species. Within growth habit groups, the application of either both treatments or neither treatment resulted in higher survival compared to a single treatment (IBA or slurry alone). Since the survival between treatment of plants by both

IBA and slurry or neither is not statistically significant, an examination of the time-effort required for treatment should be included in future salvage operations, or application should be limited to specific species. Shrubs were the dominant growth habit salvaged. Neither IBA nor slurry treatment appeared to be a factor in overall shrub survival, although if shrubs received the slurry treatment, they did have a higher survival with the additional application of IBA treatment. The application of both treatments did not statistically improve survival suggesting that time-effort should be assessed for future salvage efforts. For forbs, a similar situation resulted. *Astragalus preussii*, *Baileya multiradiata*, and *Stephanomeria pauciflora* had improved survival with both treatment applications. Since all three of these species are short-lived perennial forbs, this coincides with statistical analyses assessing treatment survival by growth habit: forbs had a greater survival rate, although not statistically, with neither salvage treatment applied or with both treatments applied, and when neither treatment was applied the survival rate was greater compared to both treatments applied.

Incidental Field Protocol Assessment

Salvage protocols for this project did not include a soaking overnight as a treatment. Incidental soaking overnight, likely due to field time restraints, resulted in those individuals on average having an increase in mortality. As suggested by the data, overnight soaking of plants ought to be avoided, if possible.

Nursery Care and Maintenance

Watering treatment for salvage plants was not assessed during this study; however overall salvage plants had good survival rates. Moving plants from Overton Beach Ranger housing to the LMNRA nursery facilities resulted in a reduction of overall survival marginally (~10-15% mortality; information not included above; individual species not assessed); however, it is not clear that this specific action resulted in the reduction of survival, although, in time these events were successional. There was a higher rate of seedling occurrence after the plants were moved and after plants had produced mature seed. Seedlings acquired from salvage plant pots over the course of the nursery resident period had high survival rates. This data suggests repeating this practice, if possible, instead of thinning pots without transplanting seedling individuals to a separate pot. It was not noted which seedling species occurred within specific salvage species pots.

Outplanting

Quantitatively, topsoil was influential on outplanting survival for both species which received a watering treatment and species which did not receive a watering treatment. Where the Northshore Rd corridor was actually realigned, these old road bed areas did not receive topsoil reapplication due to a lack of overall topsoil salvaged. In these instances, an effort to reduce the visual irregularity may be desired. However, a greater number of resources would be required to achieve a desired density of surviving individual plants. Additionally, handing watering and the application of DriWater treatment increased overall

survival of plants compared to a no water treatment. At a growth form level, both forbs and shrub responded better to hand watering treatment, which at a species level also appears to be the recommended treatment. For shrubs hand watering and DriWater treatments were statistically different, although quantitatively not by a significant degree. At a species level, assessment of watering treatments for shrub were limited to *Ambrosia dumosa*, which had the greatest number of individuals for a species for outplanting. In this instance, watering treatment did not vary significantly; therefore, application of watering treatment ought to be assessed based on other factors, such as cost for resources and personnel labor over time.

CONCLUSION

The results for this study are limited to gypsiferous soil and adjacent soil communities along Northshore Rd in LMNRA. However, the general results from the salvage and outplanting projects may be applied on a larger landscape to test if these results may apply to a larger geographical area that contains gypsiferous soils or can be generally applied to other soil types. Overall, salvage and outplanting was found to provide in most areas a live revegetated cover which otherwise under natural conditions would have required much longer time spans. The use of IBA during salvage did not provide a large improvement in overall survival, and for some species reduced salvage survival. The slurry treatment had an interactive effect that needs to be further examined, although slurry treatment itself had a mostly negative influence on survival. For outplanting, watering treatment appears to be necessary for plant establishment although treatment appears to be growth habit or species specific and likely should be applied at that level, if both are used in a future project.

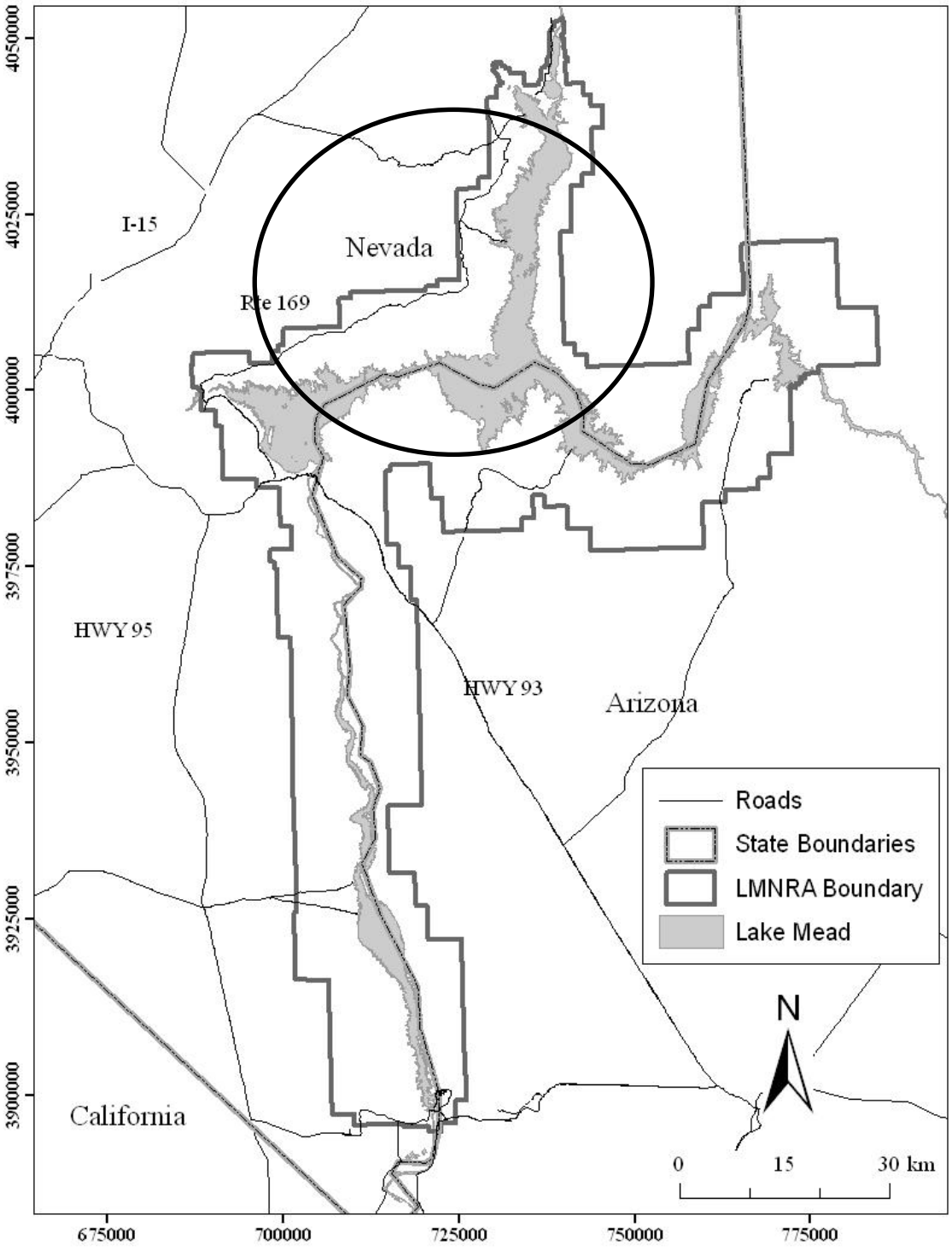


Figure 76 The extent of Lake Mead National Recreation Area (grey outline), located within the eastern Mojave Desert, USA, in the southwestern United States along the Colorado and Virgin River basins, with area circled where large, continuous areas contain gypsiferous soil habitat. UTM NAD 83, Zone 11N.

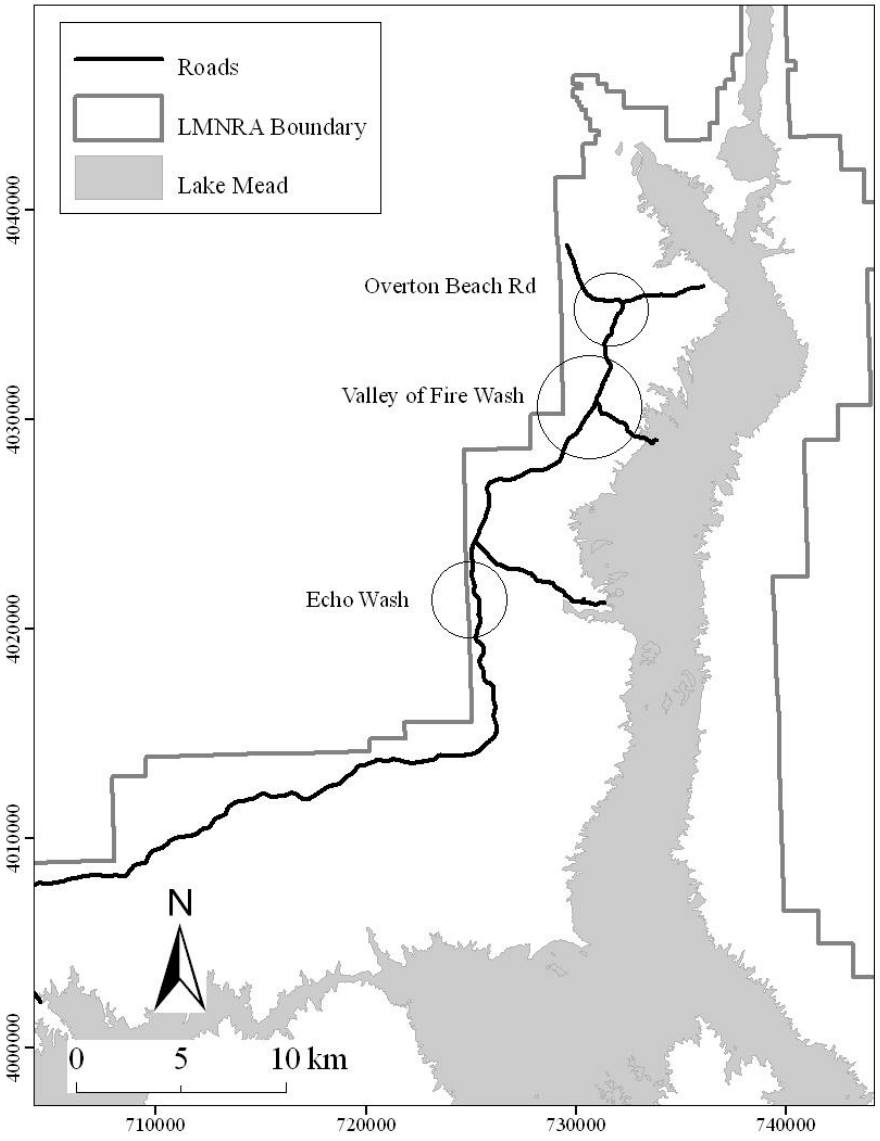


Figure 77 Areas circled along Northshore Rd in Lake Mead National Recreation Area, Mojave Desert, USA that were identified as slated for realignment in 2007 for the 2008 Rehabilitate Northshore Rd Project by the Federal Highway Administration, and salvage plant locations along Northshore Rd around Echo Wash, Valley of Fire Wash, and at the intersection with Overton Beach Rd. UTM NAD 83 Zone 11.

Table 78 Seedling survival by species for plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area, prior to outplanting (January 2010) along the same regions along Northshore Rd after road realignment and reconstruction.

Species	Died before outplanting		Survived to outplanting		Grand Total
Ambrosia dumosa	4	10%	37	90%	41
Astragalus preussii	1	20%	4	80%	5
Atriplex confertifolia			1	100%	1
Atriplex hymenelytra			1	100%	1
Baileya multiradiata	5	10%	43	90%	48
Encelia virginensis			2	100%	2
Eriogonum inflatum	1	6%	15	94%	16
Gutierrezia sarothrae	1	100%		0%	1
Isocoma acradenia			3	100%	3
Pleuraphis rigida	1	100%		0%	1
Sphaeralcea ambigua			22	100%	22
Stephanomeria pauciflora	3	18%	14	82%	17
Suaeda moquinii			1	100%	1
Tidestromia oblongifolia			4	100%	4
Grand Total	16	10%	147	90%	163

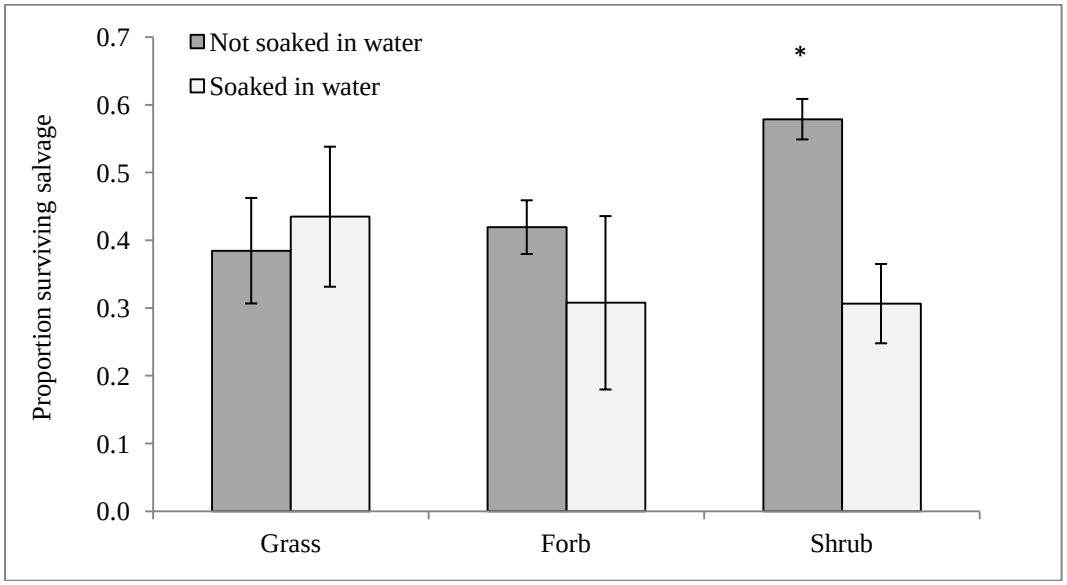


Figure 78 Proportion of plants grouped by growth habit surviving salvage with or without soaking in water overnight from plants salvaged from areas along Northshore Rd, Lake Mead National Recreation Area. Means and standard error are reported, with '*' denoting a significant difference in water treatment for that growth habit (α=0.05).

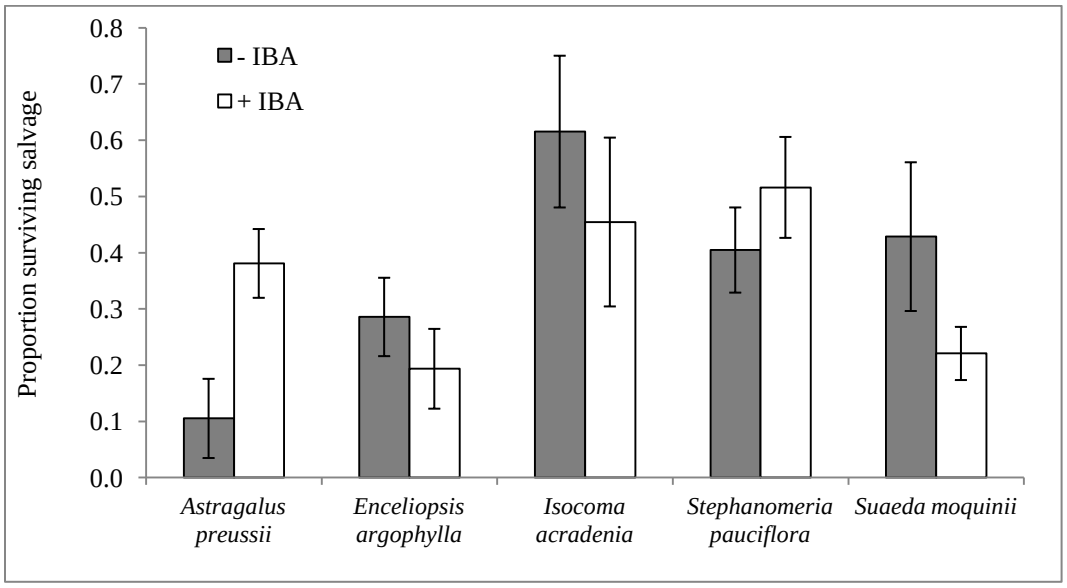


Figure 79 Means with standard error of the proportion of five plant species surviving salvage with and without the root-stimulating hormone IBA treatment across five species which were not treated with slurry or overnight soak in water for plants salvaged along Northshore Rd, Lake Mead National Recreation Area . "- IBA" is without IBA treatment, and "+ IBA" is with IBA treatment.

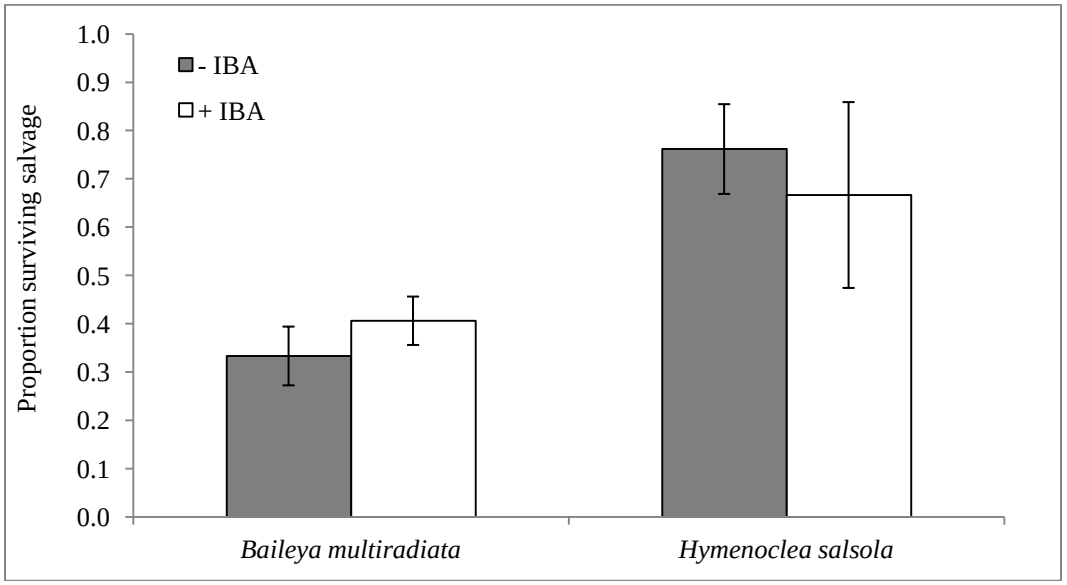


Figure 80 Means with standard error of the proportion of two plant species surviving salvage with and without the root-stimulating hormone IBA treatment across five species which were not treated with slurry or overnight soak in water for plants salvaged along Northshore Rd, Lake Mead National Recreation Area . "- IBA" is without IBA treatment, and "+ IBA" is with IBA treatment.

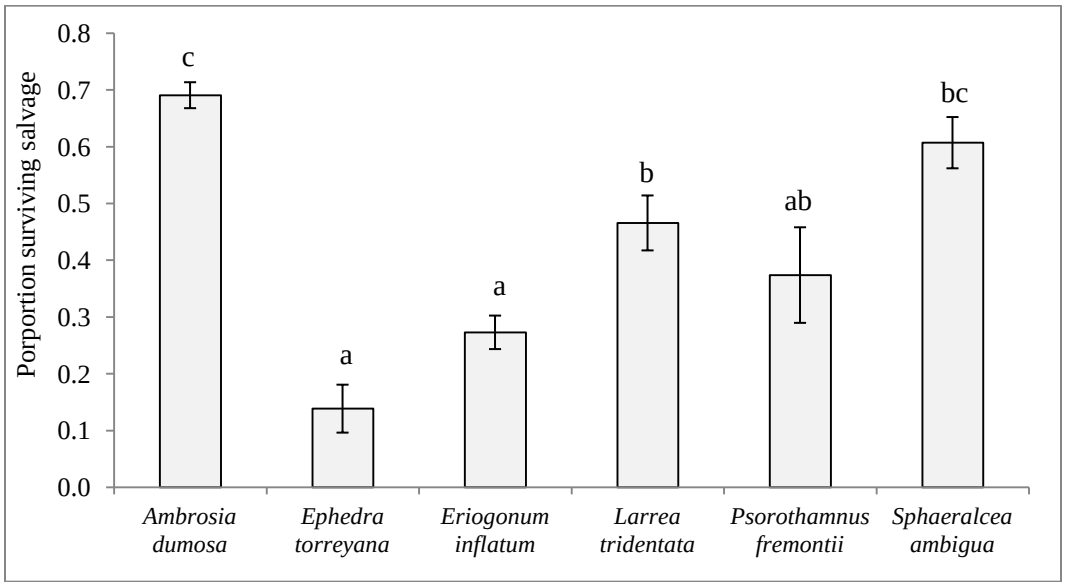


Figure 81 Means with standard error for proportion of surviving salvage plants across species used to determine effects of the root-stimulating hormone IBA, and slurry together for plants salvaged along Northshore Rd, Lake Mead National Recreation Area. Letters denote significant differences between species (α=0.05).

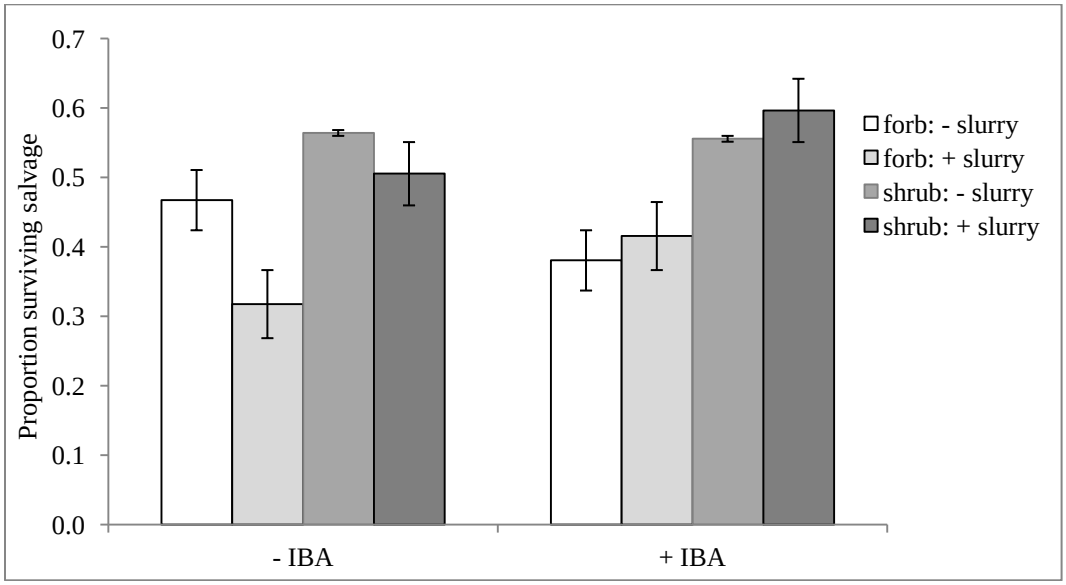


Figure 82 Salvage survival of plants from along Northshore Rd, Lake Mead National Recreation Area, grouped into growth habit and within root-stimulating hormone (IBA) and/or slurry treatment.

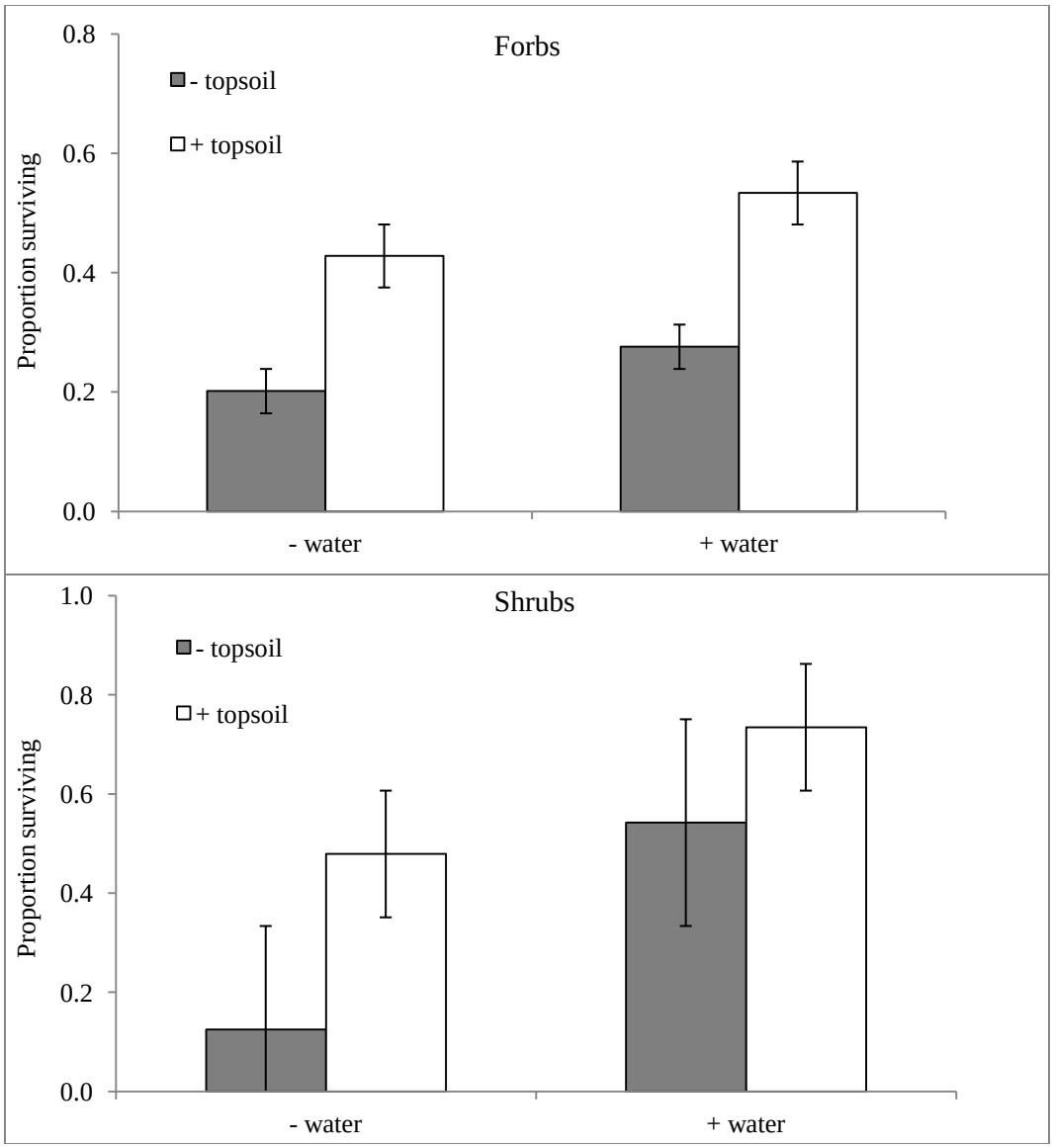


Figure 83 Mean survival with standard error for forbs (top) and shrubs (bottom) treated with (+) or without (-) topsoil and with (+) or without (-) added water treatment for outplanted plants along Northshore Rd, Lake Mead National Recreation Area.

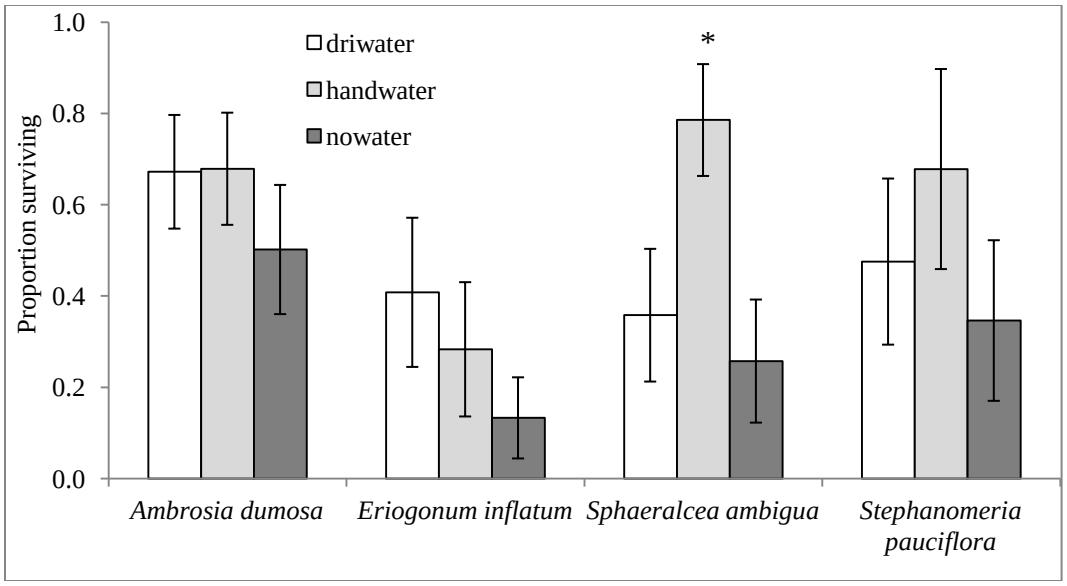


Figure 84 Means with standard error for water treatments across four main outplanted species along Northshore Rd, Lake Mead National Recreation Area. "*" denotes a significant different from other watering treatments for that species.

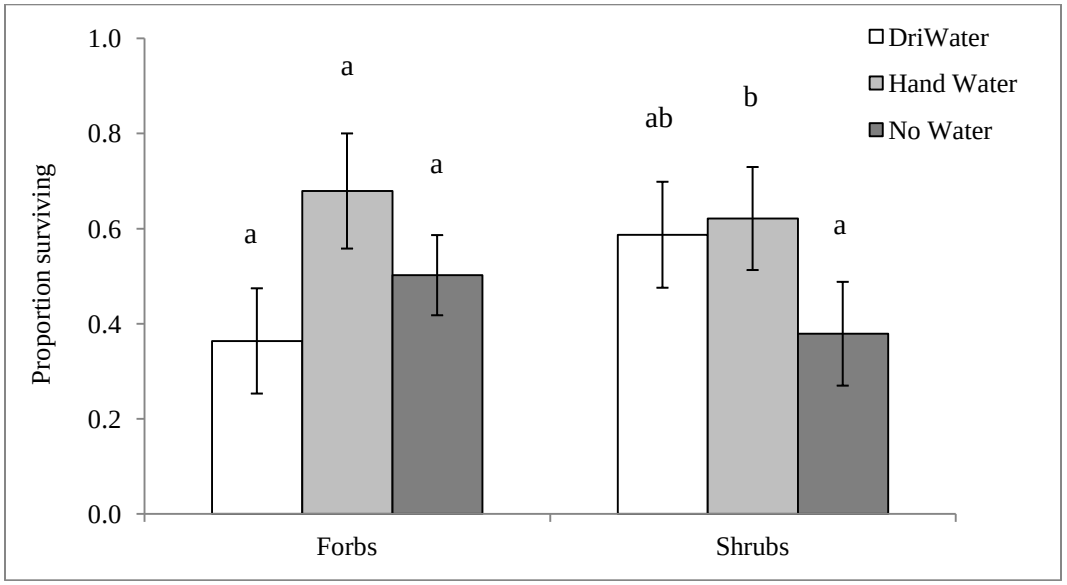


Figure 85 Means with standard error for watering treatments across all species grouped by growth habit for plants outplanting along Northshore Rd, Lake Mead National Recreation Area. Letters denote differences at $\alpha = 5$. At $\alpha = 0.10$, for forbs: a, b, ab, and shrubs b, b, a.

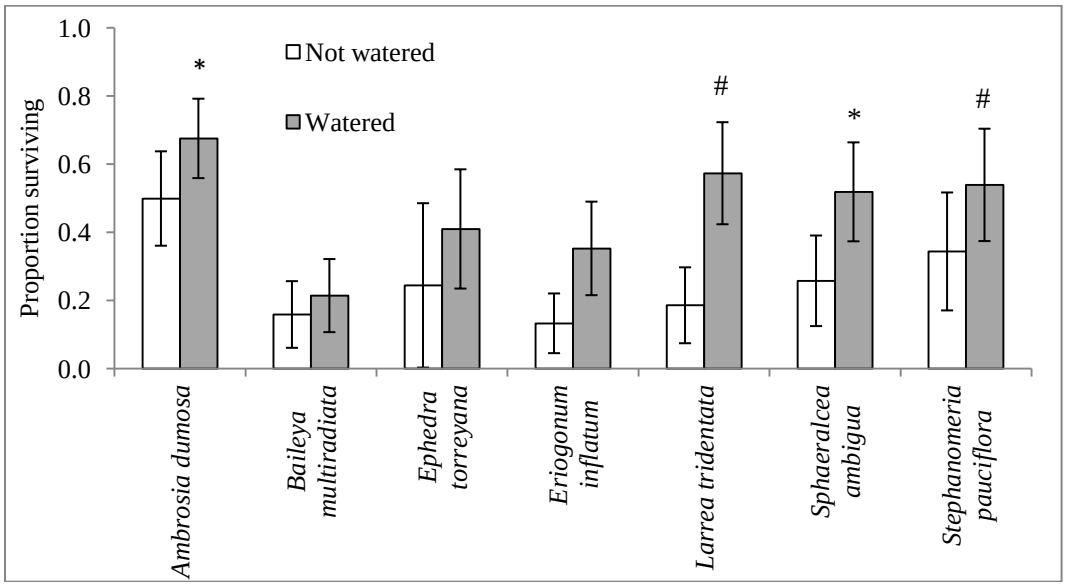


Figure 86 Means with standard error for the addition of watering treatments across species: "*" denotes *a priori* tests within species $P<0.05$ and "#" denotes *a priori* tests within species $P<0.10$.

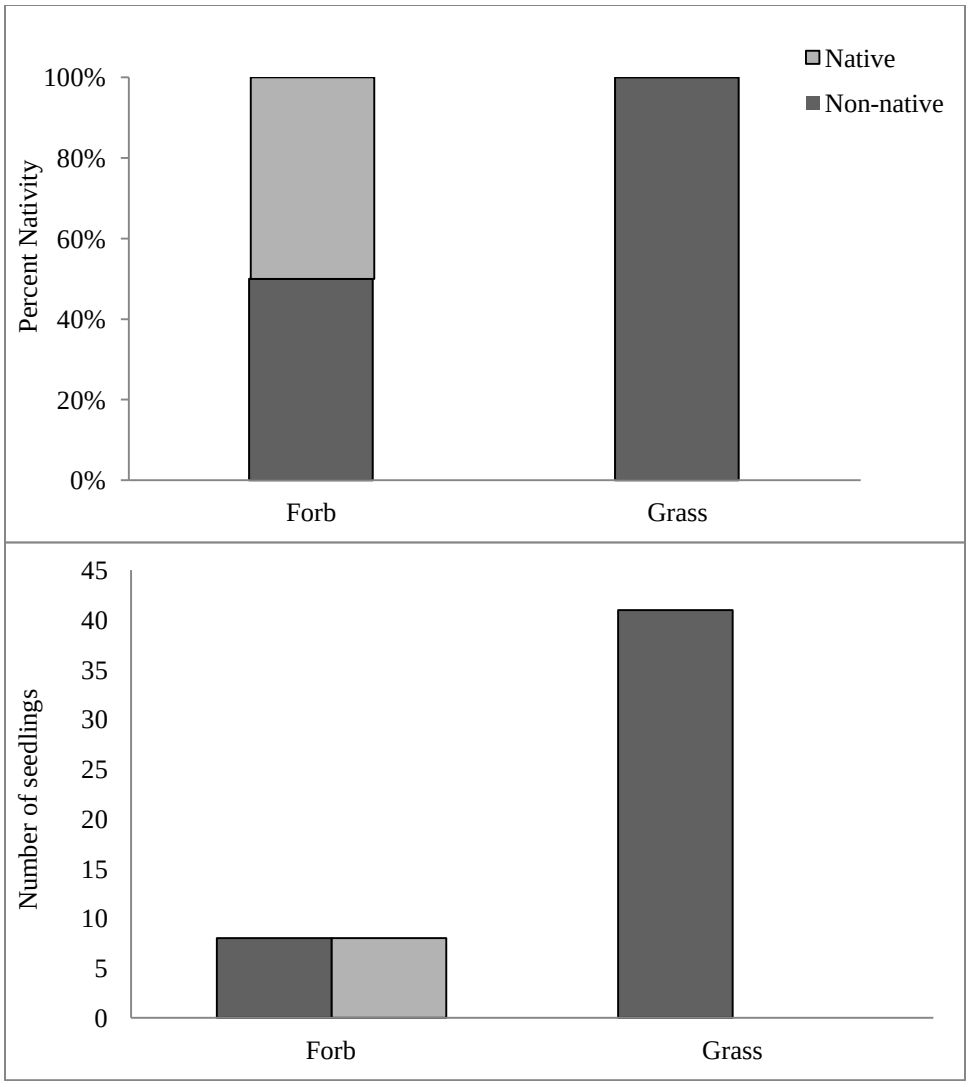
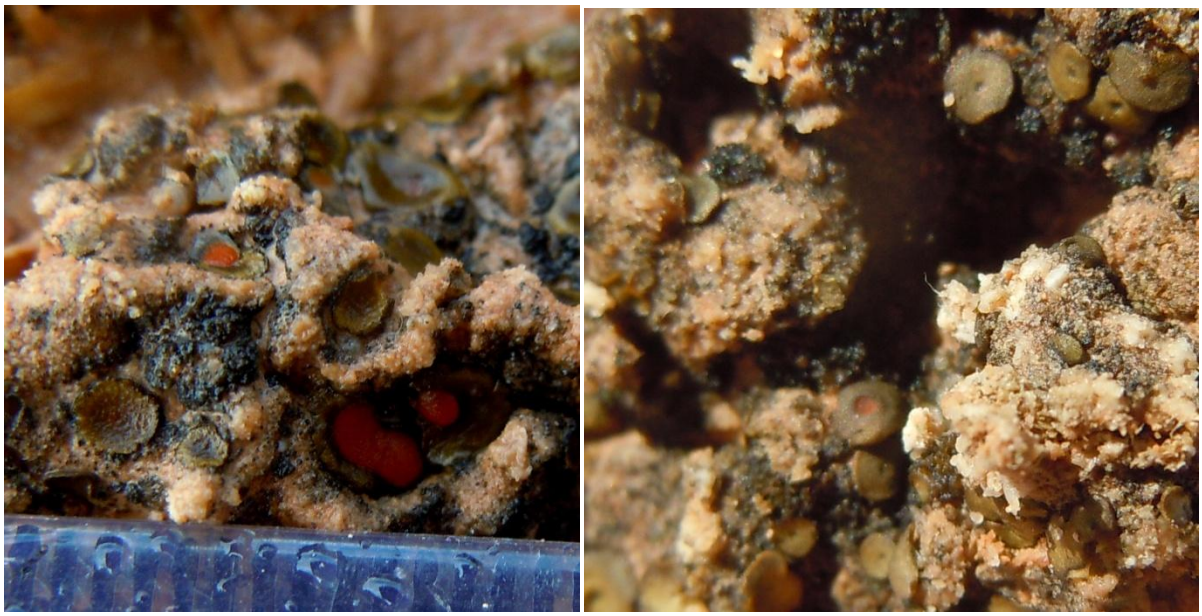


Figure 87 Percent seedling emergence per growth habit and nativity for all 20 soil transect seed bank samples from disturbed road segments along Northshore Rd, Lake Mead National Recreation Area.

PART 2. *Restoration of Biological Soil Crust on Disturbed Gypsiferous Soils in Lake Mead National Recreation Area, Eastern Mojave Desert*, MS Thesis, University of Nevada, Las Vegas



Contributed by Lindsay P. Chiquoine, Master of Science, University of Nevada, Las Vegas (2012).

Project Summary

This research explores the potential of restoring biocrust (also known as biological soil crust, BSC, biogenic crust, microbial crust, and cryptogamic crust) communities as a benefit for the overall rehabilitation of a disturbed landscape by utilizing salvaged biocrust as inocula in disturbed habitats in combination with resource augmentation and surface soil stabilization treatments to accelerate the ecosystem trajectory toward sustainability. This research monitors the progress of treatment applications to identify the impacts on biocrust organisms through the processes of salvage, storage, and field inoculation. The goals of this research were to identify the potential barriers to recovery and rehabilitation of biocrusts specifically in gypsiferous soil habitat in Lake Mead National Recreation Area, eastern Mojave Desert, and identify and test applicable restoration techniques for these systems through a comprehensive literature review of the past decades of biocrust and restoration research, and to implement experimental restoration treatments in highly disturbed gypsiferous soil biocrust communities. Field, greenhouse, and laboratory studies were used to examine the impacts of disturbance on biocrust organisms, observe the impacts of storage, and test the use of salvaged biocrusts as inocula.

Field results revealed complex relationships between the biocrust microscopic and macroscopic cover, soil stability, and

available nitrogen with the main treatments, which included biocrust inoculation to reintroduce native soil biota, topsoil reapplication to investigate the significance of the presence of surface soil, wood shavings as a method to increase surface soil stability, and a native perennial shrub in investigate any potential shrub presence-BSC interactions. Inocula increased the macroscopic and microscopic biocrust organisms, stabilized the surface soils, reduced non-native annual plants, and increased ammonium. Topsoil alone increased cyanobacteria by 186% compared to plots without topsoil. Topsoil treatments also had the highest non-native annual cover, although the addition of BSC inocula to topsoil sites resulted in reduced non-native presence.

Due to issues with blowers, humidity, and temperature controls during the greenhouse study, it was difficult to maintain adequate temperatures and hydration levels resulting in high mortality of crust organisms, particularly mosses and lichens. An evaluation of the study procedures and suggestions for future experiments are provided for methodological improvements.

In the laboratory studies after approximately 3 and 4 years of storage, the soil lichen *Collema* had reduced chlorophyll-fluorescence values compared to undisturbed field specimens. After 3 years of storage, glucose solutions, which were added to specimens to test the potential for treatment to test the effects on photosystem recovery after storage, increase the recovery and rate of fluorescence, while mannitol solutions, applied to test the same hypothesis, shortened the time for chlorophyll-fluorescence recovery. Slurry inoculation, tested only within the laboratory setting, with glucose addition applied on autoclaved native gypsiferous soils resulted in higher cyanobacteria cover compared to inoculated only flats, suggesting that the addition of easily accessible carbon may assist with improving development of biocrust and reducing the time of development.

Entire methods and results are included in the thesis manuscript, which is attached as Appendix D.

SECTION V. *The Arthropod Community in Gypsiferous Soils within Lake Mead National Recreation Area*

Contributed by Ben Jurand (Research Assistant), University of Nevada, Las Vegas

KEY FINDINGS AND MANAGEMENT IMPLICATIONS

Ants

- The 9,808 ants sampled in this study comprised 19 species in 3 subfamilies: Myrmicinae, Formicinae, and Dolichoderinae
- In the subfamily Myrmicinae, 13 species were identified in 6 genera including *Messor, Pheidole, Pogonomyrmex, Solenopsis, Aphaenogaster,* and *Cardiocondyla*
- Myrmicinae were represented by 80% of the samples, were most abundant overall, and had the greatest species richness with 13 species in 6 genera
- There was a greater abundance of ants sampled in non-gypsum (desert pavement) soils compared to gypsum soils
- Spatial distribution between open interspace and under shrub microsites was variable among species

Beetles

- There were two confirmed species new to science of flightless scarab beetles (Family Scarabidae) in the genera *Phyllophaga* and *Diplotaxis*
- In total, 3,730 beetles were identified in this sampling, representing 111 species in 23 families
- The most abundant families, also the most species rich, included soft flower beetles, snout and bark beetles, and darkling beetles
- The most abundant of the 23 beetle families were sampled in both gypsum and desert pavement habitats
- Ant-like flower beetles were much more abundant in desert pavement than gypsum habitats. Soft-winged flower beetles, scarab beetles, clown beetles, carpet beetles, and blister beetles were only relatively more abundant in desert pavement habitats
- Abundance within microsites varied with species

PROJECT PURPOSE

The purpose of this study was to provide observational and experimental data concerning species composition, distribution, relative abundance, and microhabitat use of the insect assemblage in gypsum and non-gypsum desert pavement soils at Lake Mead National Recreation Area (LMNRA). Sampling of invertebrates took place in conjunction with the realignment of approximately 2.5 km of North Shore Road. Our objectives were to: (1) establish baseline data sets of local insects in Mojave Desert habitats, particularly ants and beetles; (2) investigate patterns of species abundance and distribution in gypsum and non-gypsum desert pavement soil types; and (3) evaluate the effects of vegetation structure and environmental factors on distribution, abundance and species composition.

This section attempts to identify insects and specifically arthropods, within gypsiferous communities in LMNRA which may play a role in restoration planning. This is feasible because LMNRA has already supported a pilot inventory that has resulted in an insect reference collection to at least the functional group level. Insect colonization along the Northshore Rd corridor was evaluated using techniques that have already been used and approved by LMNRA. Additionally, a picture field guide for beetles found in gypsiferous soil communities through this study was developed and is attached (Appendix F) as a pdf to this report.

INTRODUCTION

Invertebrates are important components of desert ecosystems, serving critical functions and contributing greatly to ecosystem biodiversity. Invertebrate communities in rare plant habitats may be especially critical, given the potential links between invertebrate pollinators and seed distributors in sustaining populations of rare plant species. Lake Mead National Recreation Area (LMNRA) contains areas of unique gypsum soils, which support rare plant species such as the Las Vegas bearpoppy (*Arctomecon californica*). Gypsiferous sites also support a well-developed biological crust where a host of symbiotic relationships occur (Lovich and Bainbridge 1999). Biological soil crust can be easily destroyed by certain human activities; therefore, investigations in such habitats are limited. Because so much gypsum habitat has been lost to urban development and degradation by off-road vehicles and other land uses in the Las Vegas Valley, these unique habitats and their associated biota within LMNRA are extremely important to the ecology of the region.

Clear successional interactions between the structure of communities and invertebrate species richness (Costa et al. 2010) make invertebrates excellent bioindicators of ecosystem health. Ants (Order Hymenoptera, Family Formicidae), for example, can be thought of as ecosystem engineers, altering physical and chemical properties through their activities (Folgarait 1998). They may act as seed dispersers, pollinators, or plant guardians and as such have developed symbiotic relationships with many species (MacMahon et al. 2000). Colony building increases nutrient cycling rates and associated microbial activity affects soil structure (Fagan et al. 2010), creating islands of increased nutrient density (MacMahon et al. 2000). Additionally, harvester ants are a major consumer of seeds in deserts (Brown et al. 1979). The most specialized invertebrate granivores belong to the genera *Pogonomyrmex*, *Pheidole*, and *Messor* (Brown et al. 1979). These ants collect seeds from the surface and store

them for later consumption in nests (MacMahon et al. 2000), directly affecting the reproductive outputs and spatial distribution of the plants surrounding ant nests (Rissing 1986).

Ant diversity itself is affected by the density and diversity of plant species as well as abiotic factors like temperature, humidity, and soil composition (Costa et al. 2010). As such, ants are strong bioindicators of rehabilitation success in land management (Majer 1983, Andersen and Majer 2004). Understanding distribution and species composition of harvester ants in gypsum and non-gypsum soil types are necessary to assess their relative impact to plant communities and to evaluate management strategies of Mojave Desert habitats.

Beetles (Order Coleoptera) also perform important ecosystem functions and are one of the most species-rich groups of organisms with some 350,000 species worldwide (Evans and Hogue 2004). Some beetles act as pollinators (Kevan 1999), while others are decomposers and breakdown dead or discarded matter. Ground beetles (Family Carabidae) have been considered useful bioindicators because they not only perform important ecosystem functions, but also are sensitive to environmental changes (Cárdinas and Hidalgo 2007). Similarly, as members of one of the most conspicuous group of terrestrial desert animals (Kramm and Kramm 1972), darkling beetles (Family Tenebrionidae) are excellent candidates for studies that investigate local population size and species distribution across habitats. Previous studies have shown that the relative abundance of darkling beetles differs across habitat types, soil texture and temperature gradients in semi-arid shortgrass steppe, creosote scrub, and sand dunes mesquite habitats. In deserts, beetles may be particularly important by acting as pollinators or seed distributors, helping to sustain populations of rare plant species. LMNRA contains areas of unique gypsum soils, which support rare plant species such as the Las Vegas bearpoppy (*Arctomecon californica*). Gypsiferous sites also support a well-developed biological crust where a host of symbiotic relationships occur (Lovich and Bainbridge 1999). Biological soil crust can be easily destroyed by certain human activities; therefore, investigations in such habitats are limited. Because so much gypsum habitat has been lost to urban development and degradation by off-road vehicles and other land uses in the Las Vegas Valley, these unique habitats and their associated biota within LMNRA are extremely important to the ecology of the region. However, our knowledge of beetle distribution in gypsum soils is limited.

METHODS

LMNRA is located in southeastern Clark County, Nevada USA within an area greater than 1.5 million ha in the Mojave Desert. At LMNRA, predominant plant communities include desert scrub, gypsum benches, and gypsum uplands. Five 10 m × 10 m plots each were established in both gypsum and desert pavement (non-gypsum) habitat types (Figure E.1; Table E.1). Habitat types were selected based on existing soil maps and chemical analyses for gypsum content. Within each plot, the spatial position of five randomly selected creosote bushes (*Larrea tridentata*) was recorded using a handheld GPS unit.

To evaluate effects of microhabitat types on invertebrate abundance, five interspaces between shrubs were established based on a randomly chosen cardinal direction, positioned approximately 2 m away from a creosote bush. Ambient and soil temperatures were collected using HOBO

temp data loggers located at each microhabitat, both under a creosote bush and in an interspace.

At each microhabitat site, four pitfall traps were used to sample invertebrates. One trap was positioned in each cardinal direction. Pitfall traps consisted of a plastic cup (190 mm diameter, 120 mm deep) buried flush with the ground surface. Propylene glycol was used as a killing agent. Field sampling was conducted in April, August, and November of 2008 in the Lake Mead National Recreation area. Traps were open for four consecutive days at each sampling time.

After collection, specimens were rinsed and stored in alcohol. The specimens were sorted, first by order, then by genus and species, where possible. Beetles were identified and vouchered by the Department of Entomology at the University of California, Riverside, CA. Ants were identified using Wheeler and Wheeler (1986) and Fisher and Cover (2007).

RESULTS

Ant Species Richness

The 9,808 ants sampled in this study comprised 19 species in 3 subfamilies: Myrmicinae, Formicinae, and Dolichoderinae (Table 79). In the subfamily Myrmicinae, we identified 13 species in 6 genera including *Messor, Pheidole, Pogonomyrmex, Solenopsis, Aphaenogaster,* and *Cardiocondyla*. These harvester ants, most noted for collecting and dispersing seeds, are an extremely diverse subfamily, and are widely distributed across varied habitats (Boulton 1994). Myrmicinae were represented by 80% of the samples.

Messor pergandei was the most abundant individual ant species sampled in this study (Table 79, Figure 88) and is one of the most common ant species in Mojave (Wheeler and Wheeler 1980). The species is continuously size polymorphic with no clear divisions in worker size (Davidson 1977). *M. pergandei* creates massive colonies with large (30 cm) craters of piled chaff (Wheeler and Wheeler 1988) containing between 30,000–50,000 workers that forage in groups forming extensive columns for seeds (Johnson 2000). Foraging activity begins in late spring before sunrise and is most active after sunrise before ending by afternoon on hot days (Wheeler and Wheeler 1988).

Pogonomyrmex, an important harvester ant genus (MacMahon et al. 2000), was the most species rich genus sampled in the study. Species included were *Po. apache, Po. desertorum, Po. rugosus,* and *Po. imberbiculus* (Table 79). *Pogonomyrmex* has prominent physical features such as spines, stingers and psammophores that help transport seeds and soil (Wheeler and Wheeler 1988). *Po. Rugosus* (the most abundant species sampled within the genus) forages for seeds in trunk trail groups (Johnson 2000). Collected seeds are cached in colonies (Wheeler and Wheeler 1986) that contain between 5,000 and 10,000 workers (Johnson 2000). Colonies have distinct entrances surrounded by a crater and can be on sandy or rocky soils (Wheeler and Wheeler 1988). Although often widely spaced, overlapping territories of neighboring colonies results in both intra- and interspecies territorial defense (Davidson 1977) and aggressive behavior, especially when colonies are disturbed (Wheeler and Wheeler 1988).

The genus *Pheidole* included three morphospecies, one identified as *Pheidole desertorum* (Table 79). *Ph. desertorum* are

nocturnal and are generally solitary foragers, although workers do recruit nestmates to forage larger food sources (Johnson 2000). *Ph. desertorum* builds nest in the soil (Wheeler and Wheeler 1988) in colonies ranging from a few hundred to 10,000 workers (Johnson 2000). Most *Pheidole* (including *Ph. desertorum*) species have a starkly dimorphic worker caste of fast and aggressive workers with majors having extremely large heads compared to minors (Wheeler and Wheeler 1988).

A minute and monomorphic Myrmicinae genus, *Solenopsis* was represented by two morphospecies including *Solenopsis xyloni*. These species act as thief ants living colonies of larger species and are commonly called "fire ants" (Wheeler and Wheeler 1988). *Aphaenogaster cockerelli* is an omnivorous Myrmicinae species that lives in small to moderate sized colonies in gravel and sand soils or under rotting wood (Wheeler and Wheeler 1988). Solitary foragers, *A. cockerelli* forage in late afternoon and night for seeds, insects, and other debris (Johnson 2000).

The subfamily Formicinae is the second largest ant subfamily with over 200 North American species and is distributed across diverse habitats (Boulton 1994). We sampled three Formicine species in two genera: *Myrmecocystus* and *Paratrechina* (Table 79). Also known as carpenter ants, Formicinae species have an acidopor rather than a stinger (like Myrmicinae) that excretes formic acid (Wheeler and Wheeler 1988). Formicinae species often display temporary parasitism and slave making and subsist on plant and insect secretions, nectars, and honeydew (Creighton 1950). The genus *Myrmecocystus*, also known as honey ants (Wheeler and Wheeler 1988), included two morphospecies in the samples. Species like *Myrmecocystus yuma* are diurnal and feature a caste called repletes that store nectar in their greatly enlarged gasters. The repletes live deep within the colony, where they maintain and distribute the stored nutrients to nestmates (Wheeler and Wheeler 1988). Another Formicinae species sampled was *Paratrachina hystrix*, a nonaggressive species that forages both day and night for nectar, honeydew, and insects (Wheeler and Wheeler 1988), although this species was not greatly abundant.

The third subfamily sampled was Dolichoderinae, also known as odorous ants, and were represented by three species in two genera: *Dorymyrmex* and *Tapinoma* (Table 79). This is a small subfamily with only 19 North American species (Wheeler and Wheeler 1988) and is generally small in size (<5 mm length) (Boulton 1994). While Dolichoderinae vary in habitat and behavior, most are soil nesters and display little dietary specialization (Creighton 1950). *Dorymyrmex bicolor* and *D. insanus* are both fast moving species that nest in open unshaded interspace areas. *Tapinoma sessile* is a common species with colonies ranging from small to large. Nests are constructed in soil under stones and debris and can have multiple queens (Wheeler and Wheeler 1988).

Ant Abundance Over Time

The August sampling produced the greatest abundance of ants (n = 7,301), followed by April (n = 2,243). The November sampling (n = 264) did not include all plots used in April and August but rather only included three sites from gypsum soils; no non-gypsum desert pavement plots were sampled in November. *M. pergandei* was exclusively found in August samples where it was hugely abundant. *Pogonomyrmex* was most abundant in April and was only slightly less so in August but was virtually nonexistent in November samples. *Pheodole*, *Solenopsis*,

and *Tapinoma* increased in abundance from April to August but declined in November. Spring was the most abundant sampling time for *Myrmecocystus* and *Aphaenogaster*. *Dorymyrmex* was similarly abundant at all three sampling times (Figure 89).

Ant Abundance in Gypsum and Desert Pavement Soils

There was a greater abundance of ants sampled in non-gypsum (desert pavement) soils compared to gypsum soils, although most of the species identified were found in samples from both soil types (Table 80). Myrmicinae were most abundant overall and had the greatest species richness with 13 species in 6 genera. This was largely contributed to by *M. pergandei*, the most abundant single species by far (44%; Figure 88), found exclusively in desert pavement habitats (Figure 90). Other harvester ants abundant on desert pavement plots were in the genera *Pheidole* and *Pogonomyrmex*. Species in the genus *Solenopsis* were evenly distributed between soil types. *A. cockerelli* was only present in gypsum samples, but was in very small numbers compared to most other species. The family Formicinae was represented by the genera *Paratrechina* (only present on desert pavement sites) and *Myrmecocystus* (both gypsum and desert pavement sites). Species from the Dolichoderinae family were generally more abundant in gypsum than desert pavement soils. *Dorymyrmex* was more abundant in gypsum soils, and to a lesser degree, so was *Tapinoma*, although this genus was also found on desert pavement soils (Table 80; Figure 90).

Ant Abundance in Microsites

Spatial distribution between open interspace and under shrub microsites was variable among species (Figure 91). This is likely due to different foraging methods as well as partitioned food resources (Johnson 2000). In desert pavement habitats, the greatest abundance of ants was in interspaces. *M. pergandei* was more abundant in interspaces, as was *Paratrechina hystrix*. Although present in both microsites (and both habitats), *Pheidole* and *Pogonomyrmex* were also more abundant in interspaces. *Tapinoma* was only slightly more abundant in interspaces than under shrubs. In contrast, *Solenopsis*, *Dorymyrmex*, and *Aphaenogaster* were more abundant under shrubs than interspaces (Figure 91).

Beetle Species Richness

In total, 3,730 beetles were identified in this sampling, representing 111 species in 23 families (Table E.2). Significantly, there were two confirmed species new to science of flightless scarab beetles (Family Scarabidae) in the genera *Phyllophaga* and *Diplotaxis*. The most abundant families, also the most species-rich, included soft flower beetles, snout and bark beetles, and darkling beetles (Table 81; Figure 92). Scarab beetles and ant-like flower beetles were also abundant. Darkling beetles represented the greatest species richness by far with 29 total species and while most species were variably distributed, at least one species of darkling beetle was present in every sample (i.e., soil habitat, microsite, and time).

Beetle Abundance Over Time

Overall, beetles in most families were most abundant in the April sampling (Figure 93). In August, darkling beetles and click beetles were the most abundant families and had both increased since April. Ground beetles were also present in August, but were much less abundant.

Beetle Abundance in Gypsum and Desert Pavement Soils

The most abundant of the 23 beetle families were sampled in both gypsum and desert pavement habitats (Figure 92). Ant-like flower beetles were much more abundant in desert pavement than gypsum habitats. Soft-winged flower beetles, scarab beetles, clown beetles, carpet beetles, and blister beetles were only relatively more abundant in desert pavement habitats (Figure 93). Sap-feeding beetles, while low in abundance, were exclusively sampled on desert pavement soils.

Click beetles, false flower beetles, and ground beetles were present in both habitats but were relatively more abundant in gypsum soils. Death-watch and spider beetles, fungus weevils, metallic wood boring beetles, and hairy fungus beetles were sampled in small numbers, but were exclusive to gypsum soils (Figure 94).

Beetle Abundance in Microsites

The most abundant family, soft-winged flower beetles, had greater abundance in interspaces than under shrubs. Round fungus beetles and lady beetles (while low in abundance) had much greater abundance in interspace samples (Figure 95). In contrast, snout and bark beetles and ground beetles tended to have greater abundance under shrubs. Click beetles, clown beetles, and carpet beetles also tended to have greater abundant under shrubs but were common in under shrubs as well. Fungus weevils, metallic wood boring beetles, and hairy fungus beetles were sampled in small numbers, but were only found under shrubs (Figure 95).

Table 79 Ant species found in Lake Mead National Recreation Area, Mojave Desert, and relative abundance out of the total sampled.

Genus	**Species**	**Subfamily**	**Relative abundance**
Messor	*pergandei*	Myrmicinae	43.61%
Pogonomyrmex	*rugosus*	Myrmicinae	9.67%
Pheidole	*desertorum*	Myrmicinae	8.57%
Pheidole	sp. 2	Myrmicinae	7.62%
Tapinoma	*sessile*	Dolichoderinae	7.18%
Solenopsis	*xyloni*	Myrmicinae	5.41%
Dorymyrmex	*insanus*	Dolichoderinae	5.28%
Myrmecocystus	*(Eremnocystus) yuma*	Formicinae	4.69%
Pogonomyrmex	*apache*	Myrmicinae	2.36%
Myrmecocystus	*(Endiodioctes)* sp.	Formicinae	1.62%
Pogonomyrmex	*imberbiculus*	Myrmicinae	1.51%
Dorymyrmex	*bicolor*	Dolichoderinae	0.69%
Messor	*lobognathus*	Myrmicinae	0.46%
Pheidole	sp. 3	Myrmicinae	0.37%
Solenopsis	sp. 2	Myrmicinae	0.35%
Pogonomyrmex	*desertorum*	Myrmicinae	0.32%
Paratrechina	*hystrix*	Formicinae	0.17%
Aphaenogaster	*cockerelli*	Myrmicinae	0.12%
Cardiocondyla	sp.	Myrmicinae	0.01%

Table 80 Ant abundance in desert pavement and gypsum habitats in Lake Mead National Recreation Area, Mojave Desert.

Genus	**Subfamily**	**Relative abundance**	**Desert pavement**	**Gypsum**	**Total**
Messor	Myrmicinae	44.1%	4,277	45	4,322
Pheidole	Myrmicinae	16.6%	1,315	309	1,624
Pogonomyrmex	Myrmicinae	13.8%	1,136	222	1,358
Tapinoma	Dolichoderinae	7.2%	185	519	704
Myrmecocystus	Formicinae	6.3%	281	338	619
Dorymyrmex	Dolichoderinae	6.0%	4	582	586
Solenopsis	Myrmicinae	5.8%	279	286	565
Paratrechina	Formicinae	0.2%	17	0	17
Aphaenogaster	Myrmicinae	0.1%	0	12	12
Cardiocondyla	Myrmicinae	0.0%	1	0	1
		Total	7,495	2,313	9,808

Table 81 Abundance and species richness of beetle families identified in samples from gypsum and desert pavement habitats in Lake Mead National Recreation Area, Mojave Desert.

Family	Common name	Species richness	Total	Relative abundance
Melyridae	Soft-winged flower beetles	9	941	25.23%
Curculionidae	Snout and bark beetles	16	824	22.09%
Tenebrionidae	Darkling beetles	29	807	21.64%
Scarabaeidae	Scarab beetles	3	303	8.12%
Anthicidae	Antlike flower beetles	3	257	6.89%
Elateridae	Click beetles	2	131	3.51%
Histeridae	Clown beetles	3	107	2.87%
Dermestidae	Carpet beetles	2	95	2.55%
Carabidae	Ground beetles	4	76	2.04%
Scraptiidae	False flower beetles	7	47	1.26%
Leiodidae	Round fungus beetles	1	35	0.94%
Meloidae	Blister beetles	6	29	0.78%
Chrysomelidae	Leaf beetles	8	16	0.43%
Staphylinidae	Rove beetles	2	16	0.43%
Cleridae	Checkered beetles	4	11	0.29%
Cerambycidae	Long-horned beetles	1	9	0.24%
Oedemeridae	False blister beetles	4	8	0.21%
Coccinellidae	Lady beetles	4	7	0.19%
Nitidulidae	Sap-feeding beetles	2	4	0.11%
Anobiidae	Death-watch and spider beetles	2	3	0.08%
Anthribidae	Fungus weevils	1	2	0.05%
Buprestidae	Metallic wood boring beetles	1	1	0.03%
Mycetophagidae	Hairy fungus beetles	1	1	0.03%
		Total	3,730	

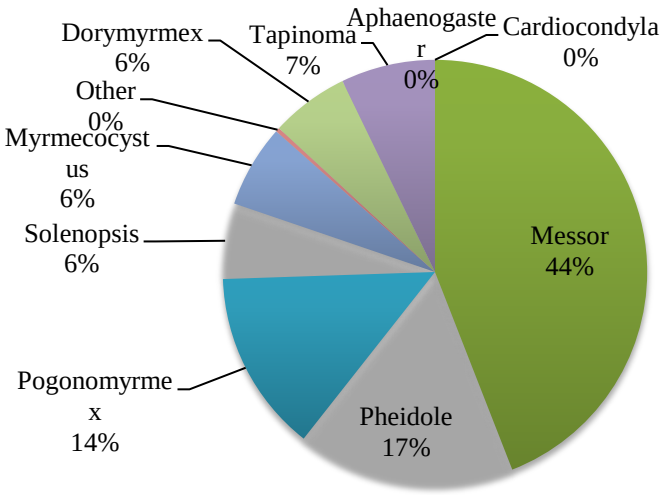


Figure 88 Ant relative abundance by genus for specimens found in Lake Mead National Recreation Area, Mojave Desert.

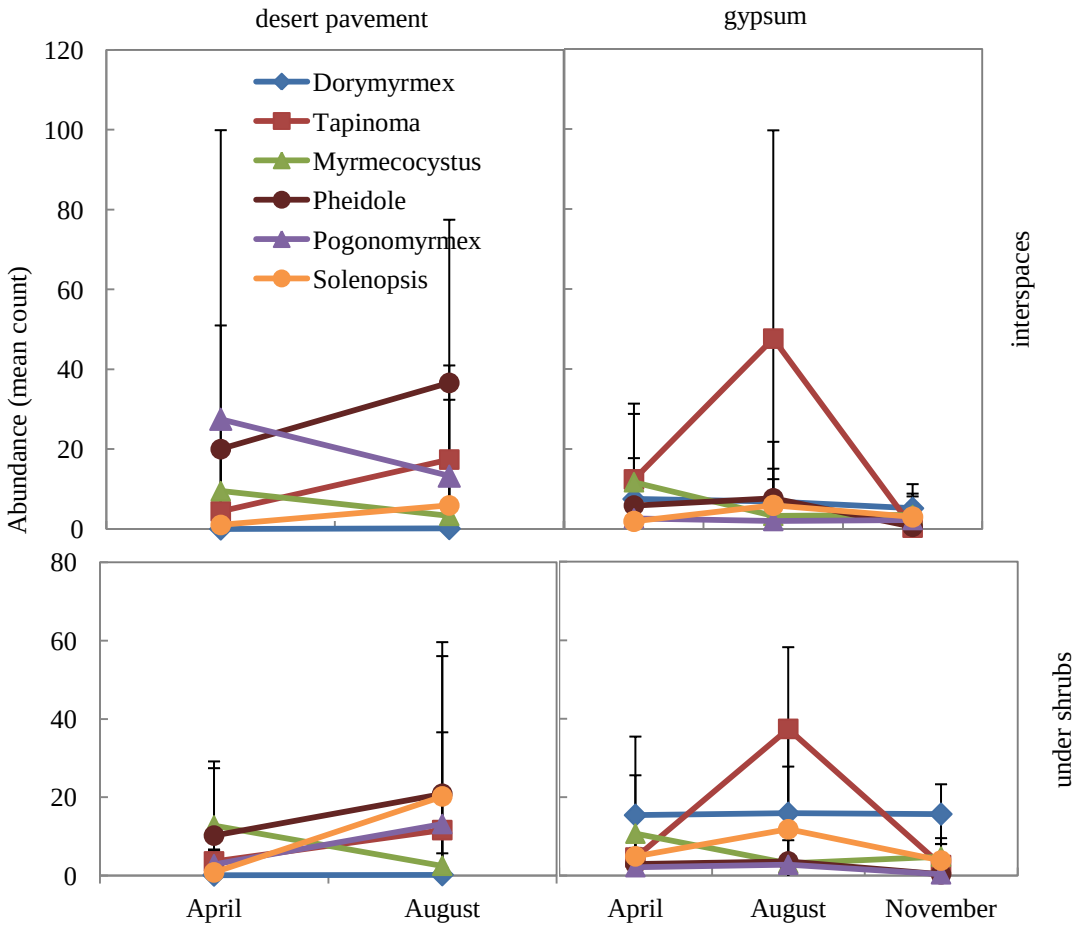


Figure 89 Ant abundance by genus in under shrub and interspace microsites at desert pavement and gypsum habitats over three sampling times in 2008 in Lake Mead National Recreation Area, Mojave Desert. November sampling only took place in gypsum habitats. *Messor pergandei*, by far the most abundant species, is not represented due to its vastly greater numbers, but was present almost exclusively on desert pavement sites in August.

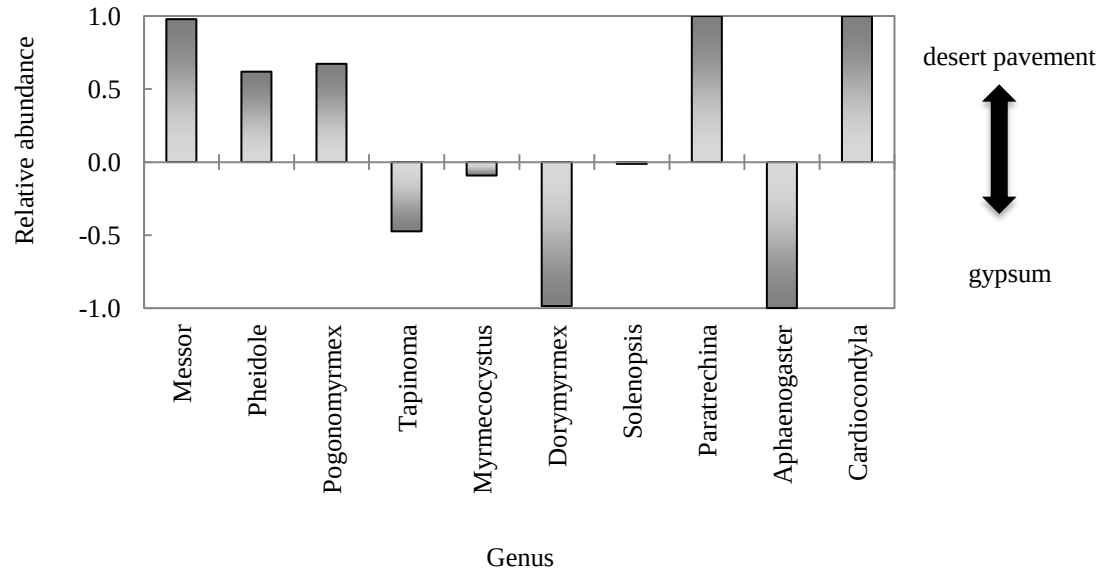


Figure 90 Relative abundance of ant genera in desert pavement and gypsum habitats in Lake Mead National Recreation Area, Mojave Desert. A standardized value on a scale ranging from -1 to 1 was calculated within each genus as the difference between proportions of individuals in desert pavement and gypsum habitats. Positive values represent a tendency toward greater relative abundance of the genus in desert pavement habitats (1.0 indicates exclusive presence in desert pavement habitats); negative values represent a tendency toward greater relative abundance in gypsum habitats. Genera decrease in overall abundance from left to right.

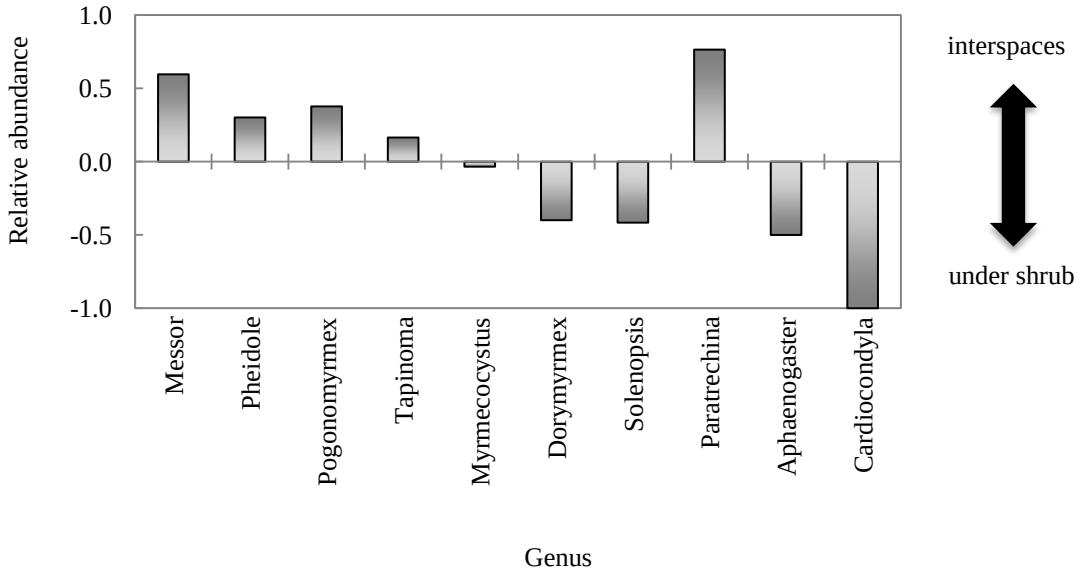


Figure 91 Relative abundance of ant genera in interspaces and under shrub microsites Lake Mead National Recreation Area, Mojave Desert. A standardized value on a scale ranging from -1 to 1 was calculated within each genus as the difference between proportions of individuals in interspace and under shrub microsites. Positive values represent a tendency toward greater relative abundance of the genus in open interspace microsites; negative values a tendency toward greater relative abundance under shrubs. Genera decrease in overall abundance from left to right.

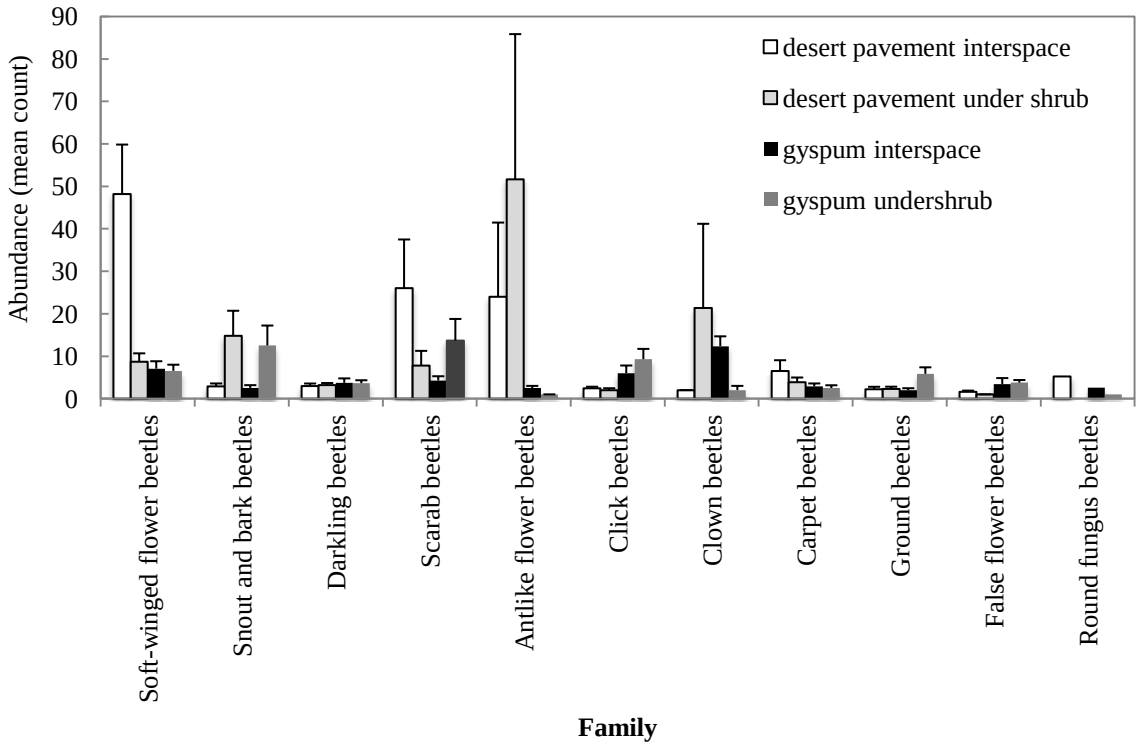


Figure 92 Mean beetle abundance by family in under shrub and interspace microsites from gypsum and desert pavement plots in Lake Mead National Recreation Area, Mojave Desert. Beetle families with relative abundance >3% shown.

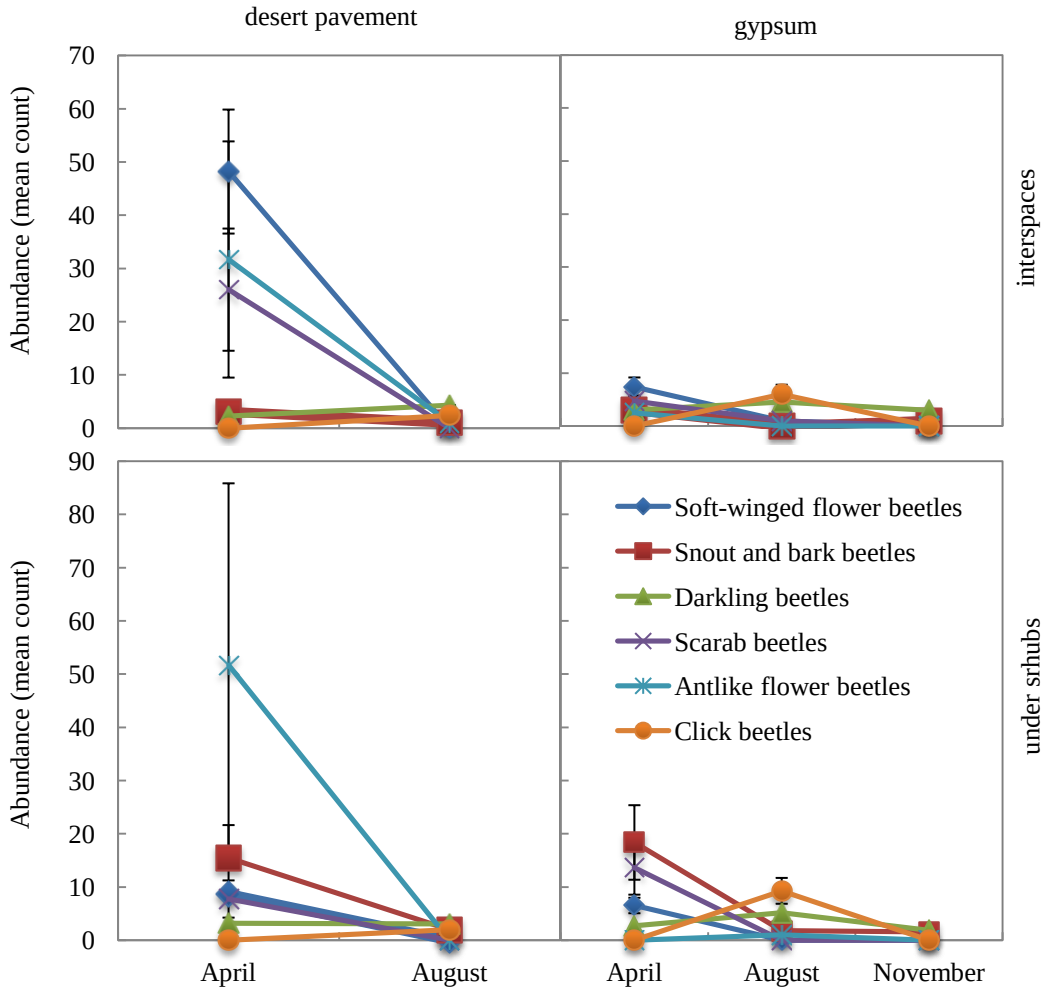


Figure 93 Beetle family abundance over time from all sites Lake Mead National Recreation Area, Mojave Desert.

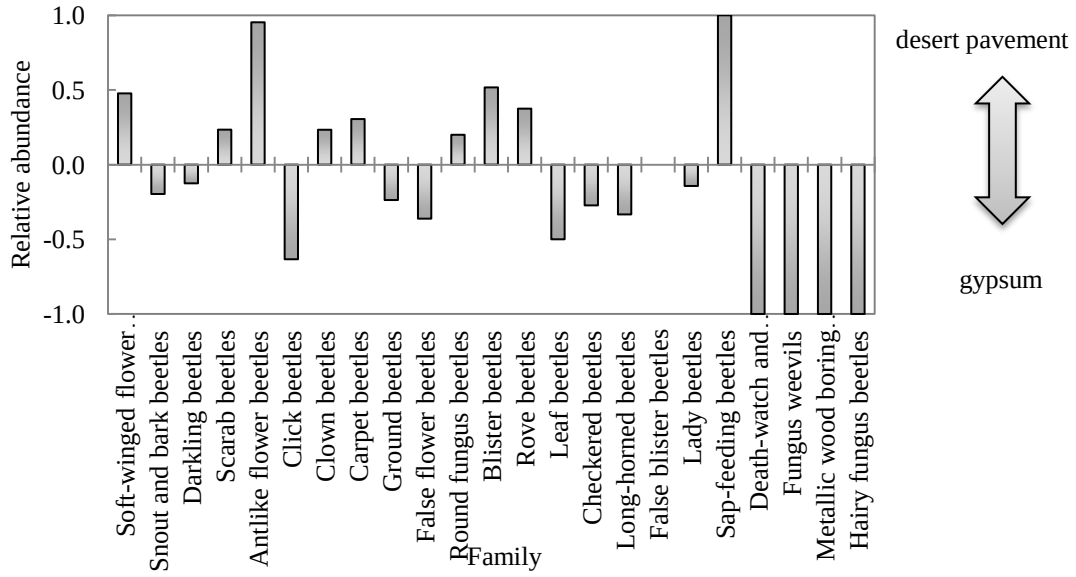


Figure 94 Relative abundance of beetle families in desert pavement and gypsum soils in Lake Mead National Recreation Area, Mojave Desert. A standardized value on a scale ranging from -1 to 1 was calculated within each family as the difference between proportions of individuals in desert pavement and gypsum habitats. Positive values represent a tendency toward greater relative abundance of the genus in desert pavement habitats (1.0 indicates exclusive presence in desert pavement habitats); negative values represent a tendency toward greater relative abundance in gypsum habitats. Families decrease in overall abundance from left to right.

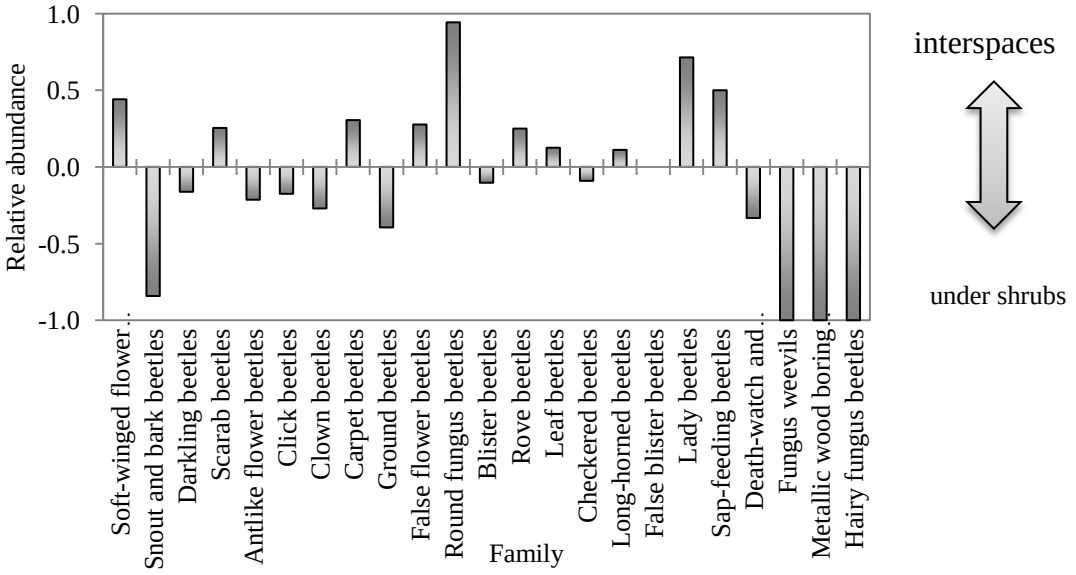


Figure 95 Relative abundance of coleoptera families in interspace and under shrub microsites in Lake Mead National Recreation Area, Mojave Desert. A standardized value on a scale ranging from -1 to 1 was calculated within each family as the difference between proportions of individuals in interspace and under shrub microsites. Positive values represent a tendency toward greater relative abundance of the family in open interspace microsites; negative values a tendency toward greater relative abundance under shrubs. Families decrease in overall abundance from left to right.

DISCUSSION

This sampling illustrates variation in species over time and across spatial and soil habitats. Ants and beetles were most abundant and were represented by numerous families and species. The ants with the greatest abundance were harvester ants *M. pergandei, Pheidole* spp., and *Pogonomyrmex* spp. For beetles, soft-winged flower beetles, snout and bark beetles, and darkling beetles were the most abundant. Darkling beetles were the most species rich family and were present in all samples.

Beetles had the greatest mean abundance in the April sampling while ants increased in abundance from April to August. This in large part was contributed by the presence of large-colony harvester ant species *M. pergandei* as summer is its most active foraging time. *Pogonomyrmex* spp. was abundant in both April and August.

There was also variation in species presence in gypsum and desert pavement habitats. Seed harvester ants had greater mean abundance in desert pavement habitats, while the subfamily Dorichoderinae tended to have greater abundance in gypsum soils. Beetle families were less clearly distributed between habitats, with the exception of a much greater mean abundance of ant-like flower beetles in desert pavement than gypsum habitats. Additionally, click beetles had greater mean abundance in gypsum habitats.

An examination of microsite variation revealed that ants tended to have greater mean abundance in interspaces, although *Dorymyrmex* spp. and *Solenopsis* spp. were more abundant in samples from under shrubs. Beetles again were less variable in microsites, but round fungus beetles had far greater mean abundance in interspaces, whereas snout and bark beetles were had greater abundance under shrubs.

The specimens sampled in this study provide a glimpse into the invertebrate (particularly ant and beetle) communities in gypsum and desert pavement habitats in LMNRA. The data derived can be a useful a baseline for future studies of invertebrate species and their ecological relationships. Harvester ants, soft-winged flower beetles, snout and bark beetles, and darkling beetles in particular had abundances, distributions, and species richness that would be conducive to further study. Additionally, further analysis and sampling is continuing in an effort to fully catalog other invertebrate species sampled at the same times.

SECTION VI. RESTROATION MANAGEMENT PLAN FOR GYPSIFEROUS SOIL HABITAT IN LAKE MEAD NATIONAL RECREATION AREA



INTRODUCTION

Gypsiferous soil habitat supports rare plant species such as the Las Vegas bearpoppy and southwest ringstem and unique biological soil crust (biocrust) communities. These habitats are considered especially fragile and susceptible to damage by construction activities, illegal off-road driving, trampling by feral cattle and burros, and other disturbances. Restoration techniques for desert ecosystems, especially those within gypsiferous soils, are not well developed. The purpose of this project was to develop restoration plans and techniques for managing gypsiferous soils habitat in Lake Mead National Recreation Area (LMNRA).

Several areas of gypsiferous soil habitat in LMNRA have been disturbed in the past, including now-closed Rd 108, Rd 105, and the Northshore Rd construction corridor. The project objectives were to develop restoration plans for these areas by assessing recovery from disturbance on gypsiferous soils and synthesizing effects of previous restoration activities on these project areas, examining revegetation techniques (e.g., salvaging plants and plant care methods), establishment techniques for targeted plant species of interest (such as Las Vegas bearpoppy), and biocrust rehabilitation.

The impacts to gypsiferous soils habitat due to disturbances are well known. Natural recovery to these habitats requires long time intervals that are out of the scope of the Park Service mission and requirements. As a result, a restoration plan using the information obtained in this report has been developed. Avoiding any disturbances in gypsum habitat is unlikely. However, where possible, mitigation techniques should be implemented to avoid illegal trespass or land use which can result in de-vegetation or destruction of biocrusts or the soil habitat.

In 2007, LMNRA personnel observed a lack of recovery of impacted gypsiferous soil systems using the same techniques in other soil types. As a result, research was implemented to identify the vegetation and soil properties of gypsiferous soil communities and to develop restoration strategies specific to these soil types. The intention of the gypsum management plan is to establish criteria whereby LMNRA, the

National Park Service (NPS), institutes restoration activities within gypsiferous soils and adjacent soil communities. The information enclosed within the "Gypsum Soil Restoration and Revegetation in Lake Mead National Recreation Area: Treatments, Monitoring, and Management Activities" Report provides guidance for identification of gypsiferous soil vegetation communities, soil and vegetation characteristics specific to these communities, as well as results from restoration research activities to identify specific restoration treatments.

RESTROATION MANAGEMENT PLAN PURPOSE

The purpose of this plan is to initial an ecological restoration approach to management of gypsiferous soil communities within LMNRA that have been or are planning to be disturbed as a means to mitigate impacts, preserve and maintain habitat, and restore habitat and ecosystem functioning. This plan, and its recommended actions, is focused on active restoration activities in pursuit of those goals.

The Society for Ecological Restoration International (SER) defines ecological restoration as the process of actively assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Due to factors such as public use, legal and illegal, LMNRA management goals, and historical and modern land use, true ecological restoration may not be suitable (or possible) for all areas within LMNRA containing gypsiferous soil habitat.

SITE LOCATION AND SETTING

LMNRA is a center for recreation east of Las Vegas, NV, and offers year-ground recreational opportunities including boating, fishing, hiking, picnicking, and sightseeing. It is boarded by Nevada, Utah, and Arizona and follows the Colorado River corridor from the western boundary of Grand Canyon National Park to north of the cities of Laughlin, NV and Bullhead City, AZ. The Virgin River also flows into the Lake Mead on the north end, just south of Overton, NV, creating the Overton Arm portion of Lake Mead. LMNRA also includes all of Lake Mead Reservoir, as well Lake Mohave Reservoir, created by Hoover Dam and Davis Dam, respectively, and the surrounding desert terrain and wilderness. Located in the eastern Mojave Desert, the regional landscapes contain desert habitats and wildlife that are adapted to survive where rain is scare and summer daytime temperatures can rise above 38°C (100°F; see Section I).

As in other desert landscapes, the eastern Mojave Desert contains unique habitats, such as which occurs in gypsiferous soils, that are sensitive to disturbances. These habitats are home to rare plant species and unique biocrusts. As part of the NPS mission, LMNRA is required to mitigate and protect these sensitive habitats. Gypsiferous soil habitat occurs in patches throughout LMNRA, however, is concentrated along the Overton Arm (Figure 93). Segments of these areas along Northshore Rd have been disturbed due to road building and reconstruction, legal and legal activities, including trespasses, and have been impacted by non-native feral herbivores.

MODERN IMPACTS AND RELATION TO RESTORATION ECOLOGY

Modern disturbances types and land uses within LMNRA include creation of power line and utility corridors, introduction of exotic herbivores (e.g., burros, horses, and cattle), mining and military activities, agricultural clearing, water drawdown, off-road driving, and urban-suburban construction (Lovich and Bainbridge 1999). Fire, increasing in frequency and severity due to invasion of flammable exotic annual grasses (e.g., *Bromus rubens* [red brome]), also has become a major disturbance that kills native vegetation. Fire denuded more than 385,000 ha, or nearly 3% of the entire land area of the Mojave Desert, in 2005 alone (Brooks and Matchett 2006). Some authors estimate that decades to centuries are required for late-successional dominants such as *Larrea tridentata* (creosote bush) and *Coleogyne ramosissima* (blackbrush) to attain their former abundance after fire, soil blading (scraping for construction or road-building), or similar disturbances (Vasek 1983, Webb et al. 1987). Disturbances that are large and severely impact soil properties or eradicate seed sources will likely be the slowest to revegetate. For these reasons, managers may wish to attempt to actively accelerate revegetation and to direct species composition and cover in desired directions.

Many of the same difficulties that make natural revegetation slow in arid environments make active revegetation through human actions challenging (Virginia and Bainbridge 1987). The rate and composition of natural revegetation following disturbance varies with disturbance type, soil fertility and type, propagule and seed availability, climate, subsequent disturbance regimes, and other factors (Webb et al. 1988). Disturbances often simplify vegetation structure, removing the "fertile islands" created by large shrubs that are hospitable microsites for regeneration of many plant species (Wallace et al. 1980). In the absence of these fertile islands, species must germinate and establish with full exposure to sunlight, wind, and herbivory. Precipitation is limited and unpredictable, causing suitable conditions for seed germination and seedling survival to be rare. Herbivory by an array of organisms, including insects, small mammals, and larger herbivores, can damage or kill plants and reduce reproductive output (Hunter 1987). Granivory (seed consumption) by seed-eating organisms can consume 75% to nearly all of natural annual seed production (Brown et al. 1979). Similarly, granivory reduces opportunities for establishment through active seeding. Many native perennial plants also do not form large soil seed banks and have stringent germination requirements, making them susceptible to seed- and germination-limitations following disturbance. Subsequent disturbances also can hinder plant establishment, such as chronic grazing or initiation of a grass-fire cycle where exotic grasses facilitate a frequent-fire regime on sites formerly burning infrequently.

Three major forms of active revegetation are outplanting, transplanting, and seeding. We define outplanting as planting containerized or bare-root plants grown in a greenhouse or nursery from seed, cuttings, or other propagules. We define transplanting as moving plants living in the wild from one site to another (possibly with an intervening period of residence in a greenhouse or nursery) or back to the same site after a period of time. Directly broadcasting seed

over an unprepared or prepared (e.g., by ripping or contouring soils) surface is the most common type of seeding (Bainbridge and Virginia 1990). However, drilling (inserting seeds into the ground), hydro (combining seeds with a slurry of water and other materials), and pelleting (encasing seeds with soil or other particles) are some of the many variations to basic broadcasting (Monsen and Stevens 2004). Each of these three forms of revegetation has advantages and disadvantages. For example, outplanting may not be practical to revegetate large areas, whereas seeding by aircraft may be feasible (Slayback et al. 1995). Seeding requires large numbers of seeds since many will not result in established plants, whereas outplanting requires just enough seed to produce the number of desired plants. Outplanting or transplanting also often need laborious and expensive maintenance, such as providing water to plants or building exclosures to reduce herbivory (Bainbridge et al. 1995). Furthermore, some species may perform better in one form of revegetation than another (Glenn et al. 2001). Species with stringent germination requirements may not be amenable to seeding, whereas bypassing the need for field germination through outplanting may be successful.

Species and treatment selection are two factors that resource managers can directly control (as opposed to climate) that can dictate the success or failure of a revegetation project. Species differ in drought tolerance, germination requirements, susceptibility to granivory or herbivory, growth rates, nutrient requirements, and other traits (Smith et al. 1997). These variations can result in differences in species performance in revegetation projects (Romney et al. 1989). One possible approach is selecting species for revegetation most likely to be successful, and having the resulting community meet management objectives or serve as an initial stage of recovery that may facilitate recruitment of other species through natural or further active revegetation (Glenn et al. 2001). This sequential approach can build upon earlier species successes.

Revegetation treatments also can modify inherent species performance. Irrigation, such as through installing drip systems on site or watering by hand, is often done in conjunction with outplanting (Brum et al. 1983). DriWater, a gel material that slowly releases moisture (Newton 2001), is another type of many possible irrigation systems (Bainbridge 2007). Creating water catchments, by recontouring land to retain rainfall, is one method of site modification for delivering water to plants. Another category of treatments, grazing protection, could include simple wire cages around individual plants (Hunter et al. 1980), more extensive fenced exclosures (Hunter 1987), or chemical deterrents (Bainbridge and MacAller 1996). Bainbridge et al. (2001) also have advocated placing cone or cylinder plastic shelters over plants to both protect them from grazing and ameliorate microclimates. Constructing rock shelters around plants and fertilization are some of the many other treatments attempted to enhance plant establishment (Biggins et al. 1985, Yamashita and Manning 1995). Because these treatments increase labor and costs for each plant, their benefits should be compared to simply planting more plants without treatments.

RESTORATION PLANNING IN GYPSIFEROUS SOIL HABITAT

Sections I-V of this report cover several subjects which were to be addressed including 1) a synthesis of gypsiferous soil community characteristics and adjacent soil communities within LMNRA complied from data from several projects; 2) information gained from several projects relating to the rare Las Vegas bearpoppy; 3) documentation on the effects of disturbance to gypsiferous soil vegetation and biocrust communities; 4) results of active restoration projects that were supported by this cooperative agreement project; and 5) the results of a survey of arthropod communities in gypsiferous soil communities in LMNRA.

Products resulting from this research include identification of all gypsiferous soil habitat within LMNRA as well as recommendations for identifying or classifying soil types and/or soil properties, a summary of vegetation and soil characteristics related to Las Vegas bearpoppy habitat and gypsiferous soil habitat, particularly along Northshore Rd within LMNRA where most of the gypsiferous soil habitat occurs within LMNRA, a detailed analysis of the Las Vegas bearpoppy sites soil seed bank, as well as a photo-library of the seeds extracted from seed bank samples (Appendix B), results of the both active and passive road rehabilitation conducted along closed Rd 108, including recommendations for future research as well as management recommendations for future projects on high gypsum and calcium soils; and results from the Rehabilitate Northshore Rd Project, including the survival results of the perennial plant salvage, nursery care and maintenance, transplanting and outplanting, along with watering treatments, which provide a guide for future focus on species for salvage and outplanting operations in LMNRA.

FUTURE SITE ASSESSMENTS: WHAT TO CONSIDER

1. Environmental Conditions and Setting: Landscape and physical components affecting ecosystem processes
    - Soil type and conditions or significant soil properties (assist with determining plant species)
    - Surrounding land use, as all as dominant types of protection (e.g. exclosures, fencing)
    - Distance from main travel corridors, including paved and unpaved roads and trails

2. Human impacts
    - Accessibility: distance from main roads and/or trails, or public access points, such as pull-offs, rest areas, camping or hiking areas
    - Disturbance: classified as undisturbed, evidence of disturbance, or disturbed (severity of impact)
    - Disturbances: Identify type
        - Illegal or legal use (Re-enforcement to prevent or dissuade use)
        - Two-track single or multiple disturbances (severity of impact related to soil compaction)
        - Is the disturbance an old occurrence or continued disturbance? How long since disturbance, if can be determined?
        - Are there measures to remove disturbance from continuing?
        - Will this be a continued limited-use area?
        - Feral animal disturbance, e.g. trampling, grazing (may be a danger to the public)
        - Construction: If a legal construction project, will there be enough topsoil salvaged or be reapplied to all areas under the influence on the construction?

3. Ecosystem structure:
    - Physical structure
        - Dominant landscape features: exposed bedrock, badlands, soils with biocrust cover, desert pavement, shrub species, perennial forb or grass species cover, density, and richness
        - Is the vegetation community an early successional community with short-lived desert shrubs or forbs?
        - Is the area of concern on a flat or sloped surface?
        - Will erosion prevention be necessary?
    - Soil type: Identify soil association or soil type utilizing soil mapping resources or soil testing
        - If tested, what are the major physical and chemical components of soil?
        - Do soil properties suggest a dominance of gypsum parent material?
        - Are biocrust and desert pavement a dominant part of the soil surface community?
        - Is surface soil intact?
        - Is surface soil removed?
        - Is subsurface soil now the top layer of soil?
    - Vegetation inventory and relative density:
        - Dominant species present within an ecological unit, either at a community level or landscape level
        - Can vegetation surveys be conducted prior to a planned disturbance event?
        - Are there representative landscapes (reference communities) within the same soil type which can be used as an analog to the previously existing community prior to a disturbance event?
        - Does the vegetation community identified by soil association or type (within this document) reflect the community identified in the field?
        - If planning prior to disturbance, can a salvage project be instituted, considering access to area, personnel, and care and maintenance facilities for salvage plants?

RESTORATION RESEARCH AND MANAGEMENT COMPONENTS

Soil Type and Vegetation

Section I of this document identifies physical and chemical characteristics of gypsiferous soil and surrounding soils at an elevation from 149-490 m along the Northshore Rd area and regionally, as well as the significant soil property differences between parent material (Tables 9-12). This section also identifies soil-environmental gradients depending on elevation. Soil mapping layers developed by the Natural Resources Conservation Service (NRCS), Department of Agriculture (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm), utilized in either ArcGIS, the Soil Web online tool, or Google Earth, assist with general identification of either the soil mapping unit (MUSYM identification number) or the soil association and parent material, which can encompass several soil types. Additionally, in some of these areas, pedons have been described in detail and soil type and horizons have been identified, as in the case for the long-term vegetation (LTV) sites from Section I. The soil survey database developed by NRCS contains more than 23,000 pedons, which increases every year, from analyses performed at the Soil Survey Laboratory and from other NRSC laboratories. Areas mapped within and surrounding LMNRA that contain soils with the top horizon classified by the presence of gypsum parent material occur in large, but limited, areas and are often paired with or in association with soils classified as Calcids (Figure 96). Calcids are soils containing calcium carbonate and are a main soil type around Lake Mead, covering extensive areas along the Lakeshore Rd and Northshore Rd, as well as Highway 93 and areas around Lake Mohave (Figure 96). If possible, site assessment for restoration-related activities should occur on a per site basis to obtain the most accurate information. However, in the absence of these data per site, either a limited number of soil tests and observations can be obtained or NRCS information can be used to identify generally the soil types at a site of interest. These limited tests may include EC, total S, texture analysis, and or macronutrients (those highlighted by an asterisk '*' in the tables below). These tests may assist in identifying if gypsum may be present within the soil matrix if soil type is unknown.

Section I also provides reference plant community data for soils with gypsum parent material (Table 34 & 43), as well as reference information for surrounding soil types that result from non-gypsum parent material (Section I). The shorted vegetation list enclosed here provides dominant species density/ha and cover for Gypsids soils for the northern region of LMNRA (Table 6) and also species cover for the Lake Mead region (Table 21). These tables can be utilized as a guide for not only identifying gypsum habitat but also for identifying species for revegetation protocols for gypsum, such as for density.

Plant Salvaging and Outplanting

The existing LMNRA salvage and outplanting protocols, with slight modifications, were used for the salvage and outplanting project along Northshore Rd. Restoration projects require several steps of pre-planning prior to implementation of treatments. Section IV provides information regarding salvage and outplanting treatments specific to common species which occur within the gypsum habitats along

Northshore Rd. These results provide a guide for future revegetation protocols. Out of 30 species salvaged, only 6 species could be tested for effectiveness of salvage treatment and 7 for outplanting treatment. However, these species encompass a majority of the individuals obtained from the path of destruction of the new Northshore Rd route.

Shrubs had the highest overall survival across salvage and outplanting and likely should be a focus for salvage operations (Figures 79-82). For species tested with salvage treatments, the survival of species with treatment compared to species that only were placed in water between salvage and potting did not significantly differ. The use of root-stimulating hormone requires more investigation: root-stimulating hormone treatment at different concentrations should be examined per species to obtain what concentrations most benefit or negatively impact particular species. Watersorb® Water Crystals was used to create the slurry to prevent roots from entangling; however no documentation during salvage was recorded to obtain if this preventative strategy worked. The application of these super absorbent polymers is primarily for use in pots or in soil to assist with absorbing large amounts of water for slow release. Therefore, it is likely that an additional salvage treatment (e.g. root-stimulating hormone or slurry) is not necessary.

Both water application and topsoil increased outplanting survival. Overall shrubs had the highest survival (Figures 84 & 85). Watering treatment impacted survival of species at a growth habit level and at a species level (Figure 83 & 86). For forbs as a growth habit group, DriWater actually caused an increase in mortality compared to hand watering and a no watering treatment, while for shrubs the no water treatment had the greatest mortality. Additionally for shrubs, hand watering statistically improved survival over DriWater treatment. Outplanting results were limited to a few species due to the nature of the resident plants obtained during salvage operations. However, those species that were not individually assessed were combined with all species and grouped by growth habit. Additional research is necessary to obtain information on all the common gypsum species. The common gypsum resident *Psorothamnus fremontii* had a low survival, although there were not enough individuals collected to test outplanting treatment effectiveness. Perennial forbs had a relatively good survival. However, the perennial grasses, *Dasyochloa pulchella* and *Pleuraphis rigida*, had poor survival, although there were not many of these species salvaged and results could not be analyzed. *Ambrosia dumosa*, a common Mojave Desert shrub that is also common within gypsum soil types and often exhibits the highest density/ha and/or cover (Tables 81 & 82), also exhibits high survival post salvage at almost 70% (Figure 94) and a relatively high post outplanting survival regardless of the type watering treatment (hand watering or DriWater application). Another species which occurs on gypsum, although is not gypsum-specific is *Eriogonum inflatum*. This species has relatively low survival post salvage at about 15% and a low survival post outplanting. Different watering treatments, including no water treatment, resulted in quantitatively different survival rates with hand watering treatment resulting in the highest survival rate of about 40%. Topsoil reapplication also improved overall survival for both shrubs and perennial forbs. This may have

been due to several factors including the presence of soil biota which decreases the negative impact of physical crust development and contributes to greater soil stability, and also the physical and chemical soil property differences between surface soil and subsurface soil, such as differences in ion presence. For example a 10% increase in EC decreased survival of transplants by 12%, while a 10% increase in sodium adsorption ratio reduced transplant survival by 9%.

Several factors may have resulted in higher mortality for some species compared to others or due to soil environmental factors.

A few of these factors may include:

- Precipitation may have played a role in assisting with establishing plants the first season after outplanting.

- During topsoil removal for salvage, subsurface layers are blended with surface layers altering the soil physical and chemical properties changing the soil structure and environment. Physical crust formation in gypsiferous soils can result in decreased water and seed infiltration and create a soil surface with a lack of physical structure to contribute to soil stability, increasing soil erosion and water runoff. Blending of subsurface layers can dilute soil biota that contribute to soil structure, development, and stability.

- DriWater was observed for form a thick plastic layer in the bottom of the DriWater tube that had to be removed prior to insertion of a new gel (Figure 97). This was not quantified over the course of the outplanting monitoring, although it was noted to have occurred over approximately one-third of the plants with DriWater treatment each time the gels were replaced.

- The presence of feral cattle resulted in trampling within one of the planting areas along Northshore Rd at the Overton Beach Rd intersection and removal several outplanted plants and trampled cages. Feral cattle have been observed throughout the planting treatment area as far south as Valley of Fire Wash with hoof print evidence and visual observations.

For future salvage and outplanting/transplanting projects, the project data suggests shrubs should be the focus of salvage, seed collection, nursery grow out, and outplanting/transplanting efforts. The project data also suggests that for salvage treatment, immediate potting with no additional treatment. Specific to seed grow out, collection locations would have to be identified and monitored during the maturity process. Current vegetation records and herbarium specimen sample locations (http://swbiodiversity.org/seinet/) provide a general location for identifying known populations of particular species. Additionally, many species require different treatments to induce germination (e.g. gibberellic acid, scarification, temperature stratification treatment) and may require additional treatment after emergence (e.g. fertilizer). Nursery protocols and other resources, such as the Native Plant Network, can provide appropriate information on these techniques. For outplanted or transplanted individuals, hand watering treatment is recommended. DriWater for application does not necessary improve survival or decrease mortality; however in situations with limited or difficult access, DriWater or another slow water release technology is recommended. Topsoil salvage is required in some highway-related projects. Due to the greater mortality of plants in non topsoil areas, either these areas will require alternative strategies for vegetation establishment or a greater number of individuals per hectare and resources to obtain desired density levels.

Road Ripping

Road ripping with subsoilers or other machines is used for increasing the infiltration capacity of formerly highly compacted surface soils. Road ripping directly impacts the potential for water infiltration, reducing erosion by creating a textured surface, and stabilizing slopes, as well as the recovery of vegetation. The effectiveness of ripping may be measured based on the restoration goal. The results of the Rd 108 Case Study indicate the need for defining the restoration goal as either restoring or maintaining a soil habitat or restoring the vegetative habitat. In this case, the goal was to provide a soil complex that would support the natural recovery of native vegetation cover and increase the visual consistency of the landscape by blending the former road area into the surrounding landscape, while reducing the visibility and further use of the road. Maintaining or recovering the natural soil structure was not a primary goal, although the differences in soil properties between treatments were examined primarily to obtain the relationships between the soil environment and vegetation diversity and cover within the road treatments. Ripping treatment resulted in possibly earlier soil developmental characteristics with higher % sand and lower % clay that would allow for water and root penetration and plant establishment. Bulk density between road treatments (ripped vs. not ripped) and between the road treatments and undisturbed sites did not differ significantly; therefore other factors are possibly influencing vegetative differences. Compaction of soil materials altered the surface soil environment by increasing soil density and altering particle size distribution (sand vs. clay) as shown between not ripped and undisturbed sites. Compaction likely resulted in a reduction of macropore size, water and gas storage and exchange capacities, as well as impacted seed infiltration and root development of any new

species. Compaction was reduced in ripped sites (greater sand; although bulk density was not significant) which may have allowed increased rates of seed infiltration and germination and emergence of perennial forbs.

The road ripping of Rd 108 provides initial information on the impact of this treatment on highly disturbed, compacted soil that contains high levels of gypsum and calcium carbonate. In this situation, ripping promoted vegetative cover. Other soil environments with different soil properties may vary in results. Continued monitoring of these sites is recommended to observe seasonal variability in annuals and also observe changes in perennial plant structure and biocrust development.

Las Vegas Bearpoppy Soil and Vegetation Habitat

Large areas across LMNRA could possibly support bearpoppy populations. However, introduction of bearpoppy to similar habitats or extending the area in which bearopppy already exists through increasing individuals within populations is still an obstacle. The tests used to promote bearpoppy seed germination were not successful. Both laboratory and field tests resulted in no individuals germinating or emerging. More research is required to elucidate methods which will best promote increasing bearpoppy populations artificially.

Biocrust

Biocrust inoculation also can enhance a disturbed environment by not only introducing native soil biota to assist in recovery of native ecosystem processes, but also to assist with reestablishing the visual consistency of the landscape. Inoculation with biocrust on disturbed gypsiferous soil significantly improved macroscopic and microscopic biocrust organism cover and abundance, soil stability, and available ammonium compared to disturbed, non-inoculated plots. Additionally, disturbed experimental treatment plots treated with biocrust inoculum were generally similar to undisturbed sites indicating that salvage and storage likely had little impact on soil biota or that soil biota were able to successfully recovery from any negative consequences of salvage and storage or damage from salvage and storage and that biocrust inoculum can successfully survive salvage, storage, and field application.

Development of biocrust inoculum is still being studied and would require greater resources and time that is out of the scope of this project. However, acquisition from natural sources, such as in the path of destruction from a known disturbance, or acquired from adjacent areas with minimal impact can provide inoculants. In the laboratory study, cyanobacteria grew quickly in inoculated flats on native autoclaved soils with regular watering treatments and covered much of the soil surface. For field application, growth and establishment would be much slower, especially in years of low precipitation. The addition of slurry as well as discrete pieces of crust would introduce a variety of organisms at several levels of succession.

CONCLUSIONS

A summary of projects, goals, results, and recommendations/comments are in Appendix E. Continued monitoring of projects will provide information on the success of the studies included in this report.

Restoration research studies in gypsiferous soil types should continue and field sites should be treated as long-term observation sites. The studies included within this report focus on a particular region within LMNRA containing gypsiferous soils. Not all gypsiferous soil communities in the recreation area may respond the same way due to several factors including microclimate conditions, differences in soil physical and chemical properties, and differences in vegetation. However, these studies provide a guide to recommendations and elucidate directions for future research.

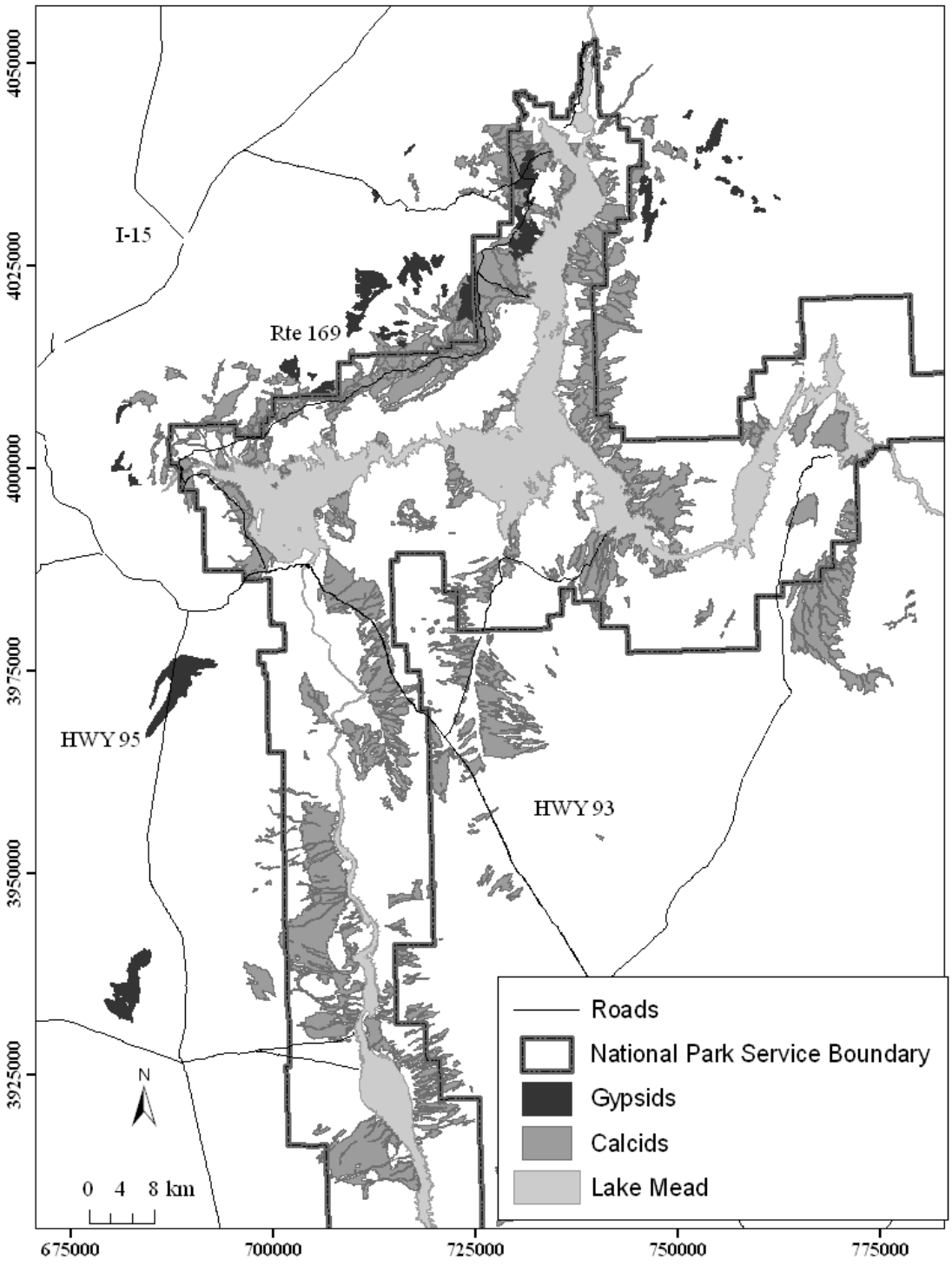


Figure 96 Gypsids (dark grey) and Calcids (medium grey) derived soils in and around Lake Mead National Recreation Area, eastern Mojave Desert.



Figure 97 The accumulation of DriWater material removed from the bottom of DriWater tubes from the Northshore Rd outplanting project 2010-2012 occurred during every DriWater replacement event, Lake Mead National Recreation Area.

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Appendix A

Provided is a summary of projects included within this document, including project goals, treatments, results, and recommendations/comments.

Table D1 Restoration projects' goals, results and recommendations/comments

Project	goal	Results	Recommendations/Comments
Northshore Rd plant salvage	Test species survivability as well as salvage treatment effectiveness; treatments included root-stimulating hormone and slurry with a water absorbing polymer to reduce root tangling. All individuals received the same soil potting mixture and watering treatment	Generally plants did not have significant differences in survival with or without additional treatment. Shrubs had the highest survival rate.	No additional treatment necessary
Northshore Rd outplanting	Test species survivability as well as outplanting treatment effectiveness; treatments included planting in areas with and without topsoil and a watering treatment, hand watering, DriWater, or no water	Topsoil presence and water treatment (hand watering or DriWater application) increased survival. Hand watering had a higher survival rate compared to DriWater application. Shrubs had the highest survival rate and perennial grasses the highest mortality.	Hand watering optimal; however, in cases with reduced or low accessibility, DriWater treatment is recommended for 2 years
Rd 108 Case Study	To identify the soil and vegetation structure differences between road segments in gypsiferous soils which were ripped or not ripped and compare these factors within treatment and between undisturbed sites	Particular to this site along Rd 108, ripped sites were more similar in vegetative density and cover to undisturbed sites, however, not ripped sites were more similar to soil structure to not ripped sites	Depends on the goal of restoration: If visual consistency and vegetative cover are the primary goal, ripping is recommended.
Biocrust restoration	To test the impact of salvage and storage on soil biocrusts, and to test inoculation treatments with the goal of promoting biocrust recovery. Treatments included carbon addition, enhancing soil stability, and inoculation with or without topsoil reapplication.	Soil biota appears to not be negatively impacted by salvage and storage after three years; and inoculation of biocrusts promote recovery of soil biota and enhance soil stability. Topsoil enhances the soil biota environment due to resident biota but not as well as inoculation with biocrusts.	Were possible, prior to a known impact, biocrusts should be salvaged and stored for later use as inoculum in restoration activities. A slurry has a limited capacity to assist with development of cyanobacteria. Discrete pieces introduces native macro and microscale soil biota to the soil environment

Table D2

Project	goal	Results	Recommendations/Comments
Las Vegas Bearpoppy Habitat	Identify habitat which is similar to habitat that bearpoppy already had a viable population	There are several regions within LMNRA that have potential supportable habitat for the bearpoppy, including soil units that do not currently contain bearpoppy	Introduction of bearpoppy to an area should be determined on a by site basis.
Las Vegas Bearpoppy Seed Germination	Identify and test methods for promoting germination and emergence of bearpoppy to assist with establishing and expanding existing populations. Treatments included scarification and soaking in either gibberellic acid or water.	None of the field or laboratory tests resulted in seed germination or seedling emergence	Further research is required.
Las Vegas Bearpoppy Seed Bank	Identify habitat components within bearpoppy habitat (at the site and microstie level) and compare effectiveness between seed bank assessment techniques, emergence assay and extraction	Microsite and method interacted to affect seed bank density. Extraction detected orders of magnitude greater seed densities than either emergence method. Extraction had the highest species richness. Annual plants overall were most abundant in “fertile island” microsites below canopies of perennial plants	Extraction detects greater seed densities and species richness and portrays a different species composition than emergence. Given the significant influences of microsite on seed bank measures, sampling by microsite can likely increase sampling efficiency when whole-site seed bank estimates are desired. An improvement to the effectiveness of both methods could be to increase our understanding of germination requirements of species to help meet these requirements for detecting seeds through emergence and estimating germinability/viability of seeds recovered by extraction
Residual effects of previous year precipitation Las Vegas Bearpoppy	To test whether annual precipitation had a residual effect on the following year's bearpoppy population.	The number of living plants is dependent on Lag Precipitation (precipitation from the previous year reflects the number of living plants seen the next spring). The previous year precipitation directly affects the population numbers for the following spring. Years with continually above average rainfall exhibit positive plant recruitment year to year.	Rare plant surveys recording population should occur additionally the following year of a high precipitation event

Appendix B

Las Vegas Bearpoppy Seed Bank Extraction 2009, eastern Mojave Desert

Prepared by Lindsay P. Chiquoine

Included is a photo-archive of seeds extracted from soil seed banks from communities in Las Vegas bearpoppy (*Arctomecon californica*) habitat at sites in Lake Mead National Recreation Area and surrounding Bureau of Land Management-administered lands. Identified species are in alphabetical order by plant families. Short descriptions are included, either from observations or from The Jepson Desert Manual (2002). Scientific names are based on current USDA Plants nomenclature. Uncertain or unknown identification is indicated.

Monocots

Family: Poaceae (also called Gramineae or true grasses)

Bromus rubens (L.) Husn.
Common name: Red brome

Spikelet: sterile florets 3+; florets overlapping at maturity.

Las Vegas bearpoppy seed bank



Schismus sp, either *Schismus arabicus* Nees (Common name: Arabian schismus) or *Schismus barbatus* (Loefl. ex L.) Thell. (Common name: Mediterranean Grass)

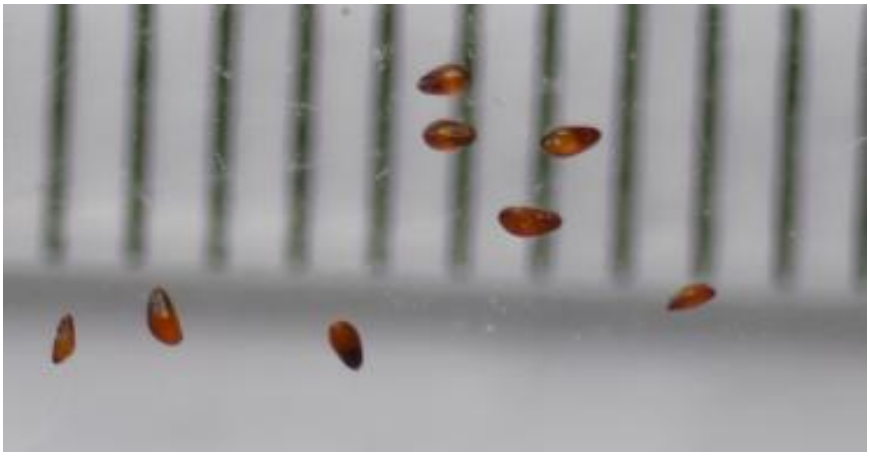
Spikelet: ± laterally compressed; axis breaking above glumes and between florets; glumes lanceolate, membranous, 5–7-veined; florets 3–8, bisexual; lemma 9-veined, ciliate proximally, toothed to notched, awn ± 0 (mucro occasionally <= 1.5 mm); palea < to > lemma.

S. arabicus: Spikelet: glumes 4.5–6.5 mm; lemma 2.5–4 mm, teeth ± 0.3 × lemma; palea 2–3 mm.
S. barbatus: Spikelet: glume 4–5 mm; lemma 2–2.5 mm, teeth ± < 0.2 × lemma; palea 1.5–2.5 mm.

Las Vegas bearpoppy seed bank



Las Vegas bearpoppy seed bank



Vulpia octoflora (Walter) Rydb.
Common name: Sixweeks Fescue

Spikelet: 4.5–10 mm; lower glume ± 2–4.5 mm, upper ± 2.5–7 mm; florets (5)7–12; lemma ± 3–5 mm; awns 0.5–5 mm.

Fruit: 2–3.5 mm.

Las Vegas bearpoppy seed bank



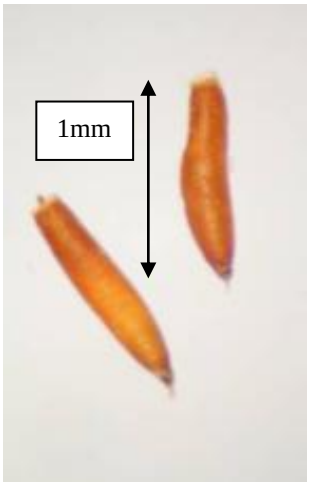
Family: Typhaceae (Cattail)

Typha sp.
Common name: Cattail

Fruit: fusiform, thin-walled, yellow-brown, wind-dispersed.

Las Vegas bearpoppy seed bank





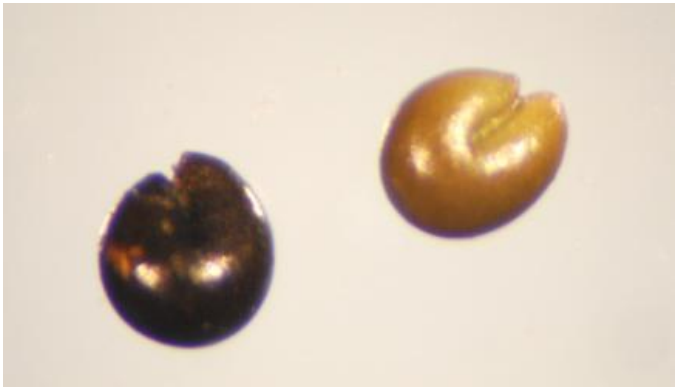
Dicots

Family: Amaranthaceae (Amaranth)

Amaranthus fimbriatus (Torr.) Benth. ex S. Watson
Common Names: Fringed Amaranth or Fringed Pigweed

Seeds: ranged from light to dark brown, about ¼ mm wide

Las Vegas bearpoppy seed bank



Family: Asteraceae (Sunflower or Composite)

Ambrosia dumosa (A. Gray) Payne
Common names: White Bursage, Burrobush, Burroweed

Fruit: bur 4–9 mm, ± spheric, golden to purple or brown, puberulent; spines 12–35, 2–4 mm, spiraled, flat, straight, sharp

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area
Burs harvested from live plant



Encelia Adans. (Either *E. farinosa* A. Gray ex Torr. or *E. virginensis* A. Nelson)
Common name: Brittlebush

Fruit: Strongly compressed, obovate or wedge-shaped; edges long-ciliate; faces glabrous or short-hairy; pappus of 2 narrow scales or 0.

E. farinosa
3–6 mm; pappus 0

Lake Mead National Recreation Area
Harvested from live plant



E. virginensis
5–8 mm; pappus generally 0

Lake Mead National Recreation Area
Harvested from live plant; may be under developed



Enceliopsis argophylla (D.C. Eaton) A. Nelson silverleaf
Common name: Silverleaf Sunray

Fruit: ± 10 mm, 6.5 mm wide, glabrous or puberulent; pappus awns ± 1 mm, smooth

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area Nursery Collection



Family: Boraginaceae (Borage or Forget-me-not)

Cryptantha utahensis (A. Gray) Greene
Common name: Scented Cryptantha

Fruit: Nutlet 1(2), 1.7–2.5 mm, lanceolate to lance-ovate, white-grainy papillate to minute-spiny, ± dull, margin distally a ± flat inward bent narrow rim to basally sharp-angled, base rounded, tip ± acute; abaxially low-rounded, ridge 0; adaxially occasionally smooth, biconvex, attachment scar edges ± narrow-gapped, triangular-flare-gapped at base; axis generally to nutlet(s)

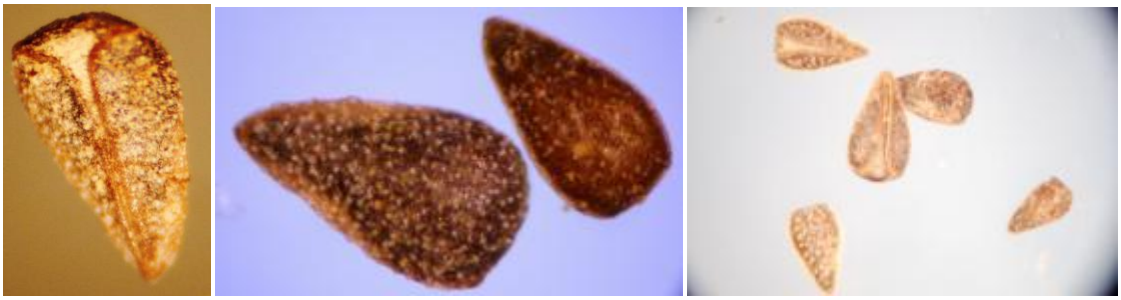
Las Vegas bearpoppy seed bank



Cryptantha holoptera (A. Gray) J.F. Macbr.
Common name: Winged Cryptantha

Fruit: nutlets 4, ± 1–2 mm, subequal, ovate to triangular, back and generally inner face sparsely tubercled, margin generally narrowly winged, groove opened widely below middle, edge generally elevated

Las Vegas bearpoppy seed bank



Cryptantha nevadensis (Nelson & Kennedy) var. *nevadensis*
Common name: Nevada Cryptantha

Fruit nutlets 1-4, free (fused), smooth to roughened, prickly or not, valvate or cirsumscissile capsule , 1.8–2.3 mm

Las Vegas bearpoppy seed bank





Family: Brassicaceae (Mustard, Crucifers, or Cabbage)

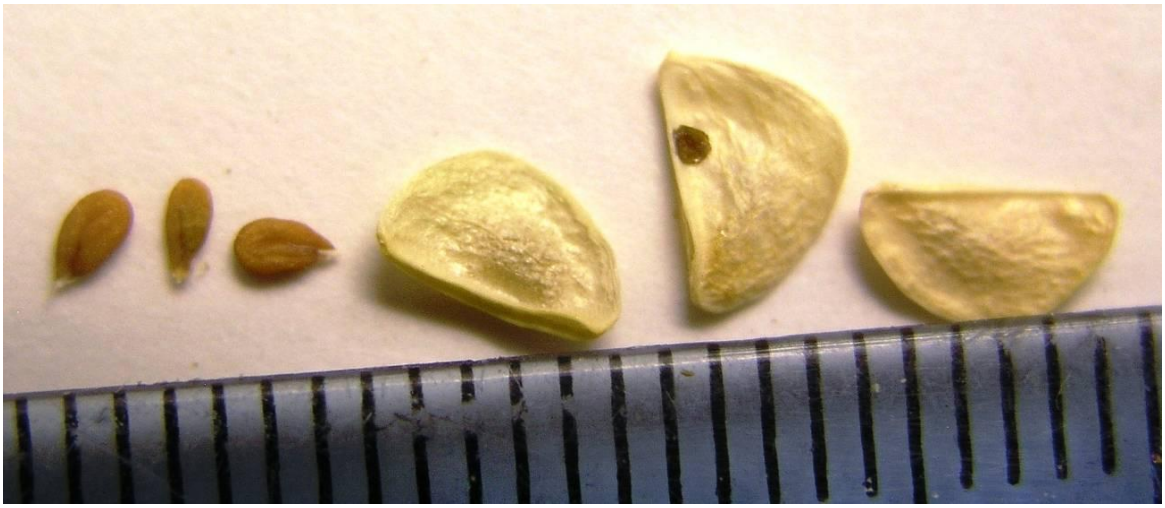
Lepidium fremontii S. Watson
Common name: Desert Pepperweed

Fruit: (4) 4.5–7 (8) mm, 4.2–7 (8) mm wide, obovate to round, flat, tip winged, notch (0.1)0.2–0.5 mm; valves glabrous, not veined; style 0.2–0.8 (1) mm, exserted beyond notch; pedicel spreading, (3.5) 4.3–7.6 (8.5) mm, cylindric, glabrous.
Seed: 1.6–2.1 mm, ovate.

Las Vegas bearpoppy seed bank



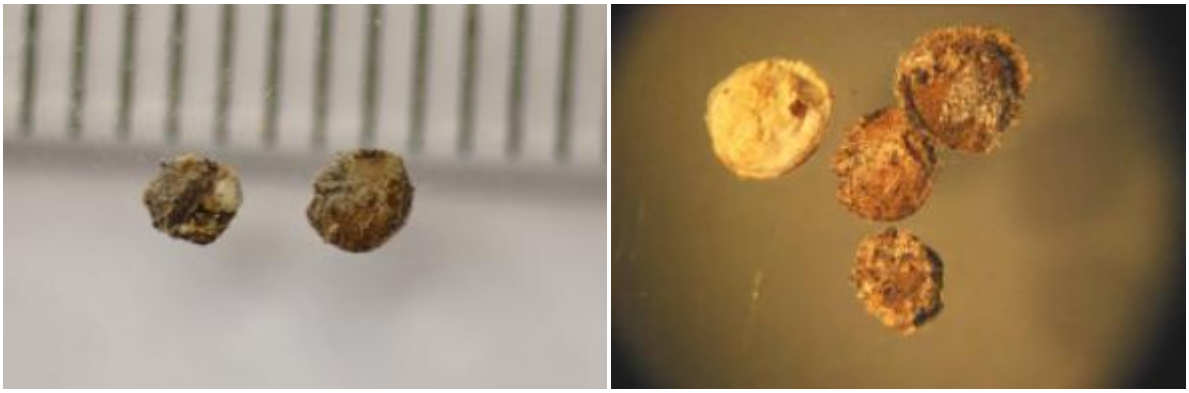
Lake Mead National Recreation Area Nursery Collection



Lesquerella tenella A. Nelson
Common name: Moapa Bladderpod

Fruit: (3.5) 4–6 mm, spheric to obovoid, generally ± compressed, sparsely hairy outside, densely hairy inside; style 2–4.5 mm; pedicel 5–15 mm.
Seed: 4–12, flattened, margined.

Las Vegas bearpoppy seed bank



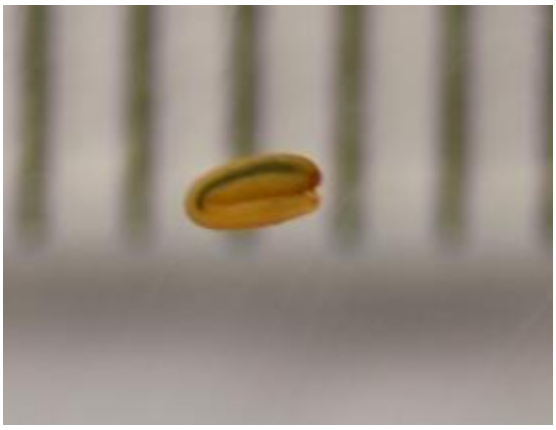
Malcolmia africana (L.) W.T. Aiton
Common name: African Mustard (non-native; uncertain)

Fruit: ascending, (2.5) 3.5–5.5 (7) cm, 1–1.3 mm wide; style 0; pedicel 0.5–2 (4) mm.
Seed: 1–1.2 mm, oblong.

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area
Harvested from live plant



Family: Chenopodiaceae (Goosefoot)

Atriplex canescens (Pursh) Nutt.
Common names: Fourwing Saltbush, Chamiso, Chamiza

Seed: 1, small, lenticular to spheric, generally erect. 1.5–2.5 mm

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area Nursery Collection



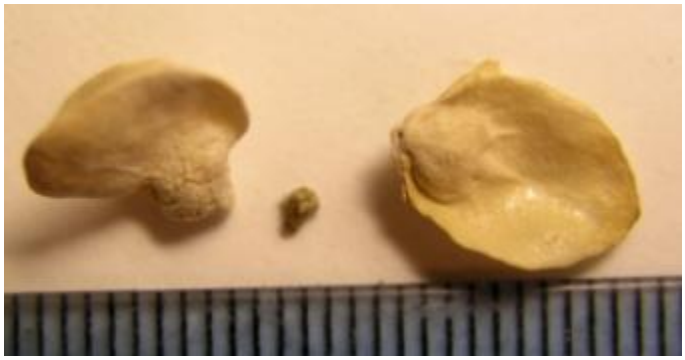
Atriplex confertifolia (Torr. & Frém.) S. Watson
Common name: Shadscale Saltbush

Seed: 1.5–2 mm.

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area Nursery Collection



Atriplex elegans (Moq.) D. Dietr.
Common name: Wheelscale Saltbush

Seed: 1–1.5 mm

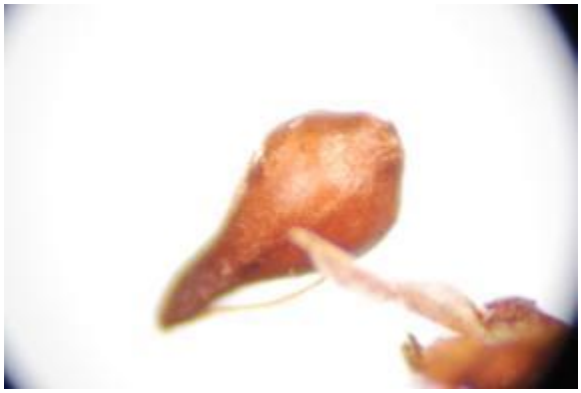
Las Vegas bearpoppy seed bank



Family: Cyperaceae (Sedge)

Carex L.
Common name: Sedge

Las Vegas bearpoppy seed bank



Family: Ephedraceae (Ephedra)

Ephedra L. Either *E. nevadensis* S. Watson or
(Nevada jointfir) or *E. torreyana* S. Watson (Torrey's jointfir) jointfir

Seed: generally 2, 6–9 mm, generally 2 × as long as wide

Las Vegas bearpoppy seed bank (species uncertain)



E. nevadensis

Lake Mead National Recreation Area Nursery Collection



E. torreyana

Lake Mead National Recreation Area Nursery Collection

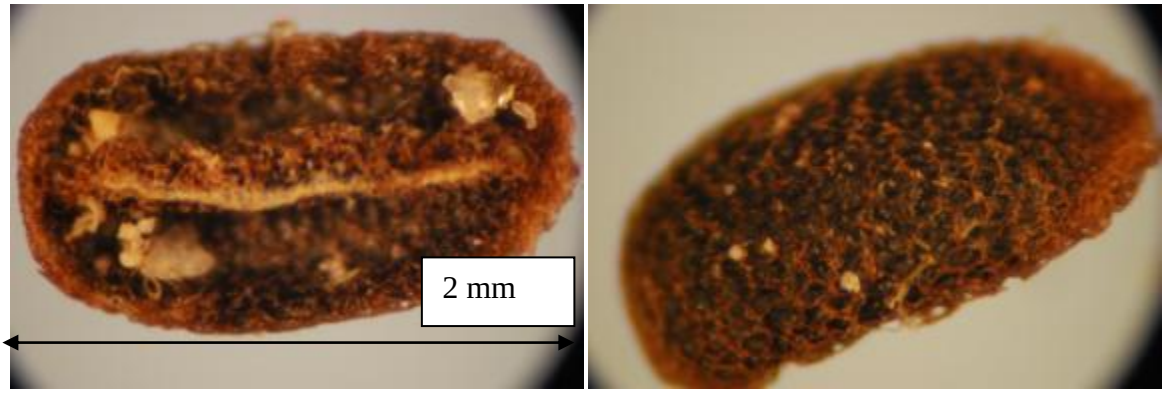


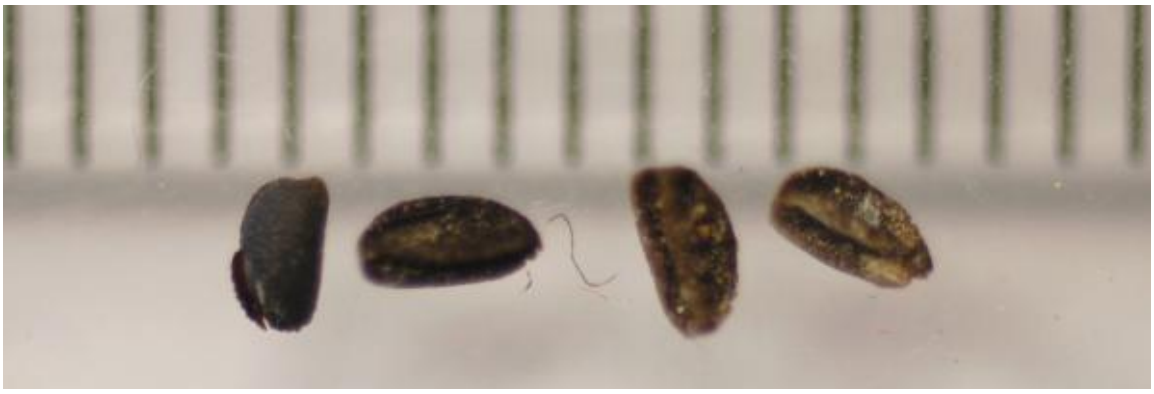
Family: Hydrophyllaceae (subfamily of the Boraginaceae family; traditionally under the Cronquist system, Hydrophylloideae was given a family rank within the order Solonales)

Phacelia palmeri Torr. ex S. Watson
Common names: Palmer's phacelia, Palmer's scorpionweed

Seeds: capsule

Las Vegas bearpoppy seed bank





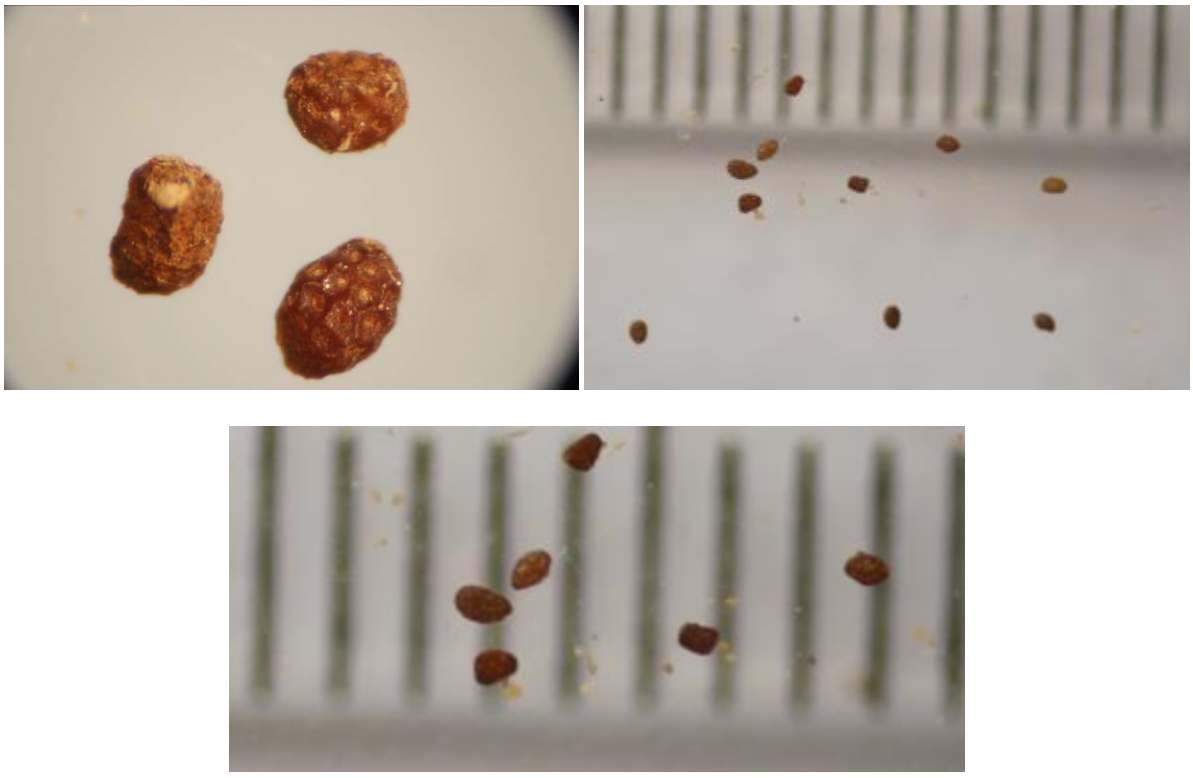
Lake Mead National Recreation Area
Collected from live plant



Phacelia pulchella A. Gray
Common name: Beautiful Phacelia

Fruit: 3–5 mm, ± oblong, short-hairy.
Seed: (25) 30–50, ± 0.5 mm, pitted.

Las Vegas bearpoppy seed bank

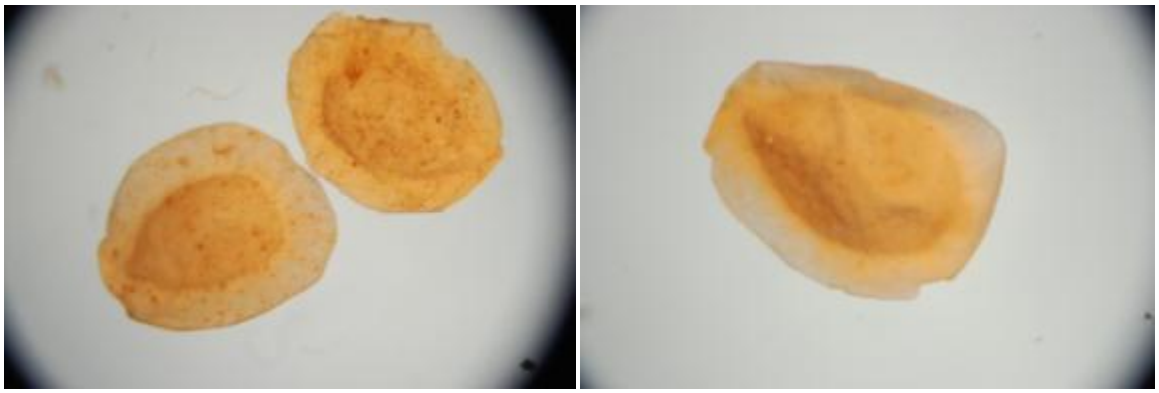


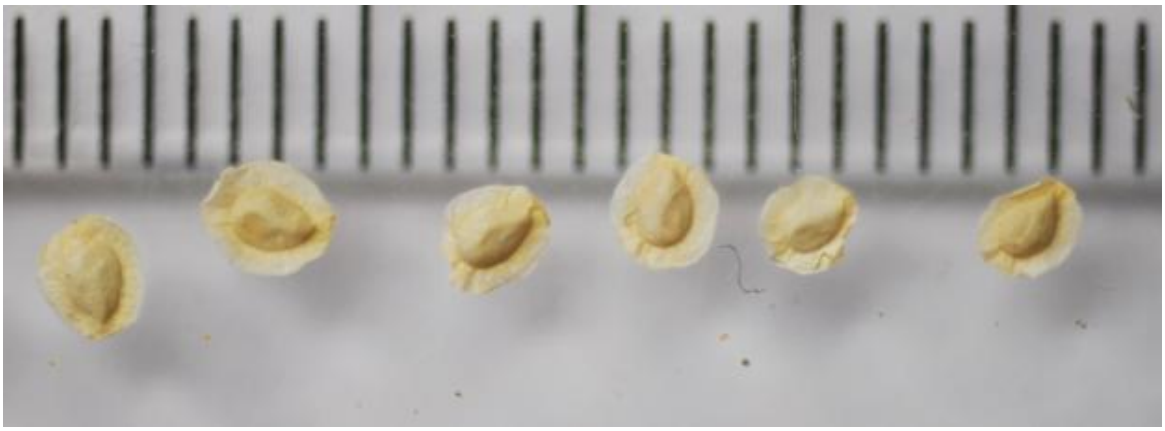
Family: Loasaceae (Loasa)

Mentzelia pterosperma Eastw.
Common name: Wingseed Blazingstar

Fruit: erect, 8–14 mm, 5–10 mm wide, cup-shaped to cylindric.
Seed: ± 2.5–4 mm, ± 3 mm wide, lenticular, winged, white.

Las Vegas bearpoppy seed bank





Family: Malveceae (Mallow)

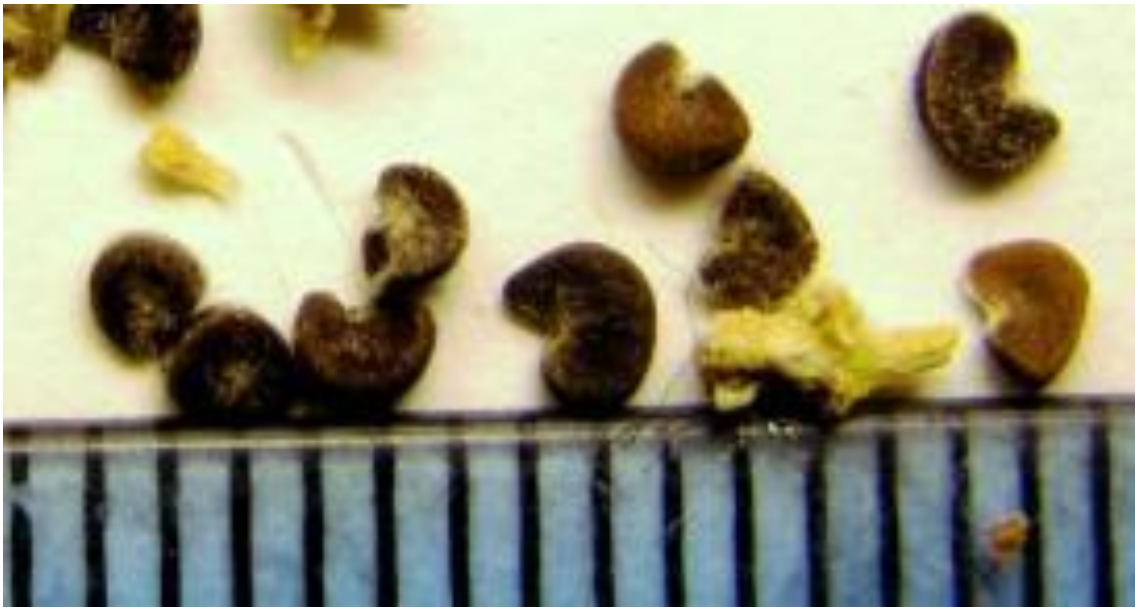
Sphaeralcea ambigua A. Gray desert
Common names: Desert Globemallow, Apricot Mallow

Fruit: segments 9–13, < 6 mm, < 3.5 mm wide, truncate-cylindric, dehiscent part < 3.5 mm, 60–75% of segment.
Seed: 2 per segment, brown, glabrous to hairy.

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area Nursery Collection



Family: Onagraceae (Willowherb or Evening Primrose)

Oenothera deltoides Torr. & Frém. (uncertain)
Common names: birdcage evening primrose, basket evening primrose, lion in a cage, devil's lantern

Fruit: 20–60(80) mm, cylindric, generally curved, ± twisted.

Las Vegas bearpoppy seed bank

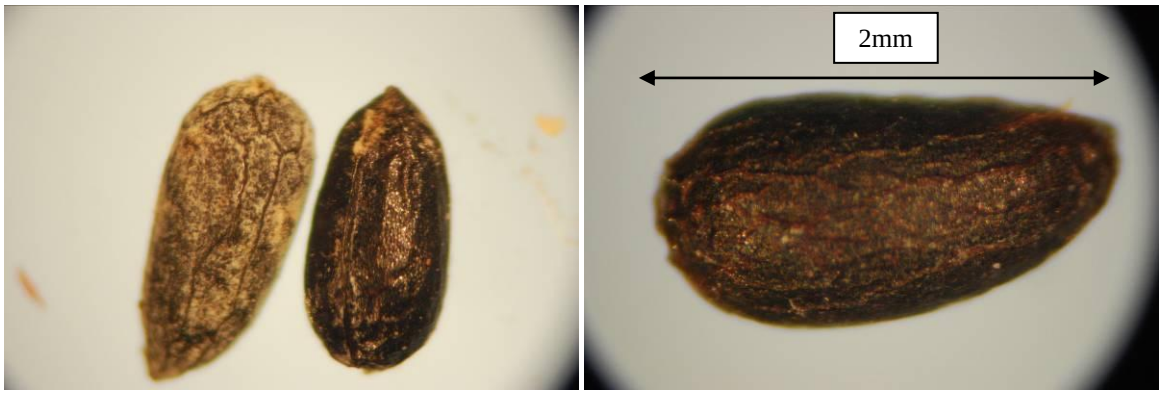


Family: Papaveraceae (Poppy)

Arctomecon californica Torr. & Frém.
Common names: California bearpoppy, Las Vegas bearpoppy, golden bearpoppy, yellow-flowered desert poppy

Fruit: ovate to oblong, dehiscent from tip.
Seed: 2 mm long, 1 mm wide. Wrinkled, withered appearance

Las Vegas bearpoppy seed bank



Family: Plantaginaceae (Plantain)

Plantago ovata Forssk.
Common names: Desert Indianwheat, blond psyllium

Seed: 2, 2–2.5 mm; gelatinous when wet

Las Vegas bearpoppy seed bank



Lake Mead National Recreation Area Nursery Collection

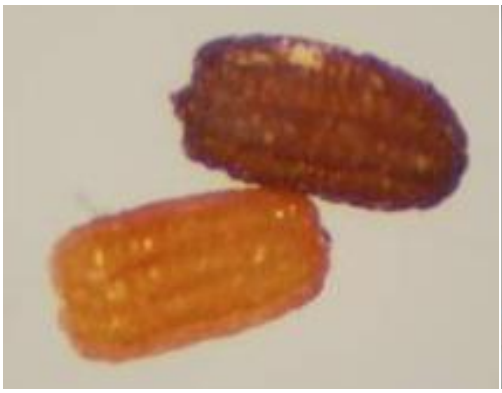


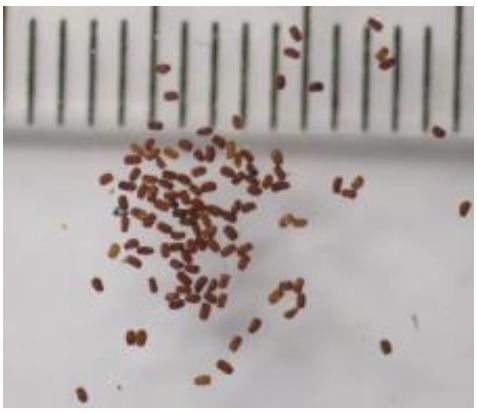
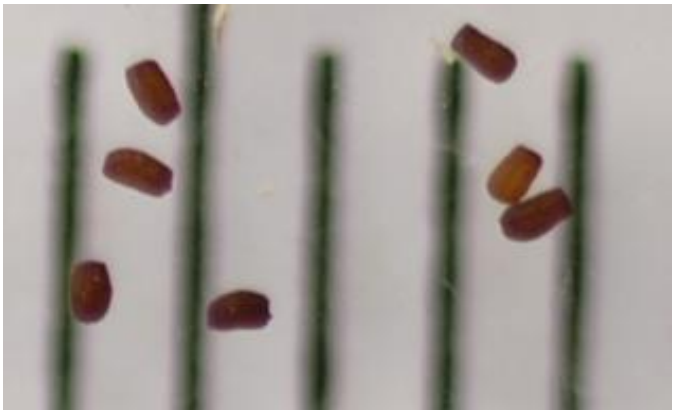
Family: Scrophulariaceae (Figwort)

Mimulus sp. (uncertain)

Fruit: generally ovoid to fusiform, generally upcurved if elongate, generally ± fragile, loculicidal near tip (hard, indehiscent), chambers 1–2.
Seed: many, generally < 1 mm, ovoid, ± yellow to dark brown.

Las Vegas bearpoppy seed bank



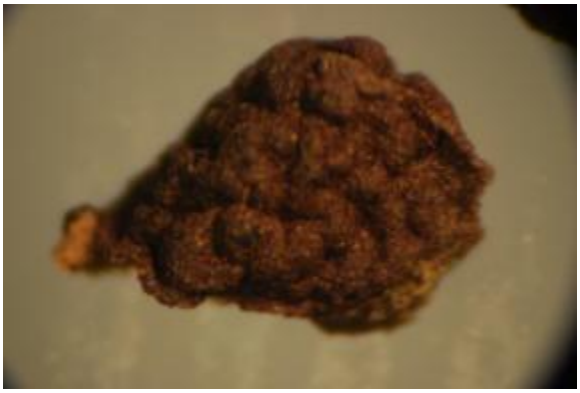
Penstemon palmeri A. Gray and sp the “spike” seed
Common name: Palmer’s penstemon

Seed: generally many, irregularly angled.

Las Vegas bearpoppy seed bank

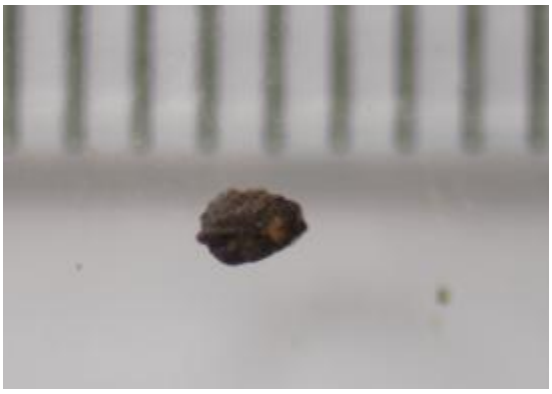


P. palmeri



Penstemon sp.





Unknown

Seed/fruit: 4.5 mm length, 2.4 mm wide, ovate to ovate-round, notched.

Las Vegas bearpoppy seed bank



APPENDIX C

Included are tables related to the full analysis of the Northshore Rd salvage and outplanting project (Section IV of this report) which occurred in Lake Mead National Recreation Area between 2008 and 2010.

Table C1 The number of plants of each species listed by growth habit for watering treatments where IBA=0 (no treatment) and slurry=0 (no treatment) assigned to salvaged plants from Northshore Rd, Lake Mead National Recreation Area in fall 2008.

		No water Overnight		Water Overnight		Included
Life Form	*Species*	# Plants	# Surviving	# Plants	# Surviving	in water analysis
Grass	*Pleuraphis rigida*	39	15	23	10	yes
Grass Total		39	15	23	10	
Forb	A*stragalus* sp.	2	1			no
	Astragalus preusii	19	2	4	0	yes
	Baileya multiradiata	3	2			no
	Eriogonum inflatum	46	17	9	2	yes
	Sphaeralcea ambigua	34	23	4	2	yes
	Stephanomeria pauciflora	42	17	14	4	yes
	Suaeda moquinii	14	6	3	1	yes
	Tidestromia oblongifolia	1	1			no
Forb Total		161	69	34	9	
Shurb	*Acacia greggii*	4	0	1	1	yes
	Ambrosia dumosa	140	95	15	8	yes
	Atriplex confortifolia	21	18	2	1	yes
	Atriplex hymenelytra	22	12	4	3	yes
	Atriplex sp.	2	0	1	0	yes
	Enceliopsis argophylla	42	12			no
	Ephedra torreyana	20	3	29	2	yes
	Ferocactus cylindraceaus	5	5			no
	Gutierrezia sarothrae	1	1	6	2	yes
	Hymenoclea salsola	1	0			no
	Isocoma acradenia	13	8	1	0	yes
	Krameria spp	1	0			no
	Larrea tridentata	37	16	6	2	yes
	Opuntia acanthocarpa	5	5			no
	Opuntia basilaris	101	101			no
	Psorothamnus fremontii	14	5	1	0	yes
	Sclerocactus johnsonii	8	8			no
Shrub Total		437	289	66	19	

Table C2 Frequency of all possible IBA-slurry combinations (denoted as 'IBA-slurry'; '0-0' is IBA=0, slurry=0) looking at IBA-slurry interaction ('interaction", "growth habit "), IBA alone, and slurry alone for salvaged plants from Northshore Rd, Lake Mead National Recreation Area in fall 2009.

			-IBA, -slurry		-IBA, +slurry		+IBA, -slurry		+IBA, +slurry	
Growth Habit	Species	#	plants	Survived	plants	Survived	plants	Survived	plants	Survived
Grass	*Dasyochloa pulchella*				1	1			4	1
	Pleuraphis rigida		39	15	2	2	4	1	7	3
Grass Total			**39**	**15**	**3**	**3**	**4**	**1**	**11**	**4**
Forb	*Astragalus spp*		2	1						
	Astragalus preussii		19	2			63	24	2	1
	Baileya multiradiata		3	2	60	20	1		96	39
	Eriogonum inflatum		46	17	81	18	42	0	99	30
	Sphaeralcea ambigua		34	23	40	20	19	9	38	27
	Stephanomeria pauciflora		42	17	5	2	31	10	5	2
	Suaeda moquinii		14	6	2	0	77	16	2	1
	Tidestromia oblongifolia		1	1				17	2	2
Forb Total			**161**	**69**	**188**	**60**	**233**	**76**	**244**	**102**
Shrub	*Acacia greggii*		4	0	5	1	6	1	1	0
	Ambrosia dumosa		140	95	152	101	67	47	99	71
	Atriplex confertifolia		21	18			8	7	1	1
	Atriplex hymenelytra		22	12			1	1		
	Atriplex spp		2	0	1	0	3	0	1	0
	Encelia virginensis				6	5			12	7
	Enceliopsis argophylla		42	12	1	0	31	6		
	Ephedra nevedensis								1	1
	Ephedra torreyana		20	3	63	11	9	1	24	3
	Ferocactus cylindreus		5	5						
	Gutierrezia sarothrae		1	1	1	1				
	Hymenoclea salsola		1	0	21	16	1	1	6	4
	Isocoma acredenia		13	8			11	5		
	Krameria spp		1	0	3	0			3	0
	Larrea tridentata		37	16	65	29	14	5	35	22
	Lepidium fremontii						1	1		
	Opuntia acanthocarpa		5	5	2	1				
	Opuntia basilaris		101	101			1	1		
	Psorothamnus fremontii		14	5	7	4	9	2	8	3
	Sclerocactus johnsonii		8	8						
Shrub Total			**437**	**289**	**327**	**169**	**162**	**78**	**191**	**112**

Table C3 The species included for the analysis of IBA-slurry interaction ('interaction", "growth habit"), IBA alone, and slurry alone for salvaged plants from Northshore Rd, Lake Mead National Recreation Area in fall 2009.

Growth Habit	Species	Included in analysis: interaction	IBA-no slurry	IBA-with slurry	Growth Habit
Grass	*Dasyochloa pulchella*				
	Pleuraphis rigida				
Forb	*Astragalus spp*				
	Astragalus preussii		1		
	Baileya multiradiata			1	
	Eriogonum inflatum	1			1
	Sphaeralcea ambigua	1			1
	Stephanomeria pauciflora		1		1
	Suaeda moquinii		1		
	Tidestromia oblongifolia				
Shrub	*Acacia greggii*				
	Ambrosia dumosa	1			1
	Atriplex confertifolia				
	Atriplex hymenelytra				
	Atriplex spp				
	Encelia virginensis				
	Enceliopsis argophylla		1		
	Ephedra nevedensis				
	Ephedra torreyana	1			1
	Ferocactus cylindreus				
	Gutierrezia sarothrae				
	Hymenoclea salsola			1	
	Isocoma acredenia		1		
	Krameria spp				
	Larrea tridentata	1			1
	Lepidium fremontii				
	Opuntia acanthocarpa				
	Opuntia basilaris				
	Psorothamnus fremontii	1			1
	Sclerocactus johnsonii				

Table C4 Groups of soil variables used to predict survival of the Northshore plants salvaged from gypsiferous soil types in October 2008 and transplanted in January 2010 to disturbed areas along Northshore Rd, Lake Mead National Recreation Area

Physical	Macronutrients	Micronutrients
Slope	Total N ($g\text{-}m^{-2}$)	Na ($mg\ L^{-1}$)
Aspect	NH4 ($g\text{-}m^{-2}$)	B ($mg\ L^{-1}$)
Organic C	NO3 ($g\text{-}m\text{-}^{2}$)	Cu ($mg\ L^{-1}$)
Clay (%)	Phosphorus- Olsen (g-m-2)	Fe ($mg\ L^{-1}$)
Sand (%)	K ($mg\ L^{-1}$)	Mn ($mg\ L^{-1}$)
Bulk density (>2mm by volume)	S ($g\text{-}m^{-2}$)	Mo ($mg\ L^{-1}$)
Particle size >2mm (% volume)	Ca ($mg\ L^{-1}$)	Ni ($mg\ L^{-1}$)
Electroconductivity	Mg ($mg\ L^{-1}$)	Zn ($mg\ L^{-1}$)
Sodium adsorption ratio		
Inorganic C		

Table C5 Summary for all species detailing the proportion surviving salvage (excluding seedlings) and the proportion surviving 27 months after outplanting for plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area. The 95% confidence interval (CI) was derived from 1000 bootstrap samples.

Species	proportion surviving salvage	95% CI	Total plants salvaged	proportion surviving 27 months after outplanting	95% CI	Total outplants
Acacia greggii	0.188	0, 0.375	16	0.000	0, 0	3
Ambrosia dumosa	0.680	0.636, 0.722	475	0.600	0.553, 0.65	360
Astragalus spp	0.500	0, 1	2	0.000	0, 0	1
Astragalus preussii	0.330	0.231, 0.429	91	0.030	0, 0.091	33
Atriplex confortifolia	0.844	0.719, 0.969	32	0.536	0.357, 0.714	28
Atriplex hymenelytra	0.593	0.407, 0.742	27	0.471	0.235, 0.706	17
Atriplex spp	0.000	0, 0	8	0.000	0, 0	0
Baileya multiradiata	0.381	0.306, 0.456	160	0.298	0.212, 0.385	104
Encelia virginensis	0.667	0.444, 0.889	18	0.357	0.143, 0.571	14
Enceliopsis argophylla	0.243	0.149, 0.351	74	0.167	0, 0.389	18
Ephedra nevedensis	0.667	0, 1	3	0.000	0, 0	2
Ephedra torreyana	0.150	0.095, 0.204	147	0.364	0.182, 0.545	22
Eriogonum inflatum	0.275	0.221, 0.325	280	0.270	0.18, 0.36	89
Dasyloclea pullchella	0.400	0, 0.8	5	0.000	0, 0	2
Ferocactus cylindraceus	1.000	1, 1	5	1.000	1, 1	5
Gutierrezia sarothrae	0.500	0.125, 0.875	8	0.250	0, 0.75	4
Hymenoclea salsola	0.724	0.552, 0.897	29	0.190	0.048, 0.381	21
Isocoma acradenia	0.520	0.32, 0.72	25	0.375	0.125, 0.625	16
Krameria spp	0.000	0, 0	7	0.000	0, 0	0
Larrea tridentata	0.481	0.409, 0.552	154	0.534	0.425, 0.644	73
Lepidium fremontii	1.000	1, 1	1	0.000	0, 0	1
Opuntia acanthocarpa	0.857	0.571, 1	7	0.667	0.333, 1	6
Opuntia basilaris	1.000	1, 1	103	0.931	0.882, 0.971	102
Pleuraphis rigida	0.413	0.307, 0.533	75	0.138	0.034, 0.276	29
Psorothamnus fremontii	0.359	0.205, 0.513	39	0.143	0, 0.357	14
Sclerocactus johnsonii	1.000	1, 1	8	1.000	1, 1	8
Sphaeralcea ambigua	0.610	0.529, 0.684	136	0.495	0.4, 0.6	105
Stephanomeria pauciflora	0.418	0.316, 0.51	98	0.473	0.345, 0.6	55
Suaeda moquinii	0.255	0.173, 0.347	98	0.500	0.308, 0.692	26
Tidestromia oblongifolia	1.000	1, 1	4	0.125	0, 0.375	8

Table C6 Results from general linear model with binomial error for salvage survival across life forms and for soaking in water overnight for plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area.

Effect	NumDF	DenDF	F	P
Growth habit	2	22	0.44	0.6484
Water overnight	1	22	2.61	0.1203
Growth habit x water overnight	2	22	2.51	0.1043

Table C7 Effects of a root-stimulating hormone (IBA) treatment on species' salvage survival of plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area. The observations used for this analysis had no water soaking and no slurry, and included five species (Table 6) which did not have sufficient observations to assess effects of IBA with slurry. Significant values, $\alpha = 0.05$, bolded; $\alpha = 0.10$, *italicized*.

Effect	NumDF	DenDF	F	P
Species	4	333	3.54	**0.0076**
IBA	1	333	0.00	0.9830
Species*IBA	4	333	2.31	*0.0576*

Table C8 Effects of a root-stimulating hormone (IBA) treatment on species' salvage survival of plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area. The observations used for this analysis had no water soaking but were all treated with slurry. This included the two species (Table 6) which did not have sufficient observations to assess effects of IBA without slurry. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
Species	1	179	7.59	**0.0065**
IBA	1	179	0.02	0.8833
Species*IBA	1	179	0.54	0.4621

Table C9 Effects of a root-stimulating hormone (IBA) treatment and slurry on species' salvage survival of plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area. The observations used for this analysis had no overnight water soaking and included the six species (Table 6) which had sufficient observations to assess effects of IBA and slurry. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
Species	5	1138	26.60	0.0000
IBA	1	1138	0.39	0.5334
Species*IBA	5	1138	0.53	0.7517
Slurry	1	1138	1.47	0.2259
Species*Slurry	5	1138	0.67	0.6490
IBA*Slurry	1	1138	2.40	0.1214
Species*IBA*Slurry	5	1138	0.88	0.4952

Table C10 Effects of growth habit, a root-stimulating hormone (IBA) treatment and slurry on salvage survival of plants salvaged in October 2008 along Northshore Rd, Lake Mead National Recreation Area. The observations used for this analysis had no water soaking and included the two growth habits (herbs and shrubs; Table 6) which had sufficient observations to assess effects of IBA and slurry. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
Growth Habit	1	20	28.10	0.0000
IBA	1	20	0.67	0.4239
Growth Habit*IBA	1	20	0.29	0.5939
Slurry	1	20	1.27	0.2728
Growth Habit*Slurry	1	20	0.72	0.4066
IBA*Slurry	1	20	5.75	0.0263
Growth Habit*IBA*Slurry	1	20	0.58	0.4543

Table C11 Analysis of variance results for effect of topsoil relative to water treatment and growth habit for outplanted plants along Northshore Rd, Lake Mead National Recreation Area. All effects were tested over their respective interaction within each site. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
topsoil	1	11	3.04	0.1090
water_yn	1	9	6.99	0.0267
topsoil*water_yn	1	9	0.55	0.4755
Growth Habit	1	10	1.46	0.2547
topsoil*Growth Habit	1	10	0.56	0.4705
water_yn*Growth Habit	1	6	1.85	0.2231
topsoi*water_*Life_f	1	6	0.55	0.4855

Table C12 Effects of watering (DriWater, hand watering, or no water treatments), on species' survival 27 months after outplanting along Northshore Rd, Lake Mead National Recreation Area. The observations used for this analysis had observation sin all three sites for all watering treatments. Growth habits included forbs and shrubs. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
Growth Habit	1	2	24.31	**0.0388**
water_plant	2	4	14.72	**0.0143**
Growth Habit*water_plant	2	4	0.22	0.8144

Table C13 Effects of watering treatment (DriWater, hand watering, or no water treatment) on outplanting survival per growth habit for outplanted plants along Northshore Rd, Lake Mead National Recreation Area. Only forbs and shrubs were available for analysis. Significant values, $\alpha = 0.05$, bolded.

Effect	NumDF	DenDF	F	P
Growth Habit	1	2	24.31	**0.0388**
water_plant	2	4	14.72	**0.0143**
Growth Habit*water_plant	2	4	0.22	0.8144

Table C14 Effects of watering treatment or no watering treatment on species' outplanting survival for outplanted plants along Northshore Rd, Lake Mead National Recreation Area. Seven species had sufficient data for this analysis. The odds ratios and p-values resulting from that analysis do not account for any other variables in the study; the coefficients reflect only the relationship between a soil variable and transplant survival after 27 months. Significant values, $\alpha = 0.05$, bolded; $\alpha = 0.10$, *italicized*.

Effect	NumDF	DenDF	F	P
Species	6	12	7.40	**0.0017**
Water_yn	1	2	12.29	*0.0726*
Species*water_yn	6	12	0.59	0.7303

Table C15 Odds ratios for physical soil variables based on effects of a 10% change in each soil variable on survival of salvaged and transplanted plants for three years along Northshore Rd, Lake Mead National Recreation Area. Values are based on a logistic regression. Coefficients are reported for logistic regression output where other variables in the group were partialled out ('with other variables') and for logistic regression for each predictor alone ('Alone'). Bold type indicates significant coefficients ($\alpha = 0.05$), while italics indicates marginal significance ($\alpha = 0.10$), after Bonferroni correction. The 'range' reflects the minimum and maximum values that were observed for each variable in the study.Variables included electroconductivity (EC), sodium absortption ratio (SAR), bulk density includes >2mm by volume, and particle size includes >2mm % by volume. Soil variables inorganic and organic C are calculated to g/m^2 at 5 cm depth of soil surface, and % clay and sand are estimated for the top 0-5 cm soil surface.

	Odds ratios (slope)- 10% change						Range			
		Confidence Interval			Confidence Interval					
Soil variable	With other variables	Lower 95%	Upper 95%	Alone	Lower 95%	Upper 95%	min	max	10% of range	range
Slope	**0.66**	0.54	0.80	1.00	0.97	1.04	2.00	50.00	4.80	48.00
Aspect	**1.34**	1.14	1.58	0.99	0.96	1.02	0.00	2.00	0.20	1.99
EC	**0.27**	0.15	0.46	**0.88**	0.84	0.92	458.00	5083.00	462.50	4625.00
Inorganic C	**0.34**	0.19	0.61	**1.11**	1.07	1.16	3.72	27.15	2.34	23.43
Organic C	**0.58**	0.42	0.81	0.97	0.91	1.02	0.10	0.57	0.05	0.47
SAR	**2.38**	1.53	3.69	**0.91**	0.88	0.94	0.16	5.00	0.48	4.84
% Clay	**0.21**	0.11	0.42	0.94	0.89	0.99	5.08	15.50	1.04	10.42
% Sand	**0.32**	0.17	0.60	1.03	0.98	1.08	50.62	71.63	2.10	21.02
Bulk density	*0.74*	0.55	1.01	**0.88**	0.84	0.92	0.79	1.28	0.05	0.49
Particle size	*2.00*	0.99	4.05	**1.19**	1.14	1.24	0.00	32.00	3.20	32.00

Table C16 Odds ratios for macronutrient soil variables based on effects of a 10% change in each soil variable on survival of salvaged and transplanted plants for three years along Northshore Rd, Lake Mead National Recreation Area. Values are based on a logistic regression. Coefficients are reported for logistic regression output where other variables in the group were partialled out ('with other variables') and for logistic regression for each predictor alone ('Alone'). Bold type indicates significant coefficients ($\alpha = 0.05$), while italics indicates marginal significance ($\alpha = 0.10$), after Bonferroni correction. Two macronutrient variables (S and K) were $\log_{10}$ transformed to improved linearity and reduce influence of outliers. The 'range' reflects the minimum and maximum values that were observed for each variable in the study. Macronutrient variables included total S and N, NH_4, NO_3, Ca, Olsen-P, K, and Mg, with all variables calculated for g/m^2 at 0-5 cm depth surface soil.

	Odds ratios (slope)- 10% change						Range			
		Confidence Interval			Confidence Interval					
Soil variable	With other variables	Lower 95%	Upper 95%	Alone	Lower 95%	Upper 95%	min	max	10% of range	range
Total N				1.02	0.97	1.08	0.03	0.11	0.01	0.08
$\log_{10}$ Total S	0.92	0.78	1.07	**0.87**	0.84	0.90	-1.23	0.92	0.21	2.15
NH_4				**0.90**	0.86	0.93	0.00	0.01	0.00	0.01
NO_3	**0.86**	0.81	0.91	**0.86**	0.82	0.90	0.00	0.01	0.00	0.01
P	0.97	0.90	1.05	0.94	0.89	0.99	0.00	0.01	0.00	0.00
Ca	**0.78**	0.69	0.88	**0.85**	0.79	0.91	78.60	1264.00	118.54	1185.40
$\log_{10}$ K	0.98	0.73	1.32	**0.86**	0.82	0.87	0.48	1.88	0.14	1.39
Mg	1.05	0.92	1.21	**0.92**	0.88	0.96	4.80	76.80	7.20	72.00

Table C17 Odds ratios for micronutrient soil variables based on effects of a 10% change in each soil variable on survival of salvaged and transplanted plants for three years along Northshore Rd, Lake Mead National Recreation Area. Values are based on a logistic regression. Coefficients are reported for logistic regression output where other variables in the group were partialled out ('with other variables') and for logistic regression for each predictor alone ('Alone'). Bold type indicates significant coefficients ($\alpha = 0.05$), while italics indicates marginal significance ($\alpha = 0.10$), after Bonferroni correction. Three micronutrient variables (Fe, Mn, Zn) were $\log_{10}$ transformed to improved linearity and reduce influence of outliers. The 'range' reflects the minimum and maximum values that were observed for each variable in the study. Micronutrient variables included Na, B, Cu, Fe, Mn, Mo, Ni, and Zn, with all variables calculated for g/m^2 at 0-5 cm depth surface soil,

	Odds ratios (slope)- 10% change									
		Confidence Interval			Confidence Interval		Range			
Soil variable	With other variables	Lower 95%	Upper 95%	Alone	Lower 95%	Upper 95%	min	max	10% of range	range
Na	0.93	0.84	1.04	**0.91**	0.88	0.94	8.10	484.00	47.59	475.90
B	**1.19**	1.02	1.39	**0.94**	0.90	0.97	0.40	14.46	1.41	14.06
Cu	0.99	0.87	1.13	**0.79**	0.73	0.86	0.27	1.30	0.10	1.03
$\log_{10}$ Fe	0.98	0.91	1.06	0.95	0.90	1.00	-1.49	0.24	0.17	1.73
$\log_{10}$ Mn	1.03	0.94	1.14	**0.88**	0.83	0.93	-2.10	-0.59	0.15	1.51
Mo	**0.75**	0.64	0.88	**0.88**	0.84	0.92	0.04	0.74	0.07	0.70
Ni				**0.87**	0.82	0.92	0.03	0.25	0.02	0.22
$\log_{10}$ Zn	**0.82**	0.75	0.91	**0.86**	0.82	0.91	-1.17	0.15	0.13	1.31

Appendix D

Enclosed is a copy of Lindsay Chiquoine's Master of Science Thesis manuscript, University of Nevada, Las Vegas, entitled:

Restoration of Biological Soil Crusts on Disturbed Gypsiferous Soils in Lake Mead National Recreation Area, Eastern Mojave Desert.

RESTORATION OF BIOLOGICAL SOIL CRUSTS ON DISTURBED GYPSIFEROUS SOILS IN LAKE MEAD NATIONAL RECREATION AREA, EASTERN MOJAVE DESERT

By

Lindsay Patricia Chiquoine

Bachelor of Arts in Environmental Humanities
Northern Arizona University
2004

A thesis submitted in partial fulfillment
of the requirement for the

Master of Science in Environmental Science

School of Environmental and Public Affairs
Greenspun College of Urban Affairs
The Graduate College

University of Nevada, Las Vegas
December 2012

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THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Lindsay Chiquoine

entitled

Restoration of Biological Soil Crusts on Disturbed Gypsiferous Soils in Lake Mead National Recreation Area, Eastern Mojave Desert

be accepted in partial fulfillment of the requirements for the degree of

Master of Science in Environmental Science
School of Environmental and Public Affairs

Scott Abella, Ph.D., Committee Chair

Lloyd Stark, Ph.D., Committee Member

Matthew Bowker, Ph.D., Committee Member

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Tom Piechota, Ph.D., Interim Vice President for Research &
Dean of the Graduate College

December 2012

ABSTRACT
Restoration of Biological Soil Crust on Disturbed Gypsiferous Soils in Lake Mead National Recreation Area, Eastern Mojave Desert

By

Lindsay P. Chiquoine

Dr. Scott Abella, Examination Committee Chair
Associate Research Professor
University of Nevada, Las Vegas

Over the past several decades biological soil crust (BSC) research has demonstrated the importance of biotic crusts to desert ecosystems and the negative consequences of disturbance. Natural recovery takes many years, and active restoration decreases the recovery time of BSC organisms and their ecosystem functions. The purposes of this thesis were to investigate the applicability of restoration activities in gypsiferous soil types and to test restoration treatments in highly disturbed gypsiferous soils after a road reconstruction project in Lake Mead National Recreation Area in the eastern Mojave Desert. Field, greenhouse, and laboratory studies were used to examine the impacts of disturbance on BSC organisms, observe the impacts of storage, and test the use of salvaged BSCs as inocula.

Field results revealed complex relationships between the BSC microscopic and macroscopic cover, soil stability, and available nitrogen with the main treatments, which included BSC inoculation, topsoil reapplication, wood shavings, and a native perennial shrub. Inocula increased the macroscopic and microscopic BSC organisms, stabilized the surface soils, reduced non-native annual plants, and increased ammonium. Topsoil alone increased cyanobacteria by 186% compared to plots without topsoil. Topsoil treatments also had the highest non-native annual cover. Topsoil and BSC treatments reduced non-

natives cover. Due to issues with blowers, humidity, and temperature controls during the greenhouse study, it was difficult to maintain adequate temperatures and hydration levels. An evaluation of the study procedures and suggestions for future experiments are provided for methodological improvements. In the laboratory after approximately 3 and 4 years of storage, the BSC lichen *Collema* had reduced chlorophyll-fluorescence values compared to undisturbed field specimens. After 3 years of storage, glucose solutions increase the recovery and rate of fluorescence and mannitol solutions shortened the time for chlorophyll-fluorescence recovery. Slurry inoculation with glucose on autoclaved native gypsiferous soils resulted in higher cyanobacteria cover compared to inoculated only flats.

Protection of these BSC systems is important for ecosystem sustainability and maintaining the resilience of BSC communities to current and future climate changes. Active restoration of disturbed BSCs in gypsiferous soils assists with rehabilitation of BSC ecosystem services. The results from this thesis research have direct implications for ecosystem management and restoration activities of BSCs and contribute to identifying the potential impacts of BSC restoration activities as well as the potential for salvaging and storing BSCS to use as inoculants in ecosystem restoration.

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DEDICATION

To Eric Cotto,

thank you for your support and encouragement during my first two and a half years living and working in the Mojave Desert.

And to Norma Dawson Cotto,

in loving support to you who has lost her son too early.

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CHAPTER 1

INTRODUCTION

The goals of this research were to identify the potential barriers to recovery and rehabilitation of biological soil crusts (BSCs) in gypsiferous soil habitat in the eastern Mojave Desert and identify applicable restoration techniques for these systems through a comprehensive literature review of the past decades of BSC and restoration research, and to implement experimental restoration treatments in highly disturbed gypsiferous soil BSC communities. Several decades of research have shown that the soil surface in hot and cold deserts, although inhospitable to many organisms, is inhabited by a myriad of organisms from several different phyla, including plant, fungal, animal, bacterial, and archaeal phyla (Bates et al. 2010; Evens and Johansen 1999; Harper and Marble 1988; Metting 1981; West 1990). In recent years there has been a greater amount of outreach by scientists to other scientists (e.g. BSC-oriented symposia, lectures) and non-scientists (e.g. signage at trailheads) about the sensitivity and importance of these intricate soil ecosystems.

BSCs, which are composed of lichens, fungi, mosses, cyanobacteria and other bacteria, archaea, green algae and other eukaryotic microorganisms (West 1990), and microfauna such as nematodes and protozoa (Zak and Freckman 1991), have important and foundational roles in ecosystems across the earth. These organisms contribute to and influence ecosystem processes and functions such as soil development (Bardgett 2005), nutrient cycling (Evens and Lange 2001), soil erosion potential (Kleiner and Harper 1972), ecosystem hydrology (Belnap 2006), seed ecology and seed banks (Belnap et al. 2001; Eckert et al. 1979), and vegetation diversity and density (Belnap et al. 2001). BSC

organisms influence how an environment is buffered by, reacts to, and recovers from physical stressors such as wind (e.g. Belnap and Gillette 1997, 1998) and precipitation events (e.g. Eldridge and Greene 1994) and yearly and seasonal climate variation (Belnap et al. 2004; Evens et al. 2001). The organisms' diverse morphologies and processes often create unique and biologically complex environments.

Opportunity for Research

The Rehabilitate Northshore Road Project (Northshore project) within Lake Mead National Restoration Area (LMNRA) has provided an area for the study of disturbed and undisturbed gypsiferous BSC communities and related restoration research. The Northshore project included impacts on formerly undisturbed sensitive BSC communities associated within gypsiferous soil types, which is the focus of this thesis research. These soil crusts contain a high diversity of organisms and include lichens and bryophytes (Rosentreter and Belnap 2001). Due to the vulnerability of BSC communities to disturbance and the estimated length of time required for desert BSCs and ecosystems to recover after disturbance (Belnap and Eldridge 2001), restoration of these systems can provide multiple benefits including restoring BSC ability to arrest or reduce soil erosion after disturbance, assisting with the reestablishment of ecosystem functions and services such as nutrient cycling, and providing a native habitat that supports native vegetation and wildlife communities. An additional benefit of restoration is fulfilling the National Park Service's mission of maintaining and reducing trammeled areas and restoring the visual consistency of the landscape. The Organic Act states that the purpose of the National Park Service is to "conserve the scenery and the natural and historic objects and the wildlife therein… by such means as will leave them unimpaired for the enjoyment of

future generations" ((39 Stat.535), 16 U.S.C. 1,3,9a,460 1-6a(e), 462(k); C.F.R. Title 36 Chpt I, (Pt 1-199)). As a result, disturbances and destruction of habitats within the national parks should be mitigated and restored as well as feasible to the visual consistency and functional roles of ecosystems close to its natural state.

Justification for Study

This research explores the potential of restoring BSC communities as a benefit for the overall rehabilitation of a disturbed landscape by utilizing salvaged BSCs as inocula in disturbed habitats in combination with resource augmentation and surface soil stabilization treatments to accelerate the ecosystem trajectory toward sustainability, and monitoring the progress of treatment applications to identify the impacts on BSC organisms through the processes of salvage, storage, and field inoculation. Disturbance to BSCs has been estimated to take decades to centuries to recover depending on the ecosystem, BSC community, and climate (Belnap and Eldridge 2001). Current studies on soil crust restoration show promising success (e.g. Maestre et al. 2006). However, restoration research on crusts containing later successional species, such as lichens and bryophytes, is limited and problematic due to slow growth and low reproduction rates.

Applied Restoration Research Goals

The intent of rehabilitation and restoration of disturbed ecosystems is to identify and mitigate the barriers to successful recovery, provide the resources necessary to assist with restoring the historical ecosystem trajectory or enable the disturbed ecosystem to set a new trajectory that will be ecologically beneficial for maintaining the structure and integrity of the ecosystem and reduce the disturbance to the surrounding native ecosystems (Society for Ecological Restoration International Science & Policy Working

Group 2004). A focus on community and ecosystem ecology within the ecological restoration of BSCs assists with identifying species interactions and interactions with the macroscopic and microscopic biotic and abiotic environmental factors, identifying the role of soil crust organisms in the soil ecosystem and succession, and establishing restoration goals.

The goals of this thesis encompass several objectives: 1) identify potential barriers to natural and assisted recovery through a review of current BSC and restoration research literature; 2) identify applicable restoration methods to apply to disturbed gypsiferous soil BSC communities in the Mojave Desert and test methods in field, greenhouse, and/or laboratory studies; 3) after study implementation identify the techniques that were successful and which were not and identify why; 4) propose further direction and research goals by building upon the results of the information provided within this study. Chapter 2 is a literature review of current BSC and restoration research. Chapter 3 contains methods and explains why particular methods were chosen. Chapter 4 presents results along with discussion. Chapter 5, the conclusion, provides a summary and covers the last objective as well as management objectives for future research.

CHAPTER 2

LITERATURE REVIEW

Introduction

In many arid and semi-arid habitats throughout the world vegetation is sparse or absent resulting in large areas void of macrovegetation. These seemingly open spaces are not depauperate but rather are filled with a diversity of organisms that form a surface biological soil crust (BSC). BSCs are a key part of a these arid systems providing essential ecosystem functions. They are quite resilient to extreme temperatures, droughts, and radiation, although extremely vulnerable to disturbances that upset their physical integrity (Belnap et al. 2001a).

Healthy, well-developed BSCs play several roles in desert ecosystems where 70 to 80 % of the living cover is composed of BSC communities (Belnap 1990). BSCs are an almost continuous photosynthetic (Garcia-Pichel and Belnap 1996; Lange et al. 1992; Metting 1981) and nitrogen-fixing surface layer in the plant interspaces (Belnap 1996; Evans and Ehleringer 1993; Fletcher and Martin 1948). BSCs influence soil surface characteristics, and these surface characteristics in conjunction with BSC processes influence the erosion potential, the hydrologic cycle, and nutrient cycling within the surface soil, and seed and vegetation ecology.

While the impact of disturbance depends on such factors as soil properties, vegetation, climate characteristics, and the type and severity of the disturbance (Belnap and Eldridge 2001), disturbance to these organic crusts are at least known to negatively influence ecosystem stability and a sustainable trajectory. Even minor disturbances can negatively impact BSC functions, creating an unstable ecosystem. In some cases

avoidance of disturbance is impossible, activities supersede or necessitate disturbance (e.g. road reconstruction), or the awareness of BSCs presence and ecosystem contributions is minimal or absent. As a result, negative consequences may impede native system processes and functioning.

Due to the increased interests in BSC communities over the last few decades, the growing knowledge about the contributions of BSCs to ecosystem health, functioning, and sustainability, and the potential use of native soil biota for practical ecosystem application, rehabilitation and restoration measures are recognized as activities contributing to ecosystem recovery and/or stabilization. However, rehabilitation and restoration research, while progressive, is yet limited. Feasible methods for assisting with rehabilitation of disturbed BSCs remain underdeveloped.

The present chapter explores current literature in BSC and restoration research and its applicability to disturbed BSC and vegetation communities in gypsiferous soils types in LMNRA and in the eastern Mojave Desert. These systems are highly resilient, but also highly vulnerable. Furthering our knowledge of these communities and testing the potential for restoration is important and has multiple opportunities for future application.

Biological Soil Crusts Overview

BSCs are composed of a diversity of organisms including lichens, a symbiotic relationship between a fungus (mycobiont) and a photosynthetic partner (photobiont), mosses, fungi, free-living cyanobacteria, a diversity of other bacteria, archaea, free-living green algae or other algae, and other eukaryotic and prokaryotic microfauna (Bates et al. 2010; Evens and Johansen 1999; Metting 1981; West 1990). This bio-rich zone varies in

thickness and is a part of a complex matrix associated with grains, voids and cracks, and sedimentary rock deposits formed during sedimentation by precipitation or recrystallization minerals (Williams et al. 2012). The composition and density of soil organisms depends on several biotic and abiotic factors including solar radiation, precipitation type and amount, temperature, climate, topography and microtopography, soil parent material, soil texture, and sources of inoculants (Rosentreter and Belnap 2001). While cool deserts tend to support greater biodiversity, including the presence of lichens and mosses in BSCs, arid and semiarid desert BSCs are usually dominated by cyanobacteria (Rosentreter and Belnap 2001). However, in some soil types in arid environments, such as gypsiferous soils, a greater diversity and density of lichens and mosses are supported (Anderson et al. 1982b; Kleiner and Harper 1972) compared to other Mojave Desert soil types (Johansen 1993).

Gypsiferous Soils and the Mojave Desert Climate

Gypsiferous soil properties and the Mojave Desert climate provide conditions which support higher BSC organism diversity and density compared to non-gypsic soils (Kleiner and Harper 1972; Anderson et al. 1982a). Gypsiferous soils with limited biotic content form a physical crust on the soil surface, reducing the surface soil texture, decreasing water infiltration, and reduce seed infiltration into surface soils and emergence (Belnap 2001a). The mineral gypsum ($CaSO_4 \cdot 2H_2O$) is hyperthermic, has a weak crystalline structure, and readily dissolves in water. Due to these properties, gypsum leaches downward into subsurface soils with water and is moved towards the surface by capillary rise if there is a high water-table. Pedogenic gypsum can accumulate in

subsurface horizons clogging the S-matrix where the growing gypsum crystals will interlock and indurate the soil horizon (Kulchitski 1956).

Gypsiferous soils are weakly aggregated and particles have no cation exchange capacity. Soils with gypsum content over 15% tend to be unstable, more permeable with poor structural stability and low water retention capacities. However, content exceeding 25% increases soil stability due to physical crust development (Boyadgiev 1974), and physical crust development restricts vegetation growth (Smith and Robertson 1962). Additionally, in higher gypsum content soils (25-35%) water is more readily retained, and gypsum above 35% increases its water retention. Gypsiferous soils can be paired with the presence of calcium carbonate ($CaCO_3$). Boyadgiev (1974) and Vieillefon (1976) observed that when calcium carbonate and gypsum are in soft powdery forms, they are negatively related: calcium carbonate content decreases and gypsum content increases. Calcium carbonate solubility decreases with gypsum present due to the common ion effect (Ca^{2+}). However, when gypsum or calcium carbonate is in other forms, this interaction is insignificant.

Gypsiferous soils tend to be low in organic content. They are also poor in phosphorus and nitrogen (Minashina 1956; Van Alphen and de los Rios Romreo 1971). Phosphorus transport is reduced in soils with higher gypsum content as available phosphorus is slowly converted to insoluble forms (Zhu and Alva 1994). Singh and Taneja (1977) found the rate of nitrogen mineralization in saline non-gypsiferous soils was stimulated by the addition of small amounts of gypsum, but with higher rates, nitrogen mineralization decreased. Gupta and Salaran (1971) found with the addition of gypsum to saline and sodic soils stimulated fungus populations.

The Mojave Desert regularly has summer time temperatures exceeding 37°C paired with extremely low relative humidity with irregular yearly monsoonal influence (Gorelow and Skrbac 2005). Mojave winters are usually mild with afternoon temperatures averaging 15°C, and most of the yearly precipitation occurs over the cooler months. High potential evapotranspiration (PET) rates in hot deserts usually create a soil environment that is dominated by cyanobacteria. As PET decreases, relative lichen and moss diversity and cover increase (Rosentreter and Belnap 2001).

The climate conditions in combination with gypsiferous soil properties create an environment conducive to support BSC lichens and mosses. With increasing amounts of carbonate, gypsum, and/or silts, the soils support a greater lichen cover (Belnap and Lange 2001) and a greater diversity of lichens which may be restricted to gypsiferous or calcium rich soils (St. Clair et al. 1993; Rosentreter and Belnap 2001). Along with supporting more diversity and density of macroscopic BSC organisms, gypsiferous BSC environments have greater soil stability than other Mojave Desert BSC communities. Dissolved minerals attach to cyanobacterial sheath material to produce strong microbial sheaths (Belnap 2006). Dissolved gypsum recrystallizes on the surface of polysaccharide sheath material of cyanobacteria obscuring the polysaccharide material (Belnap and Gardner 1993).

Gypsiferous soils tend to have a low vascular plant cover, which provides large interspaces for a continuous BSC cover. Microtopography can influence the location and density of these lichen and moss patches on the soil surface (Williams et al. 2012). These systems have a low soil surface roughness and crust absorptivity with a moderately high surface porosity (Belnap 2006).

Biological Soil Crust Ecosystem Properties, Functions, and Contributions

Over the past few decades, science and research have progressed with identifying the roles of BSCs in ecosystem processes (Belnap and Lange 2001). BSCs are recognized as indicators of landscape health (Bowker et al. 2008; Eldridge and Rosentreter 1998), especially BSCs containing lichen species which are not greatly influenced by short-term climatic changes, making them ideal indicators for long-term environmental factors (Belnap et al. 2001c).

Soil Stability and Reducing Soil Erosion

Since the early 20th century soil microorganisms, lichens, and mosses have been recognized as important agents in stabilizing surface soil crusts in areas denuded of macrovegetation (e.i. perennial or annual forbs, shrubs, and/or graminoids) by drought or erosion or void of macrovegetation (Kleiner and Harper 1972). It is well established that BSCs reduce erosion by wind (e.g. Belnap and Gillette 1997, 1998; Eldridge and Greene 1994; Leys and Eldridge 1998; McKenna-Neuman et al. 1996) and water (e.g. Barger et al. 2006; Booth 1941; Eldridge and Greene 1994; Fletcher and Martin 1948) depending on the developmental stage, species presence and surface cover, and disturbance.

Biotic crusts increase soil aggregate stability reducing erosion potential (Belnap and Gardner 1993; Bond and Harris 1964; Mazor et al. 1996; Schulten 1985). Several studies have observed the microscopic structure of cyanobacteria interlacing with soil particles (Belnap 1995; Belnap and Gardner 1993; Maqubela et al. 2009). Figure 1 is an image of filamentous cyanobacteria intertwining with soil particles in a surface soil sample obtained from gypsiferous BSCs in LMNRA. The exopolysaccharide sheaths that surround cyanobacteria bind and aggregate soil particles (Belnap 2006; Belnap and

Gardner 1993; Campbell 1979; Campbell et al. 1989). Belnap and Gardner (1993) and Friedmann and Galum (1974) observed that cyanobacteria tend to be the main stabilizing organisms on hot desert soils due to high PET (Rosentreter and Belnap 2001), where as in cooler deserts lichens and bryophytes tend to colonize in stabilized habitats, increasing stability. Lichen margins of squamule-shape lichens and anchoring structures (e.g. rhizinae, rhizoidal tuffs) (Belnap 2006) that penetrate down into the soil (Belnap 2003; Büdel and Scheidegger 1996) contribute to the surface texture and bio-sedimentary characteristics (Figure 2; Williams et al. 2012). For example, Chaudhary et al. (2009) found that the cyanolichen *Collema* contribute to surface soil erosion resistance in the semi-arid shrub lands of southern Utah because the lichen thalli cover the surface soil. Moss protonemata, which intersperse through soil surface matrix and crust, and rhizoids, which attach to the soil surface (Belnap 2006), provide greater stability and resistance to erosion (Belnap et al. 2001a).

Hydrological Cycle: Water Infiltration, Runoff and Retention

It is well documented that BSC morphology can influence the hydrologic cycle (e.g. Belnap 2006; Belnap and Gardner 1993; Eldridge and Rosentreter 1999; Verrecchia et al. 1995; Warren 2003a, 2003b; Williams et al. 1999). This is due to the poikilohydric nature of BSCs, which allows the organisms to absorb water and reduce evaporation from the soil (Kershaw and Rouse 1971), and is due to BSC influence on soil surface characteristics such as soil texture, aggregation, cohesiveness, absorptivity, roughness, cracking, micro- and macropore formation, water permeability, infiltration, and retention (Loope and Gifford 1972; Warren 2003a, 2003b). Influence on the hydrologic cycle

additionally depends upon the interactions of BSC community and soil properties (Belnap 2006).

BSC organisms are poikilohydric and highly desiccation tolerant; their water content closely reflects the fluctuations of humidity and precipitation in their environments, and they have the ability to dry out to low water contents and resume normal functioning when rehydrated. Poikilohydry is roughly a physical process of an organism reacting to the water content of its environment (Rundel 1988). This allows structures to survive in dry climates by limiting metabolic activity to hydration events.

Soil organisms influence surface soil characteristics and properties and influence water infiltration, retention, permeability (Belnap 2006; Loope and Gifford 1972), and soil evaporation rates (Xiao et al. 2010). Belnap and Gardener (1993) report that cyanobacteria provide additional structure to soils that enhanced hydraulic conductivity. Infiltration and retention depends on BSC species and morphology, and soil properties such as texture. Water infiltration and surface soil stability are related to cyanobacterial biomass and cover and the cover of more surface stabilizing species such as mosses and lichens. Some studies observed that high cover of BSCs increases infiltration rates and protects the underlying surface soil-absorbed water, reducing evaporation and water runoff (Eldridge and Greene 1994; Barger et al. 2006), but also reduces intrinsic permeability (Loope and Gifford 1972) and decreasing soil porosity (Belnap 2006). Williams et al. (1999) found that microbiotic crusts did not significantly influence soil hydrology at alluvial sites.

Crust organisms develop a textured soil surface, rolling to rugose to pinnacled, which influences the pattern of flow of water over the soil surface and can redirect water

runoff down slope. George et al. (2003) observed that any biotic cover improved water retention compared to bare soils, which may be due to several factors including the water holding capacities of BSC organisms and their surface structures covering soils. Cyanobacteria can absorb up to 10 times their volume in water (Campbell 1979; Verrecchia et al. 1995). Mosses and lichens have high water-holding capacities (Lange et al. 1998), absorb more water than cyanobacteria, and expand over the soil surface covering pores and reducing water penetration in those areas (Galun et al. 1982). Green algal lichens can absorb up to 250-400% water content and cyanolichens can be 600 to 2000% (Nash 1996). Gelatinous lichens absorb more water than crustose and squamulose lichens (Blum 1974).

Non-biotic or physical crusts, which form on gypsiferous soils, restrict water infiltration (Warren 2001a). Cyanobacteria create micropore channels increasing water infiltration (Greene 1992). However, in cyanobacteria-dominated crusts such as crusts that occur on sandy soils, Verrecchia et al. (1995) observed water infiltration was less than disturbed locations that had reduced cyanobacteria biomass suggesting that these crusts reduce infiltration. Yair (1990) observed that cyanobacteria produced smooth crusts, which reduced retention times.

Cyanobacteria trichomes absorb water and swell. It has been suspected that they will clog pores reducing soil porosity and limit infiltration after swelling (Campbell 1979; Verrecchia et al. 1995). The exopolysaccharide sheaths surrounding the trichomes retain water longer either by absorption of moisture into the sheath or obstructing diffusion (Friedmass and Galum 1974). However, Belnap and Gardner (1993) observed

cyanobacteria in sand-dominated soils with scanning electron microscope images and found that swelling of cyanobacteria was not sufficient to restrict water flow.

Nitrogen and Carbon Fixation, Nutrient Cycling, and Dust Traps

BSCs contribute to an almost continuous, textured photosynthetic and nitrogen-fixing surface layer between vegetative plants in hot deserts. BSC organisms are primary contributors to the carbon cycle via photosynthesis and to the nitrogen cycle through nitrogen fixation by cyanobacteria and cyanolichens (Belnap 2002a, 2002b; Harper and Belnap 2001). As a result BSCs play an important role in nutrient cycling (Belnap 2001b; Evens and Lange 2001). Cyanobacteria contribute to primary production and addition of organic carbon and organic nitrogen. All photosynthetic BSC organisms, including lichens and mosses, contribute to carbon fixation. Cyanolichens, lichens with a cyanobacteria photobiont, also contribute to nitrogen fixation in soils (Ahmadjian 1993; Dodds 1989). Bowker et al. (2010) noted that cyanolichens in the genus *Collema* are believed to make larger contributions to the whole ecosystem nitrogen fixation than free-living cyanobacteria, heterotrophs, and plant-bacteria associations.

BSCs also contribute bioessential nutrients to the surface soils (Garcia-Pichel and Belnap 1996). Some cyanobacteria species, such as *Microcoleus vaginatus*, and the clay particles that bind to them (Belnap and Gardner 1993) are negatively charged and may bind positively charged macronutrients (Belnap and Gardner 1993) concentrating essential biological nutrients (Harper and Pendleton 1993). Soils with BSCs may have greater concentrations of organic matter, soil nitrogen, exchangeable manganese and calcium, potassium, magnesium, and available phosphorus (Harper and Pendleton 1993).

Textured soil surfaces produced by BSC organisms trap aeolian dust. Sticky cyanobacterial exopolysaccharide sheath material, textured mosses, and lichen thalli trap airborne silts and clays (Belnap 2006), accumulating and retaining nutrient-rich dust, which contributes plant-essential nutrients to the upper most soil layers (Belnap et al. 2003b; Reynolds et al. 2001), and influences the vegetative community (Rogers and Burns 1994; West 1990). Filamentous cyanobacteria capture small amounts of dust (Belnap and Gardner 1993; Campbell 1979), while mosses and lichens capture greater amounts of dust, accumulating fine grain material (Johansen 1993; Williams et al. 2012). Overall, BSCs have been found to have greater concentrations of carbon and nitrogen enrichment as well as greater amounts of calcium, chromium, manganese, copper, and zinc (Beraldi-Campesi et al. 2009).

BSC Influences on Seed and Vegetation Ecology

Due to properties already discussed that influence the physical and chemical soil environment, BSCs additionally influence the composition and structure of the perennial and annual vascular plant community. It is difficult to assign a correlation between BSCs and all vascular plant communities. Johansen (1993), Eldridge (1993), Hawkes and Menges (2003), Prasse and Bornkamm (2000), and West (1990) found a negative relationship between vascular plant cover and BSCs, which may either indicate BSCs limit vascular plant cover or possibly that BSCs occupy open spaces which otherwise would be uninhabited (Belnap et al. 2001b). Anderson et al. (1982b) reported no correlation between BSC cover and plant cover. Carleton (1990), Graetz and Tongway (1986), and Lesica and Shalley (1992) reported positive correlations. Escudero et al.

(2007) found that BSC influence depended on the BSC species that were present and was vascular plant species-specific.

Soil texture and roughness, the physical and chemical crusts, and climate characteristics, as well as BSC species composition and density likely all influence the vascular plant community (Belnap et al. 2001b). BSCs may have an inhibitory affect on non-native plants due to surface structuring (Belnap et al. 2001a), although the literature is not conclusive. For example Rogers and Burns (1994) and West (1990) observed traps formed by BSCs increase retention of seeds, organic matter and sediments. BSCs provide safe sites for seedlings; however they may also create physical barriers to seedling emergence (Romão and Escudero 2005) and competition for early stage seedling development (Belnap et al. 2001b). Serpe et al. (2008) observed that the presence of the lichen *Diploschistes muscorum*, which was dominant on the soil surface, significantly reduced the germination of grass and root penetration compared to bare soils and soil crusts with a diversity of surface organisms. Serpe et al. (2006) observed that the short moss *Bryum argenteum* had inhibitory effects on grass seed germination, but the tall most *Tortula ruralis* only delayed grass germination. Plant-BSC interactions may also be species specific (Escudero et al. 2007). Harper and Pendleton (1993) found that BSCs had a significant influence on tissue content of several bioessential elements in certain native plants. DeFalco et al. (2001) observed that winter annuals and plant densities were greater on crusts compared to soils lacking crust cover, which was attributed to enhanced soil conditions in crusted soils. Additionally, Hernandez and Sandquist (2011) and DeCort (2011) observed significantly fewer exotic plant species establish on undisturbed BSCs than disturbed or open surfaces, respectively.

Impacts of Disturbances to Biological Soil Crusts

Ecosystem disruption by anthropogenic activities has important implications including the loss of diversity, biomass and cover of soil biota, the negative influence on vegetation communities by impacts to seed and vegetation ecology, and the decrease of ecosystem functioning, integrity, and resilience (Anderson et al 1982b; Belnap and Eldridge 2001; Belnap et al. 1994; Eldridge 1998).One of the main concerns with disturbance to BSCs is the increased potential of soil erosion (Eldridge et al. 2002). Current evidence suggests that disturbance has profound effects on the BSC cover, species composition and the physiological functioning of soil crust organisms, and adversely affects the ecosystem processes which BSCs provide. Mechanical disturbances (e.g. vehicles or construction equipment) and trampling (e.g. foot traffic or grazing) can cause compression of surface soils or overturn surface crust organisms, which bury potential surviving organisms or completely remove any material that may assist providing inoculants for natural recovery (Campbell 1979; Johansen 1993; Webb 2002).

Disturbance can decrease soil porosity and water infiltration (Eckert et al. 1979) and decrease soil stabilization by disturbance to or removal of vegetation, rock, or BSC cover (Vollmer et al. 1976). Disturbances that remove the biotic surface layer expose soils that can create physical crusts or expose soils that have little structural stability. In non-biotic crusts, raindrops impact the soil surface by breaking apart aggregates and washing smaller particles into spaces between larger soil particles. This reduces infiltration rates by clogging soil pores. As the soil dries, a physical crust forms from surface tension pulling soil components together (Tackett and Pearson 1965), which increases water runoff and soil erosion. Disturbances can also prevent the vertical

movement of cyanobacteria through the surface soil and prevent later successional species from reestablishing.

Lichens and mosses fix more carbon and cyanolichens fix more nitrogen per unit soil surface than cyanobacteria (Barger et al. 2005; Phillips and Belnap 1998). The lichens *Collema coccophorum* and *C. tenax* are two commonly occurring cyanolichen crust species that contribute to erosion resistance in the semi-arid shrubland of southern Utah and other dryland ecosystems of the southwest United States (Evens and Ehlringer 1993). On undisturbed late-successional dark cyanolichen crusts, Barger et al. (2006) observed that dissolved organic carbon, dissolved organic nitrogen, and ammonium were significantly greater compared to trampled plots. With reduced BSC cover, erosion potential increases and can lead to decreased carbon inputs (Barger et al. 2006) and nitrogen inputs (Barger et al. 2005; Barger et al. 2006; Evens and Belnap 1999; Evens and Ehleringer 1993).

Belnap and Gillette (1997, 1998) demonstrated that the wind threshold friction velocities varied between disturbed and undisturbed crusts at varying levels of development and species compositions. Recently disturbed soils or less well-developed crusts (defined as crusts only containing cyanobacteria) experienced wind speeds that exceeded stability thresholds, promoting crust biomass removal and contributing to increased erosion and reduced fertility (Belnap and Gillette 1998). Benqiang et al. (2011) observed that sand burial of cyanobacterial crusts imposed severe distress on organisms including reduced photosynthetic ability and protective pigment concentrations, damaged photosystem II activity, and decreased carbohydrate reserve.

Kleiner and Harper (1972) found BSC cover and richness were greater in ungrazed sites versus grazed sites. DeCort (2011) and Hernandez and Sandquist (2011) observed higher cover of non-natives in disturbed BSCs. Anderson et al. (1982a,1982b) determined the relationship of some physical and chemical soil factors to crust development and to grazed versus not grazed desert sites. The authors observed that the soil parameters that favor development of crusts varied with different degrees of BSC development, such as silts being significantly more common in better developed crusts, and that developed BSCs had a high correlation between the combination of electrical conductivity values, soil phosphorus levels, and pH. The authors did not find a correlation between abiotic environmental factors in grazed and not grazed areas, but did find that lichens and mosses were reduced in cover in grazed sites. Williams et al. (1999) observed that soil pH and electrical conductivity values differed statistically between undisturbed BSC plots and scalped treatments with no hydrologic or biological significance.

Natural Recovery

Natural recovery after environmental or human disturbance is difficult to estimate or assess. Methods of assessing impacts and estimating recovery have been variable in the past; some studies assessed cover, while others have focused on biomass or physiological functioning (Belnap and Eldridge 2001). The methods for monitoring are not consistent with either a focus on morphological or functional groups of macroscopic species, which can be difficult to positively identify in the field (Eldridge and Rosentreter 1999). It is agreed that the greater the disturbance, the slower the recovery. Disturbances that remove the surface BSCs completely or result in a high mortality of crustal

organisms will require longer periods of time to regenerate and/or recover (Belnap 1993; Belnap and Rosentreter 2001; Johansen 1993).

Generally, the well recognized succession of BSCs is cyanobacteria (Zhang 2005), which provide initial stabilization, then lichens and mosses. Cyanobacteria are likely to colonize first due to their greater mobility, being able to disperse by wind (Schlichting 1969) and their ability to glide vertically through the top few millimeters of the soil surface (Garcia-Pichel and Pringault 2001). Cyanobacteria-dominated crusts colonize initially (Belnap 1993), and with soil stabilization, lichens and mosses may colonize if soil and climate conditions permit (Belnap 2006). Cyanobacteria provide much of the soil crust biomass and stability through production of exopolysaccharide sheaths winding throughout the soil surface binding soil particles together (Belnap 2002a; Belnap and Gardner 1993; Garcia-Pichel and Belnap 1996).

Past literature has under- and over-estimated recovery of metrics such as BSC cover (Belnap and Eldridge 2001). Belnap (1993) found that after 2 and 5 years after scalped treatments were applied in gypsiferous and sandy soils, respectively, cyanobacteria were observed to be recovering well; however, lichens and mosses were not. Anderson et al. (1982b) also observed that lichen, moss, and algal cover was greatly reduced by domestic grazing and after exclusion increased cover from 4% to 15% during the first 14-18 years and an additional 1% over the following 20 years. Belnap and Warren (2002) observed the famous Patton's tracks from military tank maneuver exercises in the Mojave Desert during World War II and found that the cyanobacterial component had recovered after 55 years from 46-65% in tracks compared to contents found in adjacent undisturbed areas and that lichen cover recovery was much slower and

impacts on lichens were species specific, with *Collema tenax* only a recovery of 6% and *Placidium squamulosum* only a recovery of 3%.

Fire may not currently be a concern in gypsiferous soils in the Mojave; however, with climate change and/or introduction of non-native invasive plant species, the potential may still present itself. Fire is an issue in other Mojave Desert habitats (Brooks 1999). Two non-native grasses associated with potential fire, *Bromus rubens* and *Schismus* are both located within soil intrusions (e.g. washes and washlets) and disturbed soils in LMNRA. Natural fires produce a mosaic of burned and unburned areas of BSCs (Johansen et al. 1993), which provide reserve sources of native propagules (Johansen et al. 1984). Johansen et al. (1993) found that crust organisms only started to recover during optimal seasonal conditions in the winter months. There was not an apparent difference in species richness between burned and unburned plots, indicating that the burned areas were easily inoculated from adjacent unburned portions, or that the fire was not as damaging to the BSC community. Johansen et al. (1984) found that two years after fire, algae had considerably recovered, and five years after fire lichens and mosses only began to enter formerly burned areas. These studies present evidence on the succession of BSCs after fire disturbance; the earliest colonizers were also the most mobile through wind or water dispersal, followed by easily established mosses (Eldridge and Bradstock 1994; Johansen et al. 1984) then lichens with vegetative diaspores (Johansen et al. 1984). In some cases, BSC communities are unable to recover. For example Callison et al. (1985) observed no BSC recovery 37 years after fire in a blackbrush (*Coleogyne ramosissima* Torr.) community.

Factors Influencing Recovery and Potential Barriers

Yearly and seasonal climatic conditions, climate change, temperatures, precipitation, UV exposure, soil composition, soil nutrient content, soil compaction, wind and wind-blown dust, naturally occurring inoculants in close proximity to disturbance, moisture absorption, surface evaporation, and water retention, types of continuous non-human disturbance (i.e. feral burros, ants, termites, micro-invertebrate populations, etc.) or human disturbance all have the potential to influence BSC community recovery.

Soil crust organisms are only biologically active when wet (Kershaw and Rouse 1971) and require specific lengths of time of hydration for positive carbon balance to occur. During limited seasonal precipitation, soil crust organisms have reduced times when they are biologically active, when they can repair damage accrued during desiccation events, and reduced opportunity for active growth periods. The time of hydration during the year influences the ability for BSCs to remain wet. Increased seasonal summer rains, as predicted in climate change models for the Mojave Desert, may actually negatively impact BSC organisms by increasing wetting and drying cycles (Belnap et al. 1994; Belnap et al. 2007). Overall cover estimates for lichens and mosses are expected to decrease with changes in precipitation regimes (Belnap et al. 2007). For lichens, hydration periods during higher temperatures can have a negative impact on nitrogen fixation rates (MacFarlane and Kershaw 1977).

Desiccation tolerance of bryophytes has been long studied and laboratory and herbaria specimens are known to remain viable for years (Alpert 2000), which is highly relevant to the ecological and climate conditions of the Mojave Desert. As with lichens, mosses require a positive carbon balance to survive; therefore, frequent wetting and

drying cycles slow the growth and short and frequent wetting and drying events can lead to a net carbon loss (Alpert and Oechel 1985). Stark et al. (2011) observed lower above-ground biomass in the common Mojave Desert moss *Syntrichia caninervis* that received increased water treatments to mimic increased summer rains predicted with climate change models. Different life cycle phases responded differently to drying times. Heavy summer rainstorms in the Mojave Desert resulted in widespread abortion of sporophytes in the desert moss *Grimmia orbicularis* (Stark 2001). Stark (2001) postulated that stresses from desiccation/hydration cycles due to heat in conjunction with early seta elongation impacted the ability for cellular repair or nutrient deficiency for the sporophyte. Stark et al. (2007) found that in the moss *Tortula inermis* sporophytes at the early seta-elongation phase had a greater sensitivity to a rapid drying events compared to mature gametophytes.

Propagation and reproduction are additionally limited to hydration events. Cyanobacteria reproduce by cell division and subsequent separation of cells. Colonial and filamentous cyanobacteria reproduce by fragmentation in which a portion of the trichome breaks off forming hormogonia, which are motile and can glide through a soil medium when wet. Green algae reproduce asexually and sexually and require moisture for mobility and establishment. Fragmented lichen thalli will not normally reproduce a thallus. Lichen morphogenesis and reproduction require that each symbiont to independently reproduce and recombine for reproduction (Ahmadjiam et al. 1980; Büdel and Scheidegger 1996), which requires a hydration even. Lichens with vegetative diaspores, such as *Collema tenax*, are more easily able to colonize in disturbed areas (Johansen et al. 1984). Mosses also require hydration events to be biologically active and

produce spores or for gamete dispersal and combination. In 2002, Stark (2005) recorded a 191 day rainless period. Over a four year period in the Mojave Desert, only 8% of the time did the moss *Crossidium crassinerve* experience complete hydration and very few sporophytes survived (Stark 2005), demonstrating the desiccation tolerance and resilience of these organisms, but also the slow growth and reproduction rates.

Exposure to both UV and radiation degrades internal cellular structures including photosynthesis machinery and protective pigments (Castenholz and Garcia-Pichel 2000). Radiation causes DNA and RNA damage, lipid peroxidation, and specific enzyme inhibition (Rubisco) and photoinhibition of photosynthesis (Iwanzik et al. 1983; Karentz et al. 1991). Castenholz and Garcia-Pichel (2000) identified three general strategies that mitigate damage: avoidance, repair of cellular damage, and/or production of radiation-protective pigments. Disturbance or damage hinders the ability for crust organisms to respond to desiccation and rehydration events.

Some filamentous cyanobacteria glide away from the soil surface as it begins to desiccate or by tracking soil moisture (Belnap et al. 1994; Garcia-Pichel and Pringault 2001). Other species, such as *Nostoc* and *Scytonema,* have the capacity for screening photosynthetically active radiation (PAR) and UVB due to the synthesis of biochemicals which act as a screen to radiation (Wynn-Williams 2000) and are active even in rest states (Castenholz and Garcia-Pichel 2000). Studies on cyanobacteria taxa from varying habitats show that protective pigment production increases with radiation exposure (Neinow et al. 1988).

In lichens, the photobiont avoids direct exposure by the protection of photobiont cells from radiation by the mycobiont (Demmig-Adams et al. 1990). Lichens, such as

Collema rely on repair and protective pigments to assist with radiation stress. These species manufacture copious amount of UV-protective pigments in the fungal tissue (Dodds 1989; Büdel et al. 1997) and polysaccharides for protection from radiation exposure. Büdel et al. (1997) demonstrated that the occurrence of UV-absorbing substances like scytonemin and mycosporine-glycine are present in cyanobacterial lichens of the genera *Collema, Gonohymenia,* and *Peltula* all coming from high-light-intensity habitats.

Mosses reduce surface exposure by coiling the above ground structure and have biological controls to assist with transition into a desiccated state and to initiate repair mechanisms upon rehydration (Oliver et al. 2005). For the onset of surviving desiccation tolerance, it is hypothesized that desiccation tolerant bryophytes have mechanisms that constitutively initiate cellular protection and this is coupled with a rehydration-induced repair and recovery system (Alpert and Oliver 2002; Oliver et al. 2000, 2005; Wood 2007).

Altered soil characteristics may also limit or reduce the potential for recovery of BSC organisms. Cyanobacteria require macronutrient elements carbon, nitrogen, phosphorus, potassium, sulfur, and magnesium, as well as micronutrient elements. Calcium is also required as well as sodium regardless of the potassium status (Allen 1965). Compacted soil also impedes natural recovery. Mulholland and Fullen (1991) observed that loamy sand soil compacted by cattle trampling had an increase in bulk density and produced dense zones impeding drainage, but did not reduce the presence of macropores. Chamizo et al. (2012) observed hydrology alterations due to impacts on BSCs, which, along with other factors, influence recovery rates of disturbed organisms.

In the presence of disturbance, crusts may be retained at a low successional state (e.g. Harper and Marble 1988; Pietrasiak et al. 2011).

Assisted Recovery: Rehabilitation/Restoration

Assisted recovery of BSCs with active restoration activities may decrease recovery times of damaged BSC organisms, BSC functions, and their inherent successional trajectories. Active restoration activities may also mitigate the long-term impacts of disturbance on ecosystems by potentially halting or reversing damage and reestablishing a sustainable ecosystem trajectory, either returning to a historical trajectory or establishing an alternative sustainable trajectory. For example, in salvaged BSCs certain organisms may be more resilient to this process and more resilient in response to inoculation.

Active restoration activities incorporate several strategies including artificially enhancing soil stability, resource augmentation, and/or inoculation with native soil biota (Bowker 2007). Artificial stabilization can include such techniques as addition of coarse litter, planting vascular plants or erection of vertical mulch, or placement of engineering structures. Course litter combined with soils increases soil texture (Benkobi et al. 1993). Plant roots penetrate into soils forming macropores favorable to fluid transport and crease zones that fragment the soil and form aggregates (Angers and Caron 1998). Plant canopy also reduces impact of rain drops (Casermeiro et al. 2004; Parsons et al. 1992). Engineering structures on a macroscopic can reduce overall soil erosion and also collect dust. Although these methods have been successful in some instances (e.g. Li et al. 2004), they can be labor intensive and/or introduce non-native, invasive species that can result in additional negative consequences (Bowker 2007).

Resource augmentation requires evidence of cause and effect relationships and may include the addition of moisture, nutrients or substances that assist with BSC growth, recovery, and sustainability. Any supplemental watering may require restrictions on seasonal application or amount or method of application due to the potential to cause stress due to watering during the incorrect time of year (Belnap et al. 2004) or causing erosion (Davidson et al. 2002). Nutrients may include the addition of macro or micronutrients. Davidson et al. (2002) tested the addition of phosphorus and potassium in a full-factorial field experiment which resulted in no effect on nitrogenase activity or lichens, but had variable effects on chlorophyll fluorescence of lichen transplants indicating variability of influencing the photosynthetic efficiency of treatments. Bowker et al. (2005) found evidence that suggested limitation of the micronutrients manganese may limit growth of slow-growing BSCs; however, Bowker et al. (2008) observed that manganese addition had little effect on the photosynthetic rates, pigment concentrations such as chlorophyll *a* and carotenoids, and concluded that correlations between manganese and BSC organisms remain uncertain. Qiu and Gao (1999) observed a positive response in the cyanobacteria *Nostoc flagelliforme* photosynthetic recovery after desiccation after the application of potassium, but no significant response of the photosynthetic recovery with the addition of manganese.

The addition of metabolically related substances may also have a positive effect on recovery and growth of disturbed BSCs. Glucose is one of the main products of photosynthesis, is converted to many different derivatives for multiple cellular and organism functioning, and initiates cellular respiration. It has been suggested that it allows for chemoheterotrophic growth in the dark in some species of cyanobacteria

(Rippka1972). Mannitol is a sugar alcohol (polyol) and is a primary carbohydrate storage molecule for fungi and contributes to osmoregulation, antioxidant scavenging of free radicals, and desiccation and thermal tolerance of several different organisms across phyla. For damaged BSC organisms, the addition of simple carbohydrates that are related to the naturally occurring photosynthetic and metabolic pathways may assist with relieving rehydration stress and stress resulting from initiation of respiration and photosynthesis. For lichens, these substances are secreted through fungal cell walls into spaces between cells for other lichen components (Hill and Smith 1972; Honegger 1991). High concentrations of polyols and polyamines possibly protect the conformational integrity of proteins during desiccation (Nash 1996).

Glucose is the primary product of photosynthesis and the primary source of energy in photosynthetic organisms. It is used to initiate respiration in algae, photosynthetic bacteria, lichens and other photosynthetic organisms. It is important in metabolic activity as a regulator and is used for conversion into derivatives and secondary metabolites for cellular functioning including during stress events. It is used to produce polysaccharides in lichens that are important for metabolic activity. Long periods of hydration can cause loss of glucose (Kershaw 1985) and reduction of nitrogen fixation. Exogenous addition of labeled ^{14}C-glucose was used to monitor the reaction of carbon addition to lichens, which resulted in about 20% of the carbon sources from glucose to be released as carbon dioxide, 20% converted to "insoluble" glucose polysaccharide, and the remaining 60 % as soluble extracts, mostly mannitol, some glycoside and other unidentifiable substances (Smith 1961). Campbell (2010) found that an epiphytic cyanolichen was able to uptake ^{13}C-labeled glucose, initiating a strong physiological

response and a rapid incorporation of the exogenous-labeled glucose into the fatty-acid tissue. Field evidence suggests that the accumulation of exogenous carbon even without an active cyanobacterial partner encourages higher occurrences of cyanolichens in drier environments (Campbell 2010).

Aubert et al. (2007) identified metabolic processes that may contribute to reactivation of lichen physiological processes during hydration and dehydration cycles by analyzing the metabolite profile of lichen thalli. Recovery of respiration upon rehydration is prepared for during the dehydration phase by accumulation of gluconate-6-phosphate, nucleotides, and polyols pools. Due to the oxidative pentose phosphate pathway, gluconate 6-phosphate accumulates to produce reducing power (NADPH). For some free-living unicellular cyanobacteria, Rippka (1972) found that addition of glucose with inhibition of the photosynthetic apparatus allowed for minimal growth.

Glucose has been found to increase filamentous cyanobacteria in laboratory cultures, has been implemented in regulatory feedback from mRMA encoding corresponding to phycobiliproteins, and found to participate in phycobilisome pigment production (Lebedeva et al. 2005). Additionally, preliminary evidence suggests that glucose-6-phosphate may function as a phosphate donor for controlling complementary chromatic adaptation (Lebedeva et al. 2005), which is the acclimation of a photosynthetic organism to changes in light color (Kehoe and Gutu 2006).

Mannitol is one of the most abundant polyols in nature (Stoop et al. 1996). It is one of the most widely occurring polyols in fungi (Jennings 1984; Loescher and Everard 2004), some groups of bacteria (Wisselink et al. 2002), algae (Ben-Amotz and Avron 1983; Iwamoto and Shiraiwa 2005; Kremer and Kirst 1982), lichens (Smith 1961), and

vascular plants (Loescher and Everard 2002; Williamson et al. 2002). Mannitol is a six-carbon sugar alcohol and a major primary photosynthetic product. It is a control mechanism for cell turgor and osmoregulation (Farrar 1976; Schmitz and Srivastava 1975; Smith 1961) and for maintaining cellular hypertonic conditions (Karsten et al 1997; Yancey et al. 1982). It is used as a solute and for carbohydrate storage (Kremer and Willenbring 1972), particularly for fungi (Dickinson 2003; Coxson et al. 1992; Loescher and Everard 2004), for regeneration of reducing power (Voegele et al. 2005), and for scavenging of damaging active oxygen species produced during light exposure under stressful conditions (Jennings 2000; Jennings et al. 1998; Shen et al. 1997; Smirnoff and Cumbes 1989). Additionally, mannitol has been proposed to assist with drought stress and thermal tolerance for certain species of alga and some bryophytes (Smirnoff and Stewart 1985).

Mannitol is one of the primary substances in lichens that contribute to hyphal extension in the mycobiont (Galun et al. 1976), which is similar to free-living fungi, and may be required for radial growth of lobes and propagation. Evidence from Armstrong and Smith (1996) suggests that additions of exogenous polyol, including mannitol, contribute to radial growth of hypothallus; however, Armstrong and Smith (1998) found that addition of mannitol did not contribute to radial growth unless mixed with arabitol. Lindberg et al. (1953) and Trail (2002) found similar evidence in fungi development of fruiting bodies that further growth appear to be linked to the increased capacity to synthesize and accumulate mannitol to increase osmotic pressure.

Mannitol has also been found to have an enhancing effect on nitrogen-fixation activity in *Anabaena* 7120, a cyanobacteria, under salt stress in light conditions or during

active photosynthesis (Yin et al. 1996). The application of mannitol at different concentrations is experimentally determined due to the potential to reduce photosynthetic activity in some cyanobacteria at higher mannitol concentrations (Grodzinski and Colman 1973). Most studies indicate that mannitol does not play a dominant role or does not play a role in the metabolic processes of cyanobacteria; however, studies do indicate a role in cyanolichens as a source for soluble carbon.

There is a lack of understanding in the utilization of mannitol by green algae in terrestrial environments. Several groups of algae synthesize mannitol and use mannitol derivatives in metabolic processes, including green and brown algae (Davison and Reed 1985; Iwamoto and Shiraiwa 2005; Karsten et al. 1997; Yancey et al. 1982). A review by Wisselink et al. (2002) compiled evidence that certain species of bacteria have biosynthetic pathways for the production of mannitol that is used to produce energy. Wallach et al. (1974) found that with concentrations of 0.5 M mannitol proton uptake in chloroplasts occurred and a significant increase in phosphorylation rate due to the increase in osmotic pressure in chloroplasts isolated from green algal cells and that chloroplast integrity was preserved under increased pressuration. Amutha and Murugesan (2011) successfully used mannitol to increase cultivation of the fresh water green algae *Chorella vulgaris* in a lab setting.

Natural polyol production has implications for maintaining a high photosynthetic capacity (Krömer 1995), and large pools of polyols in some BSC species may contribute to protecting cell constituents and preserving cell integrity (Aubert et al.2007). Polyols contribute to higher photosynthetic rates and lower CO_2 compensation points (Fox et al. 1986) and can contribute to the functioning of such pathways as the high pentose

phosphate pathway that supplies NADPH for polyol synthesis and pathways that utilize glucose to convert this simple sugar into derivatives that accumulate during dehydration (Aubert et al. 2007). Mannitol has also been found in different photosynthetic organisms to increase oxygen uptake (Franková and Kolek 1965).

Specifically for lichens, Smith (1961) demonstrated a majority of the carbon fixed during photosynthesis in lichens initially appears as mannitol, with 40 to 50% of exogenous glucose converted to mannitol (Smith 1963). Farrar (1976) and Smith (1963) suggest that mannitol is important for maintaining high osmotic pressures in the mycelium of the fungal symbiont during water stress events. Drew and Smith (1966) were the first to suggest for lichens the location and movement of carbohydrates from the photosynthetic partner (photobiont) to the fungal partner (mycobiont) and that the mycobiont converts the photosynthetic product glucose into mannitol, which was corroborated by Honegger (1991). Lichens lack the specific cells or tissues for direct translocation of metabolites, water, and nutrients between symbionts. The translocation of molecules depends on the species and the chemical composition of the symbiont cell walls (Honegger 1991). This mechanism for translocation is similar to parasitic flowering plants that utilize mannitol as a respiration substrate in darkness (Delavault et al. 2002; Simier et al. 1998).

Inoculation is another method for assisting the BSC recovery and has shown to greatly hasten the recovery of disturbed BSCs (Belnap 1993; St. Clair et al. 1986; Weibo et al. 2009). Maestre et al. (2006) found the greatest BSC recovery occurred in slurry and composted sewage sludge application that was watered five times per week. Recovery was measured by cyanobacteria composition, nitrogen fixation, chlorophyll content, and

net CO_2 exchange rate as metrics. The net CO_2 exchange rate was higher with the slurry, and inoculation with BSCs significantly improved the nitrogen fixation and carbon sequestration capability of the soil (Maestre et al. 2006). Weibo et al. (2009) observed that 3 years after inoculation of sites with isolated and artificially cultivated cyanobacterial strains, the cover of cyanobacteria and algae reached 48.5 % and contained 14 species of cyanobacteria and algae. Chlorophyll *a* content of soil biota increased and cyanobacteria inoculation increased the organic carbon and total nitrogen soil content. Maqubela et al. (2009) demonstrated that using the cyanobacteria *Nostoc* in inocula enhanced agricultural soil structure, fertility, increased soil nitrogen and carbon, and crop growth. Rao and Burns (1990) observed improved soil carbon and nitrogen with application of cyanobacteria and bryophyte biomass. Acea et al. (2001) successfully inoculated heated soils with combinations of cyanobacterial species to simulate treatment after fire. Rogers and Burns (1994) also successfully increased cyanobacteria in field applications, and soil stability increased 18% after 300 days. Issa et al. (2007) demonstrated that addition of cyanobacteria began to improve aggregate stability 6 weeks after treatment. Howard and Warren (1998) found that inoculation of disturbed areas to enhance soil stabilization using cyanobacteria pelletized into a starch matrix was overall unsuccessful.

Middleton and Bever (2010) found that inoculation of a retired agricultural field with soil collected from remnant grassland prairie resulted in a negative response of early successional plants and a positive response to mid and late successional plants, suggesting that soil community is critical for establishing the late successional plant community. Belnap (1993) observed after two years that in mechanically scalped sites in

gypsiferous soils in a middle elevation desert contained an observable difference in cover in dry inoculated versus non inoculated sites. Chlorophyll *a* concentration, the number of lichen species present and the percent cover of BSCs were all higher in inoculated plots. Belnap (1993) also observed that natural recovery of scalped sites in sandy soils appeared to be covered by cyanobacteria after 5 years, but there was no lichen or moss recovery.

Inocula provide a source for biota that contains cyanobacteria, algae and other microorganisms, lichen symbiont reproductive structures, fungal spores, and moss spores or protonemata. Lichen fragments normally do not establish and regenerate a thallus, however, produce telemorph (sexual) and anamorph (asexual) fruiting structures from the individual symbionts and require recombination (Büdel and Scheidegger 1996). Additionally, since BSC organisms are poikilohydric and desiccation tolerant, organisms require a wetted environment for propagation or reproduction. The high desiccation tolerance and temperature tolerances of these organisms provide the physical and physiological properties necessary for use as inocula for immediate use or as a salvaged source which can be stored over a long period of time.

Summary

BSCs inhabit many ecosystems across the earth providing essential ecosystem services including increasing soil stability and providing native erosion control, impacting the hydrological cycle including water infiltration, permeability, retention and evaporation, nutrient cycling, particularly carbon and nitrogen cycling, and influencing vegetation community dynamics. Even though BSCs are resilient to extreme temperatures, drought and radiation, they are also extremely vulnerable to disturbances that disrupt their physical integrity. Disturbance to BSC communities impact the entire

surrounding ecosystem. Natural recovery may take decades to centuries or not occur at all. Climate changes over time, temperature, precipitation, soil composition, the proximity to inoculants all influence the potential for natural recovery. Assisted recovery through rehabilitation and/or restoration can be beneficial to BSC communities by guiding systems toward a sustainable trajectory that will enhance its resilience. Enhancing soil stability, resource augmentation and/or inoculation of BSCs may be feasible methods that will benefit disturbed BSC systems.

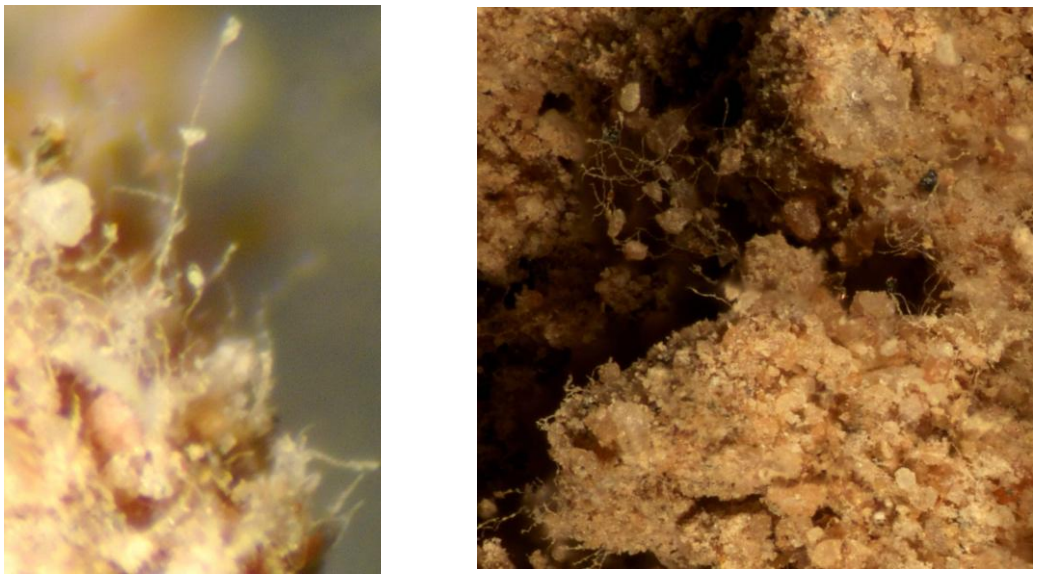


Figure 1 Filamentous cyanobacteria aggregating soil particles in a biological soil crust piece obtained from gypsiferous soils in Lake Mead National Recreation Area, USA.



Figure 2 Lichens *Collema* and *Peltula patellata* covering the soil surface in gypsiferous soils in Lake Mead National Recreation Area, USA.

Chapter III

METHODS

Field Study Area Description

In 2008 the Federal Highway Administration (FHWA) initiated the Rehabilitate Northshore Road Project in Lake Mead National Recreation Area (LMNRA).The purposes of the project were to rehabilitate and reconstruct a segment of road to improve pavement conditions and rehabilitate deteriorated and inadequate drainages (United States 2003). The project was part of ongoing, multi-year FHWA, Federal Lands Division work and National Park Service (NPS) cyclic road maintenance (Dey 2006).

This thesis is a part of a larger study that focuses on gypsiferous soil habitats within LMNRA. The study area lies within the eastern region of the Mojave Desert and is situated about 96 km northeast of Las Vegas, NV (Figure 3). The study area encompasses the corridor of Northshore Road between mile posts 27 to 48 (Figure 4). Most of the construction occurred in previously disturbed areas and the existing roadbed which resulted in minimal disturbance to the surrounding undisturbed lands with limited new disturbance. However, approximately 2.5 km of non-continuous road segments were built into previously undisturbed soils, and approximately 2.6 km non-continuous existing roadbed segments were obliterated.

For the Eastern Mojave Desert region the mean summer daytime temperatures can exceed 37°C and are often paired with extremely low relative humidity of less than 25%. In some years there are several weeks of increased humidity and precipitation associated with monsoonal influence from the south (Gorelow and Skrbac 2005). Winter months are mild, with afternoon temperatures averaging around 15°C. Most of the precipitation

occurs during the winter and early spring seasons (Gorelow and Skrbac 2005). The average percentage of possible days with sunshine is 85%. The Mojave Desert also experiences strong wind events throughout the year with the highest average wind storm events occurring from March through June (Gorelow and Skrbac 2005).

Within the study area, elevation ranges from 400-500 m. The primary vegetation for this area is consists of *Ambrosia dumosa* (A. Gray) Payne, *Atriplex canescens* (Purch) Nutt., *Atriplex confertifolia* (Torr. & Frém) S. Watson, *Atriplex hymenelytra* (Torr.) S. Watson, *Baileya multiradiata* Harv. & A. Gray ex A. Gray, *Encelia virginensis* A. Nelson, *Enceliopsis argophylla* (D. C. Eaton) A. Nelson, *Ephedra torreyana* S. Watson, *Eriogonum inflatum* Torr. & Frém., *Psorothamnus fremontii* (Torr. ex A. Gray) Barneby, *Sphaeralcea ambigua* A. Gray, and *Tiquilia latior* (I. M. Johnst.) A. T. Richardson. Soil taxonomic units consist of Typic Petrogypsides, Typic Calciargids, Haplodruids, and Druinodic Haplocalcids (Lato 2006) tend to contain high amounts of gypsum and calcium. Parent materials for these soils include igneous, metamorphic, and sedimentary rock. Soils are hyperthermic due to the gypsum and consist of extremely gravelly sandy loam soils stabilized by desert pavement, aeolian sands, or fine grain gypsiferous clays (Lato 2006; United States 2003).

As a part of the construction mitigation measures and for the broader Rehabilitate Northshore Road Project study, in October 2008 LMNRA salvaged small to medium native perennial plants, including the common perennials *Ambrosia dumosa*, *Baileya multiradiata*, *Eriogonum inflatum*, *Psorothamnus fremontii*, *Sphaeralcea ambigua*, and, although not commonly found in gypsiferous soils, *Larrea tridentata* (DC.) Coville.

Plants were cared for at the LMNRA nursery facility until transplanted within reconstructed roadside segments after construction was complete in January 2010.

As required by current FHWA policies, the road reconstruction contractor was required to salvage the top layer of desert soils (topsoil) from any of the potential impact areas and stockpile topsoil as close to salvage sites to retain native biota and seed banks. Topsoil removal depth varies from the top 5-30 cm (2-12 in) due to the equipment and landscape. Stockpiled surface soil was returned by the contractor to locations as close as possible to salvage sites after completion of construction (LeNoue, D. Personal communication. 10 February 2009; United States 2003). Due to the removal of segments of the old road, not all areas received topsoil; subsurface soil was used for filling and landscape contouring.

Additionally, undisturbed surface BSCs (depth 1-5 cm) were salvaged and initially stored at the LMNRA Nursery Facility, moved to a storage facility a few months after salvage, and eventually moved to cold storage at the University of Nevada, Las Vegas. Salvaged BSCs were stored dry and at how humidity in an environmental control room with temperatures ranging from 4°C -15°C with limited exposure to light.

Field Treatment Establishment

The field treatments consisted of a four-factorial mixed-effects design consisting of two levels (presence or absence) of each of the following factors: topsoil reapplication; the native perennial shrub *Ambrosia dumosa;* wood shavings; and BSC inoculation (Table 1). Each of the 16 treatment combinations was replicated 5 times, totaling 80 plots.

After construction was complete field examinations were conducted along Northshore Road to identify areas for the experimental study. Road segments for the field study were restricted to new disturbance related to the Northshore Project and in areas where the old road bed was removed, which created a non-continuous experimental area (Figure 4). Road segments were identified as topsoil reapplied after construction was complete or as newly exposed subsurface soil without topsoil. This provides an opportunity to observe the impacts of these activities on topsoil biota. Within topsoil and exposed subsurface soil segments all locations of the transplanted native perennial *Ambrosia dumosa* from the Northshore Road planting project were identified, making topsoil as a fixed effect. For the planting project, the twenty road segments were randomly selected to receive plants or to remain bare.

A total of twenty topsoil and subsurface soil area road segments with and without *Ambrosia* were randomized to receive the additional wood shavings and BSC inoculation treatments applied factorially to plots within the randomly assigned road segment. Only thirteen out of the twenty segments were included due to random assignment of plots. Effects of *Ambrosia*, wood shavings, and BSC inoculation and all two-way, three-way, and four-way interactions were tested over residual variance.

A perennial shrub from the Northshore Road outplanting project was included as a treatment factor due to evidence suggesting that the recovery of soil crusts may be greater in shrubby areas (Belnap and Warren 2002) and that perennial plants are known to increase subsurface soil stability, while protecting the soil surface under the influence of the shrub canopy (Casermeiro et al. 2004; Parsons et al. 1992). A single species was chosen to reduce potential variability of the influence on BSCs and soils between

different species. *Ambrosia* was specifically chosen because this species had the greatest number of individuals that were salvaged during the Northshore Road salvage project, the greatest number of individuals that survived after salvage and prior to outplanting, and the highest survival of any of the perennial shrubs after the first few months after outplanting and the largest number of same-species individuals. However, this species in not consistently the dominant shrub species found in the gypsiferous soil types found within the research area.

Wetted wood shavings were integrated into the top few centimeters of surface soil to increase soil stability, to increase soil surface texture (Benkobi et al. 1993), to slow water flow over the soil surface, and to provide dust traps. Shavings were soaked in water prior to integration with surface soil to allow to easier mixing with soils.

BSCs were inoculated over the 1-m^2 plot at an estimated 0.3 m^2 cover and spread evenly over surface with a shovel. Crust pieces ranged from approximately 0.5 cm to 3 cm thick and less than a centimeter up to 5 cm is diameter. Since most of the BSCs salvaged from the Northshore Road project contain lichens, BSCs were applied as pieces and not in a slurry as to avoid breaking up the crust pieces more than necessary to promote the presence of whole propagules.

Experimental plots were established from September-October 2010 at the beginning of the cooler and wetter season and after the potential of high heat days. All plot soil surfaces were wetted with water and roughened with hand tools prior to BSC inoculation. Eighty centimeter tall galvanized wire mesh exclusion cages were erected around all plots due to signs and the presence of feral cattle, horses and/or burros along the Northshore Road and Overton Beach Road corridors.

Reference Plot Establishment

Six permanent reference plots were randomly established within a 200-m radius area around the construction corridor. Reference plots provide an analogue for the pre-disturbance BSC communities, soil properties, and vegetation communities. The undisturbed control plots were incorporated into the statistical model to obtain the best estimate of variance for undisturbed plot observed variables; however, only disturbed treatments contributed to results in reported analysis of variance tables. Undisturbed control plot information was used as a reference to compare to other treatments in planned contrasts.

Field Data Collection and Analyses

There are several approaches for monitoring BSC organisms including species- or taxonomic-based approaches and morphological-group approaches (Eldridge and Rosentreter 1999). Each approach has limitations. It may be difficult to accurately identify soil crust organisms to species in the field and this technique only captures macroscopic or visually obvious BSCs, representing a disadvantage to a species-based approach. On the other hand, a disadvantage to a functional approach includes misinterpreting or generalizing functional roles of different species, such as attributing functions to more species base on grouping species with similar morphology. Morphology may be an indicator of how the BSC community will respond to different physical disturbances (Kaltenecker 1997). Lichens exhibit diverse morphologies; thalli can be homoiomerously (mycobiont and photobiont intermixed) or heteromerously (symbionts in layers with photobiont protected by mycobiont) arranged with diverse morphologies, such as gelatinous, crustose, squamulose, foliose and fruiticose forms

(Table 3). Mosses are grouped by similar structure and function, although some species are readily interspersed amongst lichen species, while other mosses form large patches. Microorganisms may be difficult to identify without genetic testing; however, existing studies that present species lists and morphological and physical descriptions can be used to develop a potential list of species likely present.

Macroscopic Cover

Experimental and undisturbed reference plots were assessed in spring 2012. Plots were watered to more easily identify BSC species. A species list was compiled from existing literature and field guides, along with the morphology and photobiont for each lichen species (Table 2 & 3; Belnap and Lange 2001; McCune and Goward 1995; McCune and Rosentreter 2007; Rosentreter et al. 2007). Total BSC cover was estimated across a 1-m^2 plot and the proportion of each genus or species of lichen and moss was estimated to provide the approximate percent cover per genus or species. Additionally, plots were segmented into 10-cm^2 grid cells and BSC lichen and moss species were tallied per cell to estimate frequency per species per plot. Species were identified to the highest resolution possible, and unknown species were identified in the lab. The photobiont and morphological groups were noted. All mosses identified were short mosses (Table 2 & 3). Individual moss species cover was overall very small; moss species were grouped for estimating moss cover. Additionally, in each 1-m^2 plot, percent cover was visually estimated for *Ambrosia dumosa*, where present, non-native annuals, and surface organic matter (litter/duff), which included surface-exposed wood shavings.

To explore the BSC species composition differences among the experimental field plots with BSC inoculants and undisturbed plots, non-metric multidimensional scaling

(NMS) ordination was used in auto-point thorough mode using PC-ORD 5 software (McCune and Medford 1999). BSC species composition was ordinated with additional response variables including soil stability and available nitrogen results and input as a second matrix for observing vectors that showed strong correlations.

For the disturbed field experimental plots, nineteen macroscopic variable percent cover estimates were $\log_{10}+1$ transformed and scaled to their range, and converted to a distance matrix using the Bray-Curtis dissimilarity equation (Legendre and Legendre 1998) prior to analysis to reduce the effects of outliers to the right in the distribution that would have a disproportionate impact on results and in order to test the main affects, BSC inoculation (BSC), topsoil reapplication (TS), wood shavings application (WS), *Ambrosia* (AMDU), and all two-way, three-way, and four-way interactions in a multivariate analysis of variance (MANOVA). The significance of the main affects was determined in a mixed-effect ANOVA determined from 999 permutations using PERMANOVA software (Anderson 2001; McArdle and Anderson 2001). Topsoil was applied or not applied to entire road segments; the fix effect of topsoil was tested over the random effects of the road segments within topsoil treatment. The effects of BSC inoculation, wood shavings addition, and *Ambrosia* presence were applied factorially in an incomplete block design across road segments, for a total of five replicates for each of the eight treatment conditions. Significance of BSC inoculation, wood shavings addition, and *Ambrosia* presence as well as interactions among these treatments and with topsoil, was tested over their respective interactions with road segments within topsoil treatments. Significant effects (alpha = 0.05) were further examined during post-hoc tests with Bonferroni correction. Univariate ANOVA models for cover of organic matter, non-

native plants, specifically for non-native annual species *Bromus rubens* and *Schismus* separately, total BSC, and the dominant individual BSC constituents were conducted using ANOVA methods in the same model design and significance assessment in the PERMANOVA software. Individual examinations excluded the BSC lichens *Acarospora nodulosa* var. *nodulosa*, *Aspicilia aspera, Candelariella citrina,* and *Fulgensia bracteata* due to low cover and low plot frequency occurrence; however, the cover of these lichens is included in the overall BSC cover estimates.

Planned contrasts for each treatment with the undisturbed control were conducted in a separate model using a priori pair-wise comparisons. Undisturbed reference plots were compared to all other treatment combinations in a cell means model in which the four-way interaction of BSC x topsoil x wood shavings x *Ambrosia* presence x disturbance treatment was the fixed effect in PERMANOVA software using 999 permutations to assess significance. Post-hoc tests with Bonferroni adjustment were conducted for significant effects in the ANOVAs to further explain any patterns. Reported mean values were back-transformed from $\log_{10}+1$ scale, and standard errors were computed from 1000 bootstrape samples in SAS 9.2 software (SAS Institute, 2002-2008).

Microscopic Variables

Cyanobacterial counts were conducted for all plots. As described in Chapter 2, cyanobacteria provide several ecosystem services. Laboratory methods were modified from Bowker et al. (2002). From each field plot in standardized locations within plots, four 2.5-cm disks at 0.5 cm depth were taken from surface-moistened soil. In the laboratory, the top 1-3 mm were scraped off of each of the four subsamples with a

sanitized razor, combined, and allowed to air dry. After drying surface samples per plot were homogenized with a mortar and pestle. One gram per sample was used to produce 1:10 and 1:100 dilutions for cyanobacterial counts. On a 20-mm^2 gridded slide, 0.1 mL of each of the 1:100 dilutions was placed and observed with light microscopy under 400 magnification. Twenty cells of the grid were randomly selected for observation of organism presence and frequency. Cyanobacteria were identified to family, genus, or species and grouped as filamentous, colonial, or unicellular. Species were identified to the highest resolution possible, although positive identification of all species is difficult with light microscopy due to similarities between some species and not all differentiating characteristics are distinguishable with this technique. A species list was compiled from current literature and field guides including Alwathnani and Johansen (2011), Belnap and Lange (2001), Boyer et al. (2002), and Řeháková et al. (2007) (Table 4 & 5). Taxon frequency per plot slide and abundance was estimated for 1 gram of the 1-3 mm surface soil sample.

The remaining 9 mL of the 1:10 dilution were added to approximately 10 g of autoclaved, salvaged, homogenized gypsiferous soil that was acquired from the topsoil stockpiles from the research area. Sample dishes were sealed with Parafilm and placed in a *Percival* model GL-36VL Intellus Environmental Controller (Percival Scientific, Inc. Perry, IA) with a light irradiance at 80 μmol m^{-2} s^{-1} and set on a diurnal setting with night/day temperatures at 15°C/25°C for 3-5 weeks. Dishes were examined under a microscope for species presence and verification.

For cyanobacteria and total microorganisms identified or counted with light microscopy, including filamentous, colonial, and unicellular cyanobacteria, data were

$\log_{10}$+1 transformed and analyzed in SAS in an ANOVA to test the main effects in disturbed plots of BSC inoculation, *Ambrosia* presence, and wood shavings presence, with topsoil reapplication as a fixed variable in the same model as described for the macroscopic variables. All main effects and their two-way, three-way, and four-way interactions were tested over the residuals variance. Planned contrasts, pair-wise differences across treatments, included undisturbed plots. Post-hoc contrasts were Bonferroni corrected.

Soil Stability

Soil stability is recognized an indicator of soil health. It is related to ecosystem properties, processes and functions such as the quantity and composition of soil organic matter (Belnap et al. 2001a, 2001b, 2001c; Doran and Ziess 2000) and biotic activity (Belnap 2003; Belnap et al. 2001a, 2001c), infiltration capacity (Belnap 2006) and resistance to erosion (Belnap 2006). Macroaggregation of soil is a function of active soil organic matter (Mazor et al. 1996). Soil stability was estimated using modified methods and the soil stability criteria from Herrick et al. (2001).

Within the 1-m^2 plots, six peds (6-8 mm diameter) from the top 2-4 mm of surface soil from standard locations per plot were used to estimate soil stability following Herrick et al. (2001). Peds were assigned a rank value 1-6 on an ordinal scale, with 1 having the least stability and 6 having the greatest stability (Table 7). For each ped stability rating, the value was squared to improve linearity of the scale. A non-parametric ANOVA model of the same form as described for macroscopic variables was used without the log transformation prior to forming the Bray-Curtis distance matrix.

Available Nitrogen

A composite of four soil samples for NH_4-N and NO_3^-N analysis per plot was collected from standard locations across plots. Soils were collected with a 2.5-cm diameter corer and 0-5 mm depth. Samples were transported on ice and sample preparation in the laboratory was completed within 6 to 8 hours of collection. Samples were sieved (>2mm removed) and homogenized. To a 10 g portion of the composited sample, 40 mL of 2M KCl solution were added and agitated vigorously by hand for 2 minutes and left to settle for 18-24 hours then filtered through a pre-treated #1 Whatman filter paper and frozen until concentrations could be determined by flow injection colorimetry at the Soil, Water and Forage Analytical Laboratory at Oklahoma State University (Stillwater, OK, USA).

Variables were $\log_{10}+1$ transformed prior to analysis. Main treatment affects were tested for disturbed plots in the same model as described for macroscopic variables and planned comparisons were used to compare disturbed and undisturbed plots. Post-hoc contrasts of interested were Bonferroni corrected.

Fluorescence

Use of modulated chlorophyll fluorescence as an index of recovery for desiccation-tolerant species is well documented for photosynthetic species (Stirbet and Govindjee 2011; Maxwell and Johnson 2000) including for lichens (Belnap et al. 2008), bryophytes (Marschall and Proctor 2004; Proctor 2003), and cyanobacteria (Belnap 1993; Papageorgiou 1996). Fluorescence analysis is based upon the excitation of the pigment molecule's electrons in photosystem II (PSII) as a photon enters into an open PSII reaction center. There are four paths that an electron can go to return to ground state: 1)

induce photochemical reactions in which the excited electron exits the pigment molecule and enters an electron transport chain in chlorophylls; 2) heat dissipation; 3) transference of that energy to an adjacent pigment, as can occur in the light-harvesting antenna systems of photosynthetic organisms; and 4) as fluorescence or the emission of a fluorescence photon that has a longer wavelength than the photon that was initially absorbed (Campbell et al. 1989). Four chlorophyll fluorescence parameters, dark-adapted fluorescence, light-adapted fluorescence, quantum yield and PSII efficiency factor were monitored.

The minimal fluorescence level (F_o) in the dark-adapted state or the ground state is the value when PSII reaction centers are open, and the maximal fluorescence (F_m) level in the dark-adapted state is when PSII reaction centers are closed due to light exposure. Light exposure with a high irradiance that transiently drives a high proportion of PSII reaction centers to close. F'_o is the minimal fluorescence level in the light-adapted state, and F'_m is the maximal fluorescence level in the light-adapted state. F_v (F_m-F_o) or F'_v (F'_m-F'_o) is the variable fluorescence change between PSII open and closed reaction centers. The calculated proportions F_v/F_m and F'_v/F'_m reflect the difference between the proportion of open reaction centers capable of photochemistry and the proportion of reaction centers that were used for photochemistry in the dark- and light-adapted states, respectively. F_v/F_m is the maximum quantum efficiency of PSII photochemistry in the dark-adapted state. F'_v/F'_m is the light-adapted efficiency of excitation energy capture by *open* PSII reaction centers.

Light drives the transient changes from open PSII reaction centers to closed PSII reaction centers. A decrease in F'_m compared to F_m indicates non-photochemical

quenching (NPQ) or heat dissipation (Maxwell and Johnson 2000). NPQ, or (F_m/F'_m)-1, occurs when the excited electron returns to a ground state by releasing heat or transfer of the excitation energy to an adjacent pigment occurs in the light-harvesting antenna systems of photosynthetic organisms (Campbell et al. 1989). A decrease in the F'_v/F'_m value from F_v/F_m results from the decrease of the fraction of PSII reaction centers that are capable of photochemistry and/or from downregulation or the increase in NPQ (Baker and Oxborough 2004).

The actual quantum yield of PSII electron transport in light-adapted state or Φ_{PSII} $[(F'_m- F'_s)/ F'_m]$ depends on closed PSII reaction centers and the efficiency of excitation energy that is captured (Baker and Oxborough 2004; Maxwell and Johnson 2000). Φ_{PSII} provides a useful measure of the proportion of the light that is absorbed by chlorophyll associated with PSII reaction centers and is used for photochemistry (Maxwell and Johnson 2000). Photochemical quenching parameters are related to the relative value of F'_m and steady-state fluorescence (F_s). F_s is the state where the fluorescence yield is quenched. Also, under laboratory conditions, there is a strong linear relationship between Φ_{PSII} and the efficiency of carbon fixation, although stressed organisms can cause fluctuations in this relationship (Maxwell and Johnson 2000). The Genty parameter $[F'_q/F'_m = (F'_m-F_s)/F'_m]$ or the PSII efficiency factor is a measure of the proportion of the light absorbed by PSII that is actually used in photochemistry (Maxwell and Johnson 2000) and reflects the photochemical part of fluorescence quenching or an estimate of the fraction of the PSII maximum efficiency (Baker and Oxborough 2004).

From each disturbed experimental plot containing BSC inocula and from each undisturbed plot, four *Collema* specimens were collected at standardized locations within

all plots. In the lab, small *Collema* patches approximately 3-5 mm in diameter were isolated from the original sample and placed in leaf clips. Specimens were dark-adapted for 12 hours in a dry state in a growth chamber prior to hydration and fluorescence monitoring. Dark- and light-adapted fluorescence were taken after 6, 12, 24, and 48 hours after hydration using a FMS 2 pulse-modulated fluorometer (Hansatech Instruments, Norfolk, England) and ΦPSII and F'_q/F'_m were calculated

The sampling structure is slightly different for fluorescence as it was limited to BSC inoculated plots and undisturbed plots and there were repeated measures on the same sample at four time points. Fluorescence variables were analyzed in a mixed-effects ANOVA. The model included fixed effects of topsoil, tested over plot within topsoil, wood shavings addition and *Ambrosia* presence and their two-way and three-way interaction with topsoil tested over their respective interactions with plots within topsoil. Time and all of its interactions with topsoil, wood shavings, and *Ambrosia* were also tested in a fixed effects model which tested over the interaction between the nested within plot and wood shavings/*Ambrosia* treatments and time. Planned contrasts, pair-wise differences across treatments, included undisturbed plots. Post-hoc contrasts were Bonferroni corrected.

Greenhouse Study

Greenhouse study treatments formed a five-factor experiment, consisting of two levels of inoculation with the following additional treatments: two levels of watering treatment, two levels of wood shavings, and four levels of carbohydrate addition. In total this results in 32 treatment combinations (N=5). Forty nursery flats were quartered with plastic partitions providing four carbohydrate treatments per flat. Flats were split between

watering treatments and again between BSC inoculation treatments. Twelve additional flats were used as controls and did not receive any inoculation treatment. Half of the control flats received wood shavings and all flats received the four carbohydrate addition levels.

Native soils were hypothesized to contain native microorganisms that could provide a source of native microorganisms to use for BSC. Native soils were acquired from topsoil salvage piles and homogenized with a cement mixer for 20 to 30 minutes. No other constituents were added. Approximately 375 mL salvaged soil was added to each quarter partition.

Wood shavings were added as an additional physical soil constituent and to reflect the field study application. Half the 20 flats from each watering treatment receive approximately 15 g (~250 mL) wood shavings per quarter (approximately 50% cover surface at 1-cm depth biomass in grams equivalent) that was pre-saturated in 250 mL water and thoroughly combined with the native gypsum soil.

Half of the flats received inoculation with discrete pieces at 30% cover. The other half received wet slurry produced from the equivalent of 30% cover of the quarter flat mixed with 125 mL of water. Wet slurry, discrete BSC pieces, and no additional inoculation treatment on native topsoil were used to test the effectiveness of inoculation techniques.

Glucose and mannitol were selected for carbohydrate addition due to their roles in desiccation tolerance, rehydration response, and their importance in metabolic processes. Mannitol has been indicated as part of potential pathways leading the major groups of lichen products. Glucose is the sugar product of cellulose decomposition by microbes and

other crust organisms and is commonly found in cyanobacteria, lichens and mosses. By supplying additional mannitol and glucose this is hypothesized to provide carbohydrates to growth for soil crust organisms and hyphal expansion for lichens. All flats received the following treatments between the four quarters twice a month during a two week hydration period for 18 months: a 250 mL solution of 6% D-mannitol solution, a 250 mL solution of 6% D-glucose solution, a 250 mL solution of the combination of 6% D-mannitol and 6% D-glucose solutions, and no additional treatment.

Precipitation plays an important role in BSC activity since organisms are only metabolically active when wet. Flats either received an average winter-spring transition precipitation equivalent (~5 cm) or 400% above this average precipitation equivalent (~20 cm) over a four month period to reflect current average climate conditions and potential future climate changes in precipitation. Watering treatments were on a two week rotation with hydration periods lasting 14 days and a dry period lasting 14 days. Precipitation in the Mojave Desert mostly occurs in the winter and early spring months. Watering treatment amounts estimated from the January-April monthly average precipitation records reported in Gorelow and Skrbac (2005), which includes data from 1971-2000.

Laboratory Studies and Analyses

Collema Fluorescence Monitoring and Addition of Mannitol and Glucose

Glucose and mannitol play direct roles in organism metabolism and are related to the physiological response of organisms to dehydration and rehydration. The addition of these carbohydrates to salvaged and stored *Collema* samples was tested to observe rehydration responses through chlorophyll fluorescence analysis. Small, intact 3-5 mm

diameter *Collema* disks were obtained from salvaged BSCs, which had been in dry storage for 2 years at the time of testing. The design of this experiment consisted of the addition of either 6% or 10% mannitol or 6% or 10% glucose applied either as the initial hydration event during the first hydration period after dry storage or as the last hydration event during the first hydration period (24 hours) prior to dry down. With a control there were 9 treatments with 5 replicated per treatment. Samples were prepared in a small Petri dishes and left in 50% relative humidity for 12 hours in the dark at 20°C prior to the initial hydration event.

Light-adapted chlorophyll fluorescence was measured several times over the time course during the initial 48 hour hydration period, after a second application period (30 hours) and during a second hydration period (24 hours) with repeated measures to observe the effects on *Collema* after carbohydrate additions and one slow-dry period between hydration periods. The sampling structure consisted of repeated measures of the same samples at multiple time points grouped into three sampling time frames. ANOVAs were used for repeated measures for time frame groups, 1) initial hydration with treatments after dry storage, 2) response to application of mannitol and glucose treatments after 48 hours of hydration with water, and 3) response of both time frame groups 1 and 2 after dry down and rehydration.

Fluorescence Monitoring of Salvage BSCs in Storage

Fluorescence monitoring of the storage crusts began in mid-2011, almost 3 years after initial storage. Monitoring occurred in August 2011 (3 years after initial storage) and in August 2012 (4 years after initial storage). Dark- and light-adapted chlorophyll fluorescence was used to observe the response of *Collema* specimens 24 hours after an

initial hydration event. In August 2012, previously undisturbed *Collema* specimens were acquired from the field to compare differences in chlorophyll fluorescence respond. For each year and the new specimens, 12 small, intact 3-5 mm diameter *Collema* disks were obtained from salvaged BSCs and placed in leaf clips. Samples were left in 50% relative humidity for 12 hours in the dark at 20°C prior to the initial hydration event. Fluorescence parameters were measured 24 hours after hydration. Two-sample t-tests were used to analyze the fluorescence parameters from the 2011 and 2012 measurements and the 2012 fluorescence parameters from the newly acquired previously undisturbed *Collema* specimens.

Slurry Inoculation with Glucose and Common Plant Nutrient

A laboratory study on a smaller scale than the greenhouse study was established to isolate the treatment of BSC slurry inoculation. A slurry produced from a 1:5 volume of BSC:water was used to inoculate gypsiferous soil in 10-cm^2 nursery flats. Flats were filled at a depth of 2 cm with salvaged and autoclaved native gypsiferous soil. Additional treatments included 10% glucose and/or Shultz Plant Food Plus, containing 10% nitrogen (source 1.6% ammonia, 0.2% nitrate, and 8.2% urea), 15% available phosphate, 10% soluble potash, 0.10% chelated iron, 0.05% chelated manganese, and 0.05% chelated zinc with an additional 0.5 % iron solution. Flats were stored in a *Percival* model GL-36VL Intellus Environmental Controller (80 µmol m^{-2} s^{-1} light irradiance) set on a 15°C/25°C night/day temperature diurnal setting. Flats were on a standardized hydration schedule of 14 days hydration/14 dry for 8 months after which time percent cover of any visible BSC growth was estimated for the 10 cm^2 surface. Cyanobacteria cover was arcsin square-root transformed and compared among treatments in a two-way ANOVA with glucose

solution and nutrient solution and their interaction as fixed effects. The interaction between glucose and nutrients was further studied in Tukey post-hoc tests. Back-transformed least-squares means and standard errors are reported.

Table 1 Biological soil crust experimental restoration field plot treatments in the Eastern Mojave Desert, USA.

Treatments
BSC
TS
WS
AMDU
BSCxTS
BSCxWS
BSCxAMDU
TSxWS
TSxAMDU
WSxAMDU
BSCxTSxWS
BSCxTSxAMDU
BSCxWSxAMDU
TSxWSxAMDU
BSCxTSxWSxAMDU
Disturbed, No Treatment
Undisturbed Control

BSC = Biological Soil Crust Inoculants
TS = Topsoil
WS = Wood Shavings
AMDU = *Ambrosia dumosa*

Table 2 Lichens and mosses and morphological groups identified on gypsiferous biological soil crusts in Lake Mead National Recreation Area, USA. This species list was adapted from Belnap and Lange (2001) and Rosentreter et al. (2007), and modified to reflect the species identified in this study. Not all lichen morphological groups are present in biological soil crusts in the Mojave Desert. Lichen photobiont classifications and families is list.

LICHENS		
Crustose	**Species**	**Photobiont**
	Acarospora nodulosa var. *nodulosa (*Dufour) Hue.*†	Green algae (*Trebouxia*)
	Aspicilia aspera (Mereschk.) Tomin†	Green algae (*Trebouxia*)
	Candelariella citrina de Lesd.	Green algae (*Trebouxia*)
	Fulgensia bracteata (Hoffm.) Räsänen*†	Green algae (*Trebouxia*)
Squamulose		
	Peltula patellata	Cyanobacteria (*Anacystis*)
	Peltula richardsii (Herre) Wetmore.†	Cyanobacteria (*Anacystis*)
	Placidium lachneum (Ach.) B. de Lesd.	Green algae chlorococcoid (*Pleurococcus* or *Myrmecia*)
	Placidium lacinulatum (Ach.) Breuss	Green algae chlorococcoid (*Pleurococcus* or *Myrmecia*)
	Placidium squamulosum (Ach.) Breuss	Green algae chlorococcoid (*Pleurococcus* or *Myrmecia*)
	*Psora decipiens (*Hedwig) Hoffm.*†	Chlorococcoid Green algae (*Myrmecia*)
Gelatinous		
	Collema coccophorum Tuck.†	Cyanobacteria (*Nostoc*)
	Collema tenax (Sw.) Ach.† (minutely foliose)	Cyanobacteria (*Nostoc*)
MOSSES		
Short moss		
	Aloina bifrons (De Notaris) Delgadillo	
	Bryum Hedw.	
	Crossidium Jur.	
	Didymodon Hedw.	
	Pterygoneurum Jur.	
	Syntrichia Mitt.	

* Restricted to gypsiferous soils (Belnap and Lange 2001; Rosentreter et al. 2007)
† Restricted to or commonly found on calcareous soils (Rosentreter et al. 2007)

Table 3 Morphological group descriptions for lichens and mosses found globally. Not all morphological groups occur in the Mojave Desert. Morphology descriptions are adapted from Büdel and Scheidegger (1996), McCune and Gloward (1995) and Rosentreter et al. (2007).

Morphological Groups	Description
Crustose	Thalli attach to substrate surface tightly. Subtypes include powdery, endolithic, endophloeodic, squamulose, peltate, pulvinate, lobate, effigurate, and suffruticose. Thallus organization either homoiomerous or heteromerous.
Squamulose	Thalli occur in discrete squamules that may be ear-shaped, convex, or concave and often have lobed margins.
Gelatinous	Lichens with an unstratified thallus that becomes jelly-like when moistened. Species tend to be blackish in color with a blue-green case when wet. Taxa include nitrogen-fixing cyanolichens.
Foliose/Fruiticose	Thalli have three-dimensional forms. Foliose lichens appear leaf-like; tend to have a dorsiventral organization, flattened with a definite upper and lower cortex. Thalli are either homoiomerous (gelatinous) or heteromerous. Fruiticose lichens appear hair-like and tend to be shrubby and sometimes branching.
Short moss	Mosses $\leq$ 10 mm in height, often forming right mats on the soil surface.
Tall moss	Mosses > 10 mm in height, usually forming a thick mat beneath shrub canopies that may extend into interspaces.

Table 4 Biological soil crust cyanobacteria and morphologies identified in gypsiferous biological soil crust communities in the Mojave Desert and in Lake Mead National Recreation Area, USA. This species list is adapted from Alwathnani and Johansen (2011), Belnap and Lange (2001), Boyer et al. (2002), and Řeháková et al. (2007), which contained cyanobacteria composition in Mojave Desert soil.

Cyanobacteria

Order	Family	*Genera*	Morphological Group
Chroococcales			
	Microcystaceae		
		Anacystis Meneghini	Coccoid cells
Nostocales			Colonial
	Nostocaceae		
		Nostoc	
	Rivulariaceae		Colonial/Filamentous
		Calothrix	Filamentous
	Syctonemataceae		
		Scytonema	
	Microchaetaceae		
		Hassallia	Filamentous
		Tolypothrix	Filamentous
Oscillatoriales			
	Phormidiaceae		
		Microcoleus	Filamentous
		Phormidium	Filamentous
		Pseudophormidium	
		Symploca	Filamentous
	Schizotrichaceae		
		Schizothrix	Filamentous
Pseudanabaenales			
	Pseudanabaenaceae		
		Arthronema	Filamentous
			Filamentous
		Leptolyngbya	Filamentous
	Schizotrichaceae		
		Trichocoleus	Filamentous

Table 5 Descriptions of cyanobacteria morphology found globally.

Growth Form	Description
Filamentous	Cell division is primarily in one direction; certain cells may divide perpendicular to arrangement producing branching filaments
Unicellular	Occur as a single-cells organism; both motile and non-motile.
Colonial	An aggregate of cells loosely attached that occur in two forms; infinite number through cell division reproducing by fragmentation or a colony (coenobium) formed from a set number of cells.

Table 6 Free-living and lichenized green algae identified in biological soil crust communities in the Mojave Desert, USA. Free-living green algae species are common in desert soils. Lichenized forms are identified from Table 2.

Green Algae species			
Order	*Family*	*Genera*	Free-living/ Lichenized
Chaetophorales			
	Chaetophoraceae		
		Pleurococcus Meneghini	Lichenized
Chlorellales			
	Chlorellaceae		
		Chlorella M.Beijerinck	Free-living
Chlorococcales			
	Chlorococcaceae		
		Chlorococcum Meneghini	Free-living
Cladorphorales			
	Cladophoraceae		
		Rhizoclonium Kützing	Free-living
Prasiolales			
	Prasiolaceae		
		Desmococcus F. Brand	Free-living
Trebouxiales			
	Trebouxiaceae Freidl		
		Myrmecia Printz	Lichenized
		Trebouxia Puymaly	Lichenized

Table 7 Soil Stability Criteria. Criteria descriptions from Herrick et al. (2001).

Stability Class	Criteria for assignment to stability class
1	Soil too unstable to sample (falls through sieve); or 50% of structure integrity lost within 5 s of insertion in water
2	50% of structural integrity lost within 5-30 s after insertion
3	50% of structural integrity lost within 30-300 s after insertion; or < 10% of soil remains on sieve after five dipping cyles
4	10-25% of soil remains on sieve after 5 dipping cycles
5	25-75% of soil remains on sieve after 5 dipping cycles
6	75-100% of soil remains on sieve after 5 dipping cycles



Figure 3 The Extent of the Mojave Desert (grey) in the southwestern United States and Lake Mead National Recreation Area (black).

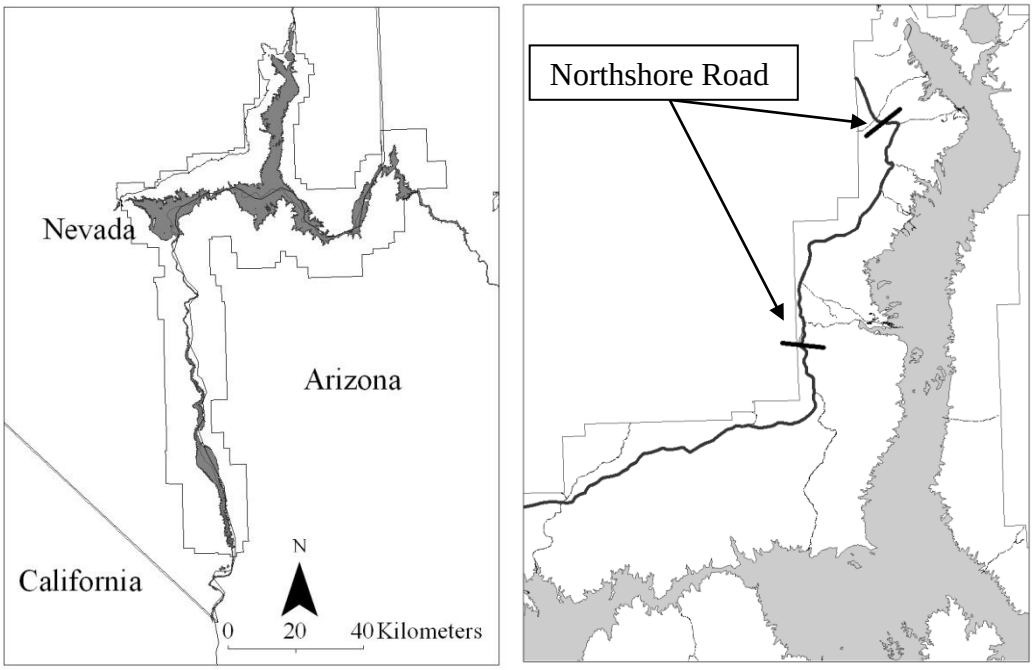


Figure 4 Lake Mead National Recreation Area and the Northshore Road reconstruction corridor. Construction corridor between mile posts 27 and 48 is designated by the brackets.

CHAPTER 4
RESULTS AND DISCUSSION

Field Results

In most cases for this study all possible main effects and interaction effects were tested regardless of their meaningfulness and/or interpretability and interpretation was carefully consider the original hypotheses associated with the experimental design. In some situations interactions were statistically significant, and generally less attention was paid to the interpretation of the main effects. Post hoc comparison tests were used to examine possible interactions between main effects since several of the main effects were statistically significant. Large main effects were weighted more greatly relative to the interactions, such as with cyanobacteria abundances and soil stability. BSCs are generally accepted as having the greater influence on soil stability and topsoil application and BSC inoculation was expected to have significantly greater cyanobacteria abundances. Hypothetically, other effects may minorly impact measured variable compared to the effects of topsoil addition and BSC inoculation, and therefore appear statistically significant when applied with other large main effects.

Macroscopic Variables Cover

Collema species consisted of *C. coccophorum* and *C. tenax,* although the former to a higher degree. These species can be difficult to distinguish in the field and/or intermix readily. *Collema* occurred in 100% of the experimental and undisturbed field plots and occurred most frequently within plots. *Placidium* species included *P. squamulosum, P. lacinulatum,* and *P. lachneum,* with the first two listed species occurring most often and the last being difficult to distinguish in the field. *Peltula patellata* also occurred within all experimental plots, although not in all undisturbed

plots, whereas *Peltula richardsii* only occurred in 21% of the experimental plots. *Psora decipiens* occurred at a low frequency of only 13% of all BSC inoculated plots and had low frequencies within plots and low percent cover when present (<0.5 %). *Acarospora nodulosa* var. *nodulosa*, *Aspicilia aspera*, *Candelariella citrina*, and *Fulgensia bracteata* all had low frequencies of occurrence between BSC inoculated plots (5%, 15%, <1%, and <1%, respectively) and had even lower frequency and percent cover than *Psora* within plots where it was present. Overall the cyanolichen *Collema* had the highest mean cover in BSC inoculated plots and undisturbed plots followed by *Placidium* and *Peltula* species, other soil crust lichens, and then total moss cover, which is the same approximate order of cover as undisturbed plots (Figure 5).

The permuted MANOVA results for the disturbed plot treatments reveal that BSC inoculation had the greatest impact on the macroscopic variable BSC cover and the individual BSC components tested and non-native annual plants (Table 8). ANOVA and NMS results revealed that plots treated with BSC inoculants did not significantly differ from the undisturbed reference plots (Table 9; Figure 6), while those not receiving BSC inoculation were different from the undisturbed plots (Tables 9 & 10). BSC inoculation had the greatest impact and had a strong correlation with BSC cover and cyanobacteria surface soil abundances regardless of additional treatment factors (Table 11).

The individual ANOVAs revealed a more complex relationship between treatments and macroscopic variable cover (Tables 11-17). There was no evidence that the interactions between the BSC inoculation, topsoil addition, wood shavings addition and *Ambrosia* presence influenced overall macroscopic cover. BSC inoculation did not affect organic matter cover. Overall macroscopic variable cover had no measureable

response to the addition of topsoil treatment. Overall macroscopically observed cyanobacteria cover was low (Figure 7). *Ambrosia* and wood shavings application influenced the macroscopically observed cyanobacteria cover (Table 14). Cyanobacteria in the field observed as a macroscopic variable was greater in field plots that had wood shavings, particularly when *Ambrosia* was absent, although only marginally significant (Figure 8).

Topsoil and wood shavings treatments had significant individual and two-way interactive effects on organic matter. Topsoil treatments alone increased organic matter (Tables 15 &18; Figure 9). Wood shavings statistically and significantly increased organic matter observed across all field treatment plots (Tables 15 & 18; Figures 10 & 11). Topsoil addition and wood shavings treatments and their interaction across all treatments increased the observable organic matter on the soil surface (Figure 11).

Non-native annual plants included the forbs *Brassica tournefortii* L., *Erodium cicutarium* (L.) L'Hér. ex Aiton, *Malcolmia africana* (L.) W.T. Aiton, *Salsola tragus* L., and the graminoids *Bromus rubens* L. and *Schismus* P. Beauv. Across all plots, total non-native annual cover for both forbs and graminoids was low, with means ranging from 0.2-4.8% (Table 19; Figure 12). *B. rubens* and *Schismus* had a high enough plot frequency occurrence to analyze separately (Tables 17; Figure 13). Other non-native annuals were not present in enough plots to include in separate analyses and were pooled to observe overall non-native annual cover (Table 17). All non-topsoil plots, regardless of other treatments had little to no non-native annual plant cover (Figure 14).

For total non-native annual plant cover, topsoil application and wood shavings presence, and the two-way interaction between both main treatments were statistically

significant (Table 16). All differences between topsoil treatments were statistically significant. The addition of topsoil increased total non-native annual cover (Figure 14) and specifically *B. rubens* and *Schismus* (Figure 15). In most occurrences of non-natives their presence was related to the presence of topsoil (Table 16; Figures 12 & 15). Topsoil and wood shavings combination treatment had slightly higher non-native cover than wood shavings treatment alone, although this only included a higher mean cover of *S. tragus*, and cover was significantly less than plots treated with just topsoil.

With addition of BSC inoculation on topsoil treatments had little to no non-native annual cover except when the additional treatments of wood shavings and/or *Ambrosia* were also present (Figure 12). No interactions were observed between main treatments and the pair-wise comparisons were not significant. With the addition of wood shavings to topsoil and BSC treatments, the non-native annual grass *Schismus* increased (Figure 16). However, neither difference between wood shavings treatments with topsoil treatments was statistically significant. Topsoil addition and wood shavings addition separately did influence *Schismus* cover.

Fluorescence Results for *Collema* spp. Collected in the Field

In almost every time period, 6, 12, 24, and 48 hours, for every fluorescence variable, F_m/F_v, F'_m/F'_v, Φ_{PSII}, and F'_q/F'_m, the *Collema* sampled from undisturbed control plots had statistically lower values than any of the treated plots (Table 20; Figures 17-20). None of the main treatment effects were statistically significant. All of the parameters F_m/F_v, F'_m/F'_v, Φ_{PSII}, and F'_q/F'_m showed no significant responses to main treatments (Tables 21-24). For all experimental plots with BSC inoculants only time significantly influenced chlorophyll fluorescence parameters, although this was expected (Table 25).

Microscopic Variables

The most commonly observed cyanobacteria from cell counts included species in the genera *Microcoleus*, *Phormidium*, *Pseudophormidium*, *Symploca*, *Nostoc*, *Scytonema*, *Hassallia*, *Tolypothrix*, and *Leptolygnbya*. Green algae observed included species in the genera *Chlorellaceae* and *Chlorococcaceae* as free-living forms and species from the families Chaetophoraceae and Trebouxiaceae, likely sourced from lichens.

Using light microscopy with 1:100 dilutions to observe microorganisms in surface soil samples per plot revealed that all plot treatments had evidence of microbial life. Plots not containing topsoil or BSC inoculants had few to no observable cyanobacteria or algae using this method. However, the 1:10 dilutions after 3-4 weeks did show evidence of cyanobacteria in all treatments, likely due to the presence was below detectable levels in the 1:100 dilutions. Only those disturbed plots treated with BSC inoculants had total observed cyanobacteria and algae, and specifically filamentous cyanobacteria, abundances comparable to the undisturbed plots.

BSC inoculation and topsoil treatments had significant effects on the presence of cyanobacteria and the total organisms observed with light microscopy (Table 26). The addition of BSCs and topsoil treatments individually had greater estimated abundances of cyanobacteria and algae observed in surface soil samples, particularly filamentous cyanobacteria (Figure 21). Topsoil treatment without BSC inoculation increased the total observed cyanobacteria and algae significantly (186% increase); however, topsoil treatment with BSC inoculation was not significant (17% increase from an already large value). With the exclusion of BSC inoculants and topsoil, cyanobacteria and algae estimated surface soil abundances were substantially reduced (Figures 22-25).

Unicellular and colonial cyanobacteria presence was greater in BSC inoculated plots; however, topsoil and *Ambrosia* presence had an interactive effect on unicellular abundance values (Table 26; Figures 22-25). Cyanobacteria had larger abundances in *Ambrosia* plots compared to no treatment plots; however this is only minorly significant for filamentous cyanobacteria (P=0.082*).* When topsoil and/or BSC inoculation was present *Ambrosia* likely had little influence on cyanobacteria compared to the influence of the other two main treatments. The increase in overall cyanobacteria and algae abundances in the presence of *Ambrosia* when topsoil treatment was absent is not statistically significant due to high variation between plots. In inoculated plots, colonial cyanobacteria responded minorly to the absence of wood shavings when *Ambrosia* was present. Topsoil with *Ambrosia* significantly decreased unicellular cyanobacteria. When inoculated with BSCs, colonial cyanobacteria were greater when *Ambrosia* was present and when wood shavings were absent. For plots receiving BSC inoculation and topsoil, wood shavings and *Ambrosia* treatments did not significantly affect colonial cyanobacteria. Plots with BSC inoculants without topsoil and with *Ambrosia* significantly increased colonial cyanobacteria when wood shavings were not present, but *Ambrosia* had no effect when wood shavings were present.

Field Soil Stability

Greater values of soil stability corresponded most strongly with BSC inoculation, followed by topsoil presence (Tables 27 & 28). The soil stability in plots inoculated with BSCs did not differ significantly with soil stability in undisturbed plots (Table 29). The two-way, three-way four-way interaction of main treatments did not show any significance (Table 27). Topsoil had an intermediate effect on soil stability compared to

plots without topsoil; however, this was only when compared to treatments without BSC inoculation (Table 27; Figure 26). The possible main effects and interaction effects were tested regardless of their meaningfulness and/or interpretability. If the interaction is statistically significant, less attention is generally paid to the interpretation of the main effects. Post hoc comparison tests were used to examine possible interactions between main effects because several of the main effects were statistically significant.

Available Nitrogen

Nitrate and ammonium were different with respect to treatment (Table 30; Figures 27 & 28). Experimental disturbed plots with no treatment had the largest mean nitrate concentration out of all the experimental and undisturbed plots. Nitrate was not statistically different between BSC inoculated and non inoculated plots, and there appears to be no trend between treatments. With the absence of BSC inoculants, nitrate levels were significantly greater when neither topsoil nor *Ambrosia* were present (Table 31). The interaction between wood shavings and *Ambrosia* resulted in a decrease in nitrate relative to wood shavings treatment without *Ambrosia*, while nitrate was the same with or without *Ambrosia* when wood shavings were absent (Figure 29). There was an interaction between topsoil and *Ambrosia*, resulting in a significantly increased nitrate mean value compared to topsoil alone and a decrease in the nitrate mean value compared to *Ambrosia* alone (Figure 30).

BSC inoculation did produce a statistically significant effect on ammonium values without any interactive effects with other main treatment variables, however the mean ammonium values were comparable to or less than mean ammonium values for treatments with BSC inoculants and other treatment (Table 31; Figure 28). Wood

shavings presence resulted in different effects on ammonium compared to nitrates. Wood shavings addition resulted in significantly lower ammonium values compared to plots without wood shavings (Figure 31). There was an interaction between topsoil and *Ambrosia* as with mean nitrate values, although the patterns differ between the types of nitrogen considered. The mean ammonium value was lower in plots treated with topsoil and *Ambrosia* compared to topsoil plots without *Ambrosia*, although the addition of topsoil to *Ambrosia* plots resulted in a lower mean ammonium value (Figure 32). The addition of topsoil treatment alone increased ammonium, although this was not significant.

Greenhouse Observations and Results

As a result of greenhouse climate conditions and watering techniques, all lichens and mosses began to bleach within three-four months. Initially the blowers within the greenhouse were constantly blowing due to program malfunctioning increasing the drying time of BSC organisms. Proceeding, the greenhouse had several temperature failures resulting in high ambient temperatures. As a result of these repeated events the soil surface dried quickly. In an attempt to salvage the study, plastic was used to cover the flats and maintain higher surface soil humidity. Plastic was removed in two week intervals for a rest period.

The plastic covering resulted in an extremely high humidity environment altering the BSC species cover diversity and density. Cyanobacteria, particularly *Microcoleus*, and mosses, particularly *Syntrichia*, adapted well to higher moisture content in the air and in the soil. Observationally, cyanobacteria had the highest cover in both slurry and dry inoculated plots. Non-inoculated flats contained little to no cyanobacteria obvious with

visual observation. Eventually, chlorosis occurred in cyanobacteria regardless of other treatments. Data were not analyzed due to the potential non replicability of results.

Laboratory Tests Results

Fluorescence Monitoring and Addition of Mannitol and Glucose Results

Glucose and mannitol solutions had different results on chlorophyll fluorescence values for *Collema* (Tables 32-35; Figures 33-36).The 6% glucose treatment had the greatest response for the initial hydration event, particularly the longer the samples were hydrated. Fluorescence parameters were higher than the control and maintained a higher mean light-adapted fluorescence over the 48 hour period of monitoring ($P<0.05$). The 6% mannitol treatment effect was negatively correlated to fluorescence parameters and more greatly retarded the recovery of fluorescence for the initial hydration event after storage. The addition of glucose and mannitol solutions after 48 hours of hydration with just water did not significantly alter fluorescence values. For the second hydration event, the addition of 6% mannitol and 10% mannitol shortened the time for recovery of fluorescence compared to the control and maintained a higher fluorescence throughout the 24 hour monitoring period; however these were not statistically significant. For samples that received treatments before dry down, the rehydration with of samples treated with 10% mannitol and 6% glucose reduced the overall fluorescence for the first 12 hours after rehydration ($P<0.10$).

Effect of Dry Storage and BSCs Results

Over time, the mean light and dark-fluorescence reduced as storage time increased, and this was statistically significant for both the dark-adapted ($P<0.05$) and light-adapted fluorescence parameters ($P<0.001$) (Figure 37). Differences were

statistically significant between the 3 year, 4 year, and 0 year (newly collected) light- and dark-adapted fluorescence and pair-wise except for dark-adapted fluorescence between the 3 year and newly collected *Collema* samples.

Effect of Slurry Inoculation to Autoclaved Native Soils

Flats inoculated with slurry had a significant cover of cyanobacteria, mostly *Microcoleus*. The cyanobacteria formed a patchy to continuous cover in inoculated flats, while the non-inoculated flats maintained bare soil. Glucose significantly increased cyanobacteria cover (Tables 36 & 37). Nutrient addition had no significant impact on cyanobacteria cover alone, but the combination of nutrients and glucose produced cyanobacteria cover that was significantly greater than treatments with no glucose and qualitatively greater than the plots with glucose alone (Figure 38).

Discussion

Examining the Potential of Biological Soil Crust Restoration in Gypsiferous Soil

Inoculation with BSCs on disturbed gypsiferous soil significantly improved macroscopic and microscopic BSC organism cover and abundance, soil stability, and available ammonium compared to disturbed, non-inoculated plots. Additionally, disturbed experimental treatment plots treated with BSC inocula were generally similar to undisturbed sites indicating that salvage and storage likely had little impact on BSC organisms or that BSC organisms were able to successfully recovery from any negative consequences of or damage from salvage and storage and that BSC inocula can successfully survive salvage, storage, and field application.

Several studies have examined the impacts of environmental disturbance to BSC communities and/or observed natural recovery. After a disturbance, the generally

recognized species succession includes cyanobacterial establishment followed by early successional lichens and mosses. Estimates for natural recovery range from years, decades to centuries. While cyanobacteria more easily colonize disturbed areas, recovery of later-successional BSC organisms such as lichens and mosses require longer timer frames for recovery.

Belnap (1993) observed that 2 years after disturbance in gypsiferous soil plots, cyanobacteria communities began to recover with minimal natural recovery of the main surface lichen *Collema.* Similarly, this thesis work also utilized BSCs that contained *Collema,* which constitutes a large proportion of the Mojave Desert gypsiferous BSC community and has the greatest influence on soil stability and available nitrogen. Belnap (1993) found that plots that were treated with BSC inocula did have minimal lichen recovery after 2 years with 3.6% cover compared to 43.3% in undisturbed plots and none in non-inoculated plots. Plots were inoculated with approximately 25% of the material that was scraped off, resulting in an estimated inoculation of 11.5% soil crust. Survival of BSC inocula for this thesis study was almost 100% with almost the same cover of BSC inocula present after 18-22 months (~30%). Belnap (1993) also observed that 5 years after scalping crusts from sandy sites that cyanobacteria had covered the surface and pedicellation had began, but there was no evidence of lichens or mosses. In the disturbed experimental treatment plots for this thesis, there was little to no evidence of visually obvious cyanobacteria or other BSC organisms in plots not inoculated with BSCs and there were few plots with visually estimable cyanobacteria. Anderson et al. (1982) observed that 14-18 years after grazing exclusion, BSC recovered from 4% to 15%, while 37-38 years after grazing exclusion there was only an additional 1% recovery, indicating

that BSC recovery slowed as cyanobacteria and algae cover was taken over by lichens and mosses. It is possible returning to the experimental thesis plots in the near future will show minimal additional macroscopic cover and the abundances of cyanobacteria may decrease as lichens and mosses increase in BSC inoculated plots.

BSC inoculated experimental plots and undisturbed plots had relatively equivalent cyanobacteria abundances indicating that BSC inoculation assists with restoring the microorganism consistency and abundance of cyanobacteria communities after disturbance. The addition of salvaged topsoil also resulted in a positive response for cyanobacteria abundance, indicating that topsoil salvaging and reapplication is also beneficial to microorganism populations if BSC inoculation is not feasible.

In the laboratory study, cyanobacteria grew quickly in inoculated flats on native autoclaved soils with regular watering treatments and covered much of the soil surface. Since cyanobacteria were observed in all treatments in the 1:10 dilutions inoculation compared to 1:100 dilution observed with light microscopy, it is evident that in the 1:100 dilutions, organisms were below detectable levels and water is likely the main limiting factor for hindering the recovery of cyanobacteria in the field. The limited opportunities for extended wetted periods in the field create a deficit for promotion of cyanobacterial biomass. Over time, and with increased opportunity for repeated wetted events within optimal temperature ranges over several years, cyanobacteria biomass will likely increase.

Compacted soils limit micropore space. For the Northshore project topsoil reapplication was conducted in a manner to reduce soil compaction and encourage physical crusts to form. Soil compaction was not measured and the influence of

disturbance directly to surface soils and to the habitat of BSC organisms is uncertain. The wood shavings break up the physical crust on the surface providing a discontinuous physical barrier. Cyanobacteria observed at a macroscopic level in the field occurred at a higher frequency in plots with wood shavings, which could be due to increased surface texture and an increase in watering pooling and moisture retention. It is less likely that cyanobacteria were impacted by the decomposition of the wood shavings. However, as wood shavings decompose over the long-term, the addition of organic matter may improve conditions for cyanobacteria. Maestre et al. (2006) observed greater cyanobacterial biomass from slurry inoculation when combined with autoclaved sewage sludge containing a high concentration of total carbon.

Cyanobacteria were positively influenced by the main treatments *Ambrosia*, topsoil reapplication, and BSC inoculation. However, interactions between the main treatments may require further examination for clarify the role of *Ambrosia* presence. The presence of native perennial shrubs has been observed to support greater diversity and density of BSC organisms. Shrub structure can provide shade with increased canopy cover, diffusing light when leaves are present, as well as having a structural impact on the surrounding area. As particulates are blown across the soil surface, a shrub provides a brief wind break settling particles around and under the shrub, which may result in dust covering some lichens, reducing their photosynthetic capacity. However, 18 months to 2 years may not have been enough time for *Ambrosia* presence to impact the BSC community. The addition of *Ambrosia* did not show a main effect and had minimal if any influence on the field plots or BSC organisms. Additionally, some of the transplanted *Ambrosia* died disproportionately in non-topsoil areas during the field study, possibly

skewing the results and increasing variation in response of some response variable such as nitrate concentration. New transplants may utilize greater amounts of nitrate, reducing the concentration in the soil surface. However, a source of increased variance may be a result of some of the *Ambrosia* dying after the first year. There were not enough replicated for the treatments to analyze live and dead *Ambrosia* separately, although the interaction between BSC inocula and outplanting treatments should be further examined since outplanting treatments are a common restoration practice.

BSCs and native plants play interactive roles with influencing nutrient cycling and carbon and nitrogen content of the surface soil. Higher ammonium concentrations occurred in plots inoculated with BSCs and is likely related to nitrogen fixation by cyanobacteria and cyanolichens, which dominate the BSCs. *Collema* and *Peltula* are lichen species with cyanobacterial photobionts and are a significant component to the gypsiferous BSC communities in the eastern Mojave Desert.

Wood shavings and *Ambrosia* treatments without BSC inoculation had little to no microscopically observed cyanobacteria evident in surface samples, coinciding with the lower ammonium concentrations for these treatments. The qualitative trend for ammonium suggests that either topsoil application or *Ambrosia* alone may have enhanced ammonium due to influences on nitrogen-fixing organisms, but with both or neither of these treatments ammonium was reduced in the soil. This may be an artifact of the field study or such variation is a result of the disproportionate number of *Ambrosia* transplants that died in plots that were without topsoil.

Wood shavings and *Ambrosia* debris had only a short time to begin decomposition and will eventually contribute carbon in the soils. However, the temporary

addition of a readily available carbohydrate, like mannitol or glucose, or other nutrients commonly used for vascular plants, may additionally assist with increasing and accelerating rehydration recovery, photosynthetic capacity, or carbon acquisition, enhancing cyanobacteria growth, or increasing nitrogen fixation rates. Bottomley and Stewart (1977) demonstrated that nitrogenase activity declines in the dark due to the reduction of ATP via photosynthesis and that cyanobacteria species have the ability to utilize exogenous carbon sources if available to assist with rehydration recovery and use for other metabolic functions, such as nitrogen fixation.

Nitrate analysis did not emerge any trends related to BSC or topsoil application. This may be explained by several factors. All plots had evidence of microorganisms and nitrate incorporation may be a result of soil microbial activity. Or precipitation is limited throughout the year and nitrates may not have had time to leach to subsurface soils. Subsurface desert soils have been found to accumulate nitrate over millennial time frames (Walvoord et al. 2005) and during the reconstruction process subsurface and surface soils were mixed due to the limitations of construction techniques. In areas that do not have topsoil reapplied, former subsurface soils are not exposed. In either situation, it may be difficult to classify a disturbance over a large area due to the depth of impact into subsurface soil layers and potential mixing of the top layer of soil with subsurface soils that were not exposed until disturbance. Also, subsurface layers over a large area may differ in composition and parent materials.

Stabilizing soil is one of the main concerns with any disturbance. The strong correlation between soil stability and BSCs provides strong support for utilizing a native biota that will incorporate into the environment as it recovers and establishes a

sustainable trajectory. For the thesis field study soil stability was influenced along a gradient with the treatments, with increasing soil stability with the addition of wood shavings, then topsoil, and finally the greatest increase with BSC inoculation. Any main treatment variable combine with BSC inoculation resulted in high soil stability ratings. The increase in soil stability with the application of topsoil coincides with the larger presence of observed cyanobacteria. Since topsoil is more easily disturbed by heavy precipitation and wind events and is more easily destabilized by human and non-human traffic, continued disturbance to topsoil should be avoided to provide time for the cyanobacteria community to establish.

BSC inoculation of lichens and mosses to new surface soils increase soil stability much greater than cyanobacteria in topsoil can accomplish alone. The influence of *Ambrosia* on surface stability was expected to be negligible and have a greater influence on subsurface stability. *Ambrosia* treatments were correlated with higher abundances of unicellular or colonial cyanobacteria which do not as effectively bind soil particles as filamentous cyanobacteria and correlated with lower soil stability ratings. The presence of filamentous cyanobacteria within *Ambrosia* treatments was highly variable likely due to the survival of *Ambrosia*, the impact on airborne dust settling around the shrub canopy, shade effects, and the increased soil surface humidity around which provide extended periods of time in a metabolically active state compared to BSCs in interspaces, which are more exposed.

Recognizing and Reducing Stress for BSC Inocula

Chlorophyll fluorescence provides insight to BSC response to salvage, storage, and field applications. It is recognized as an index of stress and recovery in desiccation

tolerant species (Proctor 2010, 2003; Stirbet and Govingjee 2011). Field and laboratory fluorescence responses differed depending on treatment, which may be due to several environmental factors, including physiological and chemical inducement. It must be noted that there are several sources of error that influence fluorescence parameters for cyanobacteria and cyanolichens other than stress. Healthy measurements include F_v/F_m up to 0.8. Lu and Zhang (2000) observed lower F_v/F_m values in measurements of the cyanobacteria *Spirulina.* Belnap et al. (2007) observed that the cyanolichen *Collema* lower fluorescence values. Phycobiliprotein presence, pigment concentration fluctuations, and PSI fluorescence may be responsible for lower than expected chlorophyll fluorescence parameters measured for *Collema* specimens. Using newly acquired samples from the field provide an analogue for quality chlorophyll fluorescence values

Phycobiliproteins found in cyanobacteria fluoresce contributing to F_o and PSII only contributes a portion of the total chlorophyll present. As a result, F_v/F_m may not be a reliable indicator of PSII functioning if there are non-constant pigment concentrations. Constant pigment concentrations and F_v/F_m correlate well with independent measurements of PSII function (Campbell et al. 1989) providing F_v/F_m as an acceptable parameter. Stress impacts pigment concentrations and will impact F_v/F_m values for cyanobacteria and cyanolichens. Additional error may occur with photosystem I (PSI) fluorescence, which contributes to overall fluorescence measure and decreases the value of F'_q/F'_m. The exposure of a specimen to a saturating pulse of light to measure F'_m can result in increased values of F'_q/F'_m. Therefore this value cancan be inaccurate, although the influence of PSI is assumed to be negligible as it impacts fluorescence generally (Stirbet and Govingjee 2011).

Chlorophyll fluorescence is impacted by the concentration of chlorophyll *a* pigment molecules. Damage to photoreceptors or the degradation to chlorophyll *a* content or pigment molecules will cause a reduction in chlorophyll fluorescence and a negative physiological response. During desiccation, PSII becomes inactive and mechanisms are in place to physically and physiologically limit the exposure of these systems to damage or radiation (Veerman et al. 2007). However, even though these organisms are resilient to desiccation, they are brittle. *Collema* can be damaged during salvage and storage. Stored salvaged crusts were maintained from October 2008 to December 2010 in facilities that ranged in temperatures in the summer 15°C to 26°C and 1°C to 4°C in winter months. Beginning in January 2011, crusts were moved to the University of Nevada, Las Vegas in an environmental control room set at 4°C (varied between 4°C and 7°C) with a relative humidity averaging about 20%. It is likely that during these changes in storage conditions and the movement from one place to another brittle crust organisms were broken damaging their photosystems. In storage pigment molecules may degrade, eventually decreasing photosynthetic power but also making the organism more susceptible to irradiation damage.

It appears that *Collema* is impacted with prolonged storage, as was shown in observing chlorophyll fluorescence after three and four years since storage began. Any physical or physiological damage to photosystems results in an inhibition or hindrance of recovery during rehydration (Allakhverdiev et al. 2005). Due to damage, the mycobiont increase the flow of carbohydrates to the photobiont to increase the production of repair molecules, or the photobiont reacts to damage upon rehydration and begins repairing

damaged photosystems and DNA. The mycobiont regulates the abundance of the photobiont in lichens (Clark et al. 2001; Honegger 1991).

When *Collema* were first analyzed using chlorophyll fluorescence with the addition of glucose and mannitol treatments, crusts had only been in more consistent cold storage for 6 months. Fluorescence values were about the same a year later when in August 2011 yearly monitoring began. After two years in cold storage, fluorescence values had significantly reduced. It is possible that pigment molecules had degraded to a point of impacting photoefficiency. Further research will be necessary to elucidate the impacts of longer-term storage on salvaged BSCs.

In the laboratory glucose addition reduced the time of chlorophyll fluorescence recovery and maintained higher fluorescence values throughout the hydration period, showing a positive response to the treatment and possibly a deficiency in glucose production or photosynthetic efficiency for attaining a positive carbon balance. The addition of mannitol initially did not have a positive response with the first hydration event, although there was a positive response during the second hydration event. As already noted some cyanobacteria species grow photoheterotrophically with the addition of glucose in the presence of a photoautotrophs growth inhibitor; and some species grow chemoheterotrophically with glucose in the dark (Rippka 1972). The addition of an adequate amount of glucose may assist with repair mechanisms and photosystem recovery as well as assist with preparing for desiccation, while too high of a concentration may impact osmoregulation. These treatments may be useful for BSC organisms that have been in a prolonged state of desiccation or stress, or may be used to prepare BSCs for use as inocula.

Research Limitations and Proposed Improvements

The experimental approach and methods for this thesis have several limitations. The study was only conducted over a limited period of time. Additional monitoring of salvaged and storage crusts and field sites would provide greater information available to estimate the impacts of disturbance and restoration activities on BSC organisms. Soil properties per treatment were not included in the analysis. Soil analysis would provide information of the impacts of disturbance to gypsiferous soils and how experimental treatments impact disturbed soils. This information may guide a hypothesis for BSC species succession or a range for improvements in BSC ecosystem processes after disturbance. Additionally, a block full-factorial design limited to specific known soil sites would have provided more control. The field study area consisted of a long corridor of non-continuous road segments, which encompassed every different soil types with varying levels of gypsum, calcium, and textures.

Chlorophyll fluorescence is influenced by field conditions resulting in seasonal fluctuations in chlorophyll content. Obtaining fluorescence in field conditions would provide seasonal observation on the same specimens without invasive or destructive treatment. Other important parameters such as soil respiration, chlorophyll *a* content, and nitrogenase activity were not measured; however, the parameters that were used for analyses, such as chlorophyll fluorescence and available nitrogen, have been found to correlate with chlorophyll *a* content and nitrogenase activity, respectively. The assumption that the quantum yield of chlorophyll fluorescence is an index of the maximal photochemical efficiency for PSII in higher plants cannot be extended to cyanobacteria and cyanolichens since other factors contribute to fluorescence and are enhanced when

the organism is stressed (Campbell et al. 1989). Available nitrogen measurements only provide a measure of what is available in the surface soils, which may be accumulated from more than soil crust organisms. Nitrogenase activity would provide an estimated measure of the proportion of available nitrogen that is being contributed by soil crust organisms.

The main limitations for the greenhouse study were a result of the facilities and the watering technique. An automatic watering system in an enclosed area with minimal direct air blowing across crusts may reduce the evaporation rates and increase hydration times. Using deeper containers with more soil and a humidifier can increase the relative humidity and reduce the evaporation rates. More water would be able to penetrate into deeper soil layers, increasing water retention time in soil. It may also be beneficial to replicate the treatments on a small scale under laboratory conditions and use a growth chamber where climate conditions are more easily controlled.

Implications for Non-Native Annual Plant Treatments

Salvaging, stockpiling, and reapplying topsoil is a required practice for road impacts where possible, which could have great benefits for preserving the soil chemistry and seed bank of the native soils. For many areas this mitigation measure is the only rehabilitation treatment implemented. Soil salvaging activities also have the additional benefit of retaining the native surface soil biota that will facilitate the initial BSC recovery and soil stabilization. Additionally, salvaging, transplanting, or growing and planting native perennial shrubs assist with reestablishing native plant communities while reestablishing the visual consistency of the landscape. However, both practices appear to facilitate and promote non-native annual plants. The addition of BSC restoration

treatments either alone or in conjunction with either or both of these practices can be beneficial for suppressing and/or reducing the spread of non-native annuals.

BSCs were stored up to two years prior to reapplication in the field, with the first year and a half of storage in facilities maintain on average higher temperatures (15°C-25°C), which may have negatively influenced the viability of BSC organisms or any native or non-native seeds collected along with the crusts. Since plots treated with just BSC inoculants had little to no non-native presence, it may be assumed that either the salvaged BSCs contained few seeds or suppressed germination either through physical or chemical means.

Within the Northshore Road reconstruction area, several non-native annuals were identified before, during, and after construction above ground and in the seed bank (Abella et al. unpublished data) and after the establishment of the BSC experimental plots, as observed by this study. Topsoil was a significant factor in the presence of non-native annual plants likely due to seeds already present in the existing seed bank which were retained when topsoil was salvaged and reapplied. Disturbing the soils likely exposed non-native seeds. Also, non-native seeds may have accumulated on topsoil stock piles in the field, adding yearly to the viable seeds in the topsoil stockpiles. Visual observation showed that soils with high clays and gypsum content contained fewer no-native above ground plants compared to soils will more sand and less gypsum content, although this was not analyzed statistically and varied greatly over the course of the 4 years of the Northshore Road projects.

In experimental treatment field plots *Schismus* appeared to be negatively influenced by the addition of wood shavings to topsoil plots, which may be due to the

decrease in surface area and reduced soil penetration and/or emergence. Wood shavings were observed at higher surface exposures in topsoil plots. The two-way interaction between the presence of topsoil and wood shavings also resulted in a reduction of nitrate and ammonium, which may also have been a factor in the lower cover of *Schismus* in plots with both topsoil and wood shavings. BSC inocula alone did not appear to support non-native annual plants, and BSC inocula on top of topsoil appears to have suppressed non-native presence. The addition of any other treatment factor with BSC inocula other than BSCs and just topsoil resulted in a greater presence of non-native annuals. BSC processes, such as nitrogen fixation may provide an optimal location for non-natives such as *B. rubens* or *Schismus* by replicating a fertile island effect. BSC inoculation and *Ambrosia* presence resulted in the highest *B. rubens* and *Schismus* cover, however other non-native forbs were reduced in presence. *Ambrosia* presence had a tendency to reduce overall cyanobacteria presence and ammonium in BSC inoculated plots, while slightly increasing nitrate concentration.

It may be optimal to actively treat stockpiled topsoil with herbicides. However, it is unclear how these chemicals will impact cyanobacteria and algae or other microorganisms in the soil. Also, if BSC inocula are used in restoration treatments, it is unclear how the commonly used herbicides and anti-emergent chemicals will impact the physiological functioning of lichens and mosses. Further testing would be required to understand the impact of these chemicals on BSC organisms and how herbicide treatments can work in conjunction with BSC inoculation as a method to suppress or reduce the spread of non-native annual plants.

The Dilemma of the Land Manager

Land managers have to contend with necessary or accidental disturbances and the requirements of rehabilitation after disturbance. The National Park Service (NPS) is required to maintain the biota and visual aesthetics of the landscape, which includes vegetation and BSC communities, which are wide spread in Mojave Desert ecosystems. Damage to these areas is highly visual and rehabilitation techniques currently used do not necessarily cover up damaged areas or restore damage. Topsoil salvage and reapplication and salvage and transplanting of native perennial plants will not accelerate recovery of severely disturbed desert ecosystems enough to reduce the long-term impacts of the disturbance. For example, the presence of non-native annual plants is problematic due to the likelihood these plants will benefit from disturbance. The NPS needs methods to hasten recovery while also reducing the visual inconsistencies in the landscape.

BSC inoculation on disturbed gypsiferous soils may provide an additional benefit by reducing some non-native annuals, increasing nitrogen and carbon inputs, and provide greater soil stability than topsoil reapplication and engineering structures alone. However, a source of inocula is not always readily available. The Rehabilitate Northshore Road project was anticipated to impact undisturbed BSC patches, providing inocula. If this is not an option with future disturbances or for treatment of past disturbances, disturbing another area to obtain inocula could increase the risk of introducing or facilitating non-native annual plants at the site of salvage or result in additional ecosystem damage. It may be prudent to first observe the soil seed bank prior to any sacrificial salvaging. Additionally, an initial measure that may reduce the amount of inocula salvaged would be to use part salvaged material for artificially promoting the cyanobacterial component.

Even though topsoil may contain non-native annual plant seeds, BSC organism composition would be more closely acclimated to this topsoil community compared to subsurface soils. Depending on the type of disturbance, the soil properties may shift the BSC population to a community that is less stable with reduced carbon and nitrogen inputs, as with cyanobacteria-dominated BSC communities.

In this thesis, field plots were inoculated at approximately 30% cover. It is possible that similar results for increasing soil stability and facilitating the return of carbon and nitrogen cycling could be achieved with lower percent application. It is not likely that BSC macroscopic cover will increase substantially in these plots over the next decade. However, the cyanobacterial community will increase and colonize between lichen and moss pieces, reestablishing an almost continuous cover. Belnap and Warren (2002) observed a 46-65% recovery of cyanobacteria in disturbed BSC communities on desert pavement sites in the Mojave Desert since WWII; disturbed plots were compared to adjacent undisturbed plots. Over this 50-60 year time frame, about half of the cyanobacteria community recovered its population in areas where it was just driven over.

Likely, highly disturbed sites, like those along the Northshore Road will require twice that time or greater if areas are not within close proximity to potential native inoculants. It is likely that either a light slurry or 10-20% BSC inoculation with discrete pieces will greatly facilitate cyanobacteria recovery, as was observed in the laboratory slurry inoculation study and in the field inoculation study.

Table 8 Multivariate analysis of variance (MANOVA) results for cover of macroscopic variables, lichens, mosses, organic matter, and non-native annual plants, in gypsiferous soil restoration treatment plots in the eastern Mojave Desert, analyzing the effects of the main treatments, biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values in bold, alpha 0.05.

Treatment	df	F	P
BSC	13	16.69	**0.001**
TS	13	1.68	0.187
WS	13	6.25	**0.005**
AMDU	13	0.52	0.672
BSCxTS	13	0.47	0.916
BSCxWS	13	0.00	1.000
BSCxAMDU	13	0.00	0.987
TSxWS	13	1.34	0.265
TSxAMDU	13	1.09	0.364
WSxAMDU	13	0.32	0.805
BSCxTSxWS	13	0.00	0.979
BSCxTSxAMDU	13	0.13	0.937
BSCxWSxAMDU	13	0.16	0.914
TSxWSxAMDU	13	0.00	0.984
BSCxTSxWSxAMDU	13	0.44	0.734

Table 9 Comparisons of macroscopic variables of lichens, mosses, organic matter, and non-native annual plants between undisturbed and experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert for main treatments effects, biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments	Undisturbed	df	F	P
BSC	Undisturbed	18	0.393	0.777
TS	Undisturbed	18	4.6	**0.008**
WS	Undisturbed	18	4.99	**0.006**
AMDU	Undisturbed	18	4.78	**0.007**
BSCxTS	Undisturbed	18	0.702	0.586
BSCxWS	Undisturbed	18	0.901	0.449
BSCxAMDU	Undisturbed	18	0.668	0.604
TSxWS	Undisturbed	18	5.313	**0.005**
TSxAMDU	Undisturbed	18	4.606	**0.008**
WSxAMDU	Undisturbed	18	5.052	**0.009**
BSCxTSxWS	Undisturbed	18	0.859	0.483
BSCxTSxAMDU	Undisturbed	18	0.573	0.663
BSCxWSxAMDU	Undisturbed	18	0.959	0.427
TSxWSxAMDU	Undisturbed	18	4.86	**0.007**
BSCxTSxWSxAMDU	Undisturbed	18	0.788	0.531
Disturbed, no treatment	Undisturbed	18	4.69	**0.008**

Table 10 Mean total biological soil crust cover for undisturbed and experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. The main treatments, biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU).

Treatments	BSC Mean Cover
BSC	42
TS	0
WS	0
AMDU	0
BSCxTS	28
BSCxWS	30
BSCxAMDU	36
TSxWS	0
TSxAMDU	0
WSxAMDU	0
BSCxTSxWS	25
BSCxTSxAMDU	28
BSCxWSxAMDU	37
TSxWSxAMDU	0
BSCxTSxWSxAMDU	29
Disturbed, No Treatment	0
Undisturbed Control	45

Table 11 Individual permutation-based analysis of variance (PERMANOVA) results for biological soil crust cover in experimental treatment field plots in gypsiferous soils in the eastern Mojave Desert analyzing the effects of the main treatments, biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments	BSC		
	df	F	P
BSC	1,64	18.14	**0.002**
TS	1,64	0.01	0.928
WS	1,64	0.00	0.995
AMDU	1,64	0.01	0.956
BSCxTS	1,64	0.00	0.990
BSCxWS	1,64	0.00	0.995
BSCxAMDU	1,64	0.00	0.989
TSxWS	1,64	0.00	0.998
TSxAMDU	1,64	0.00	1.000
WSxAMDU	1,64	0.00	0.987
BSCxTSxWS	1,64	0.00	0.997
BSCxTSxAMDU	1,64	0.00	1.000
BSCxWSxAMDU	1,64	0.00	0.989
TSxWSxAMDU	1,64	0.00	0.997
BSCxTSxWSxAMDU	1,64	0.00	0.999

Table 12 PERMANOVA results for the cover of the cyanolichen *Collema* in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments	*Collema*		
	df	F	P
BSC	1,13	18.12	**0.002**
TS	1,13	0.00	0.992
WS	1,13	0.00	0.989
AMDU	1,13	0.05	0.839
BSCxTS	1,13	0.00	1.000
BSCxWS	1,13	0.00	0.988
BSCxAMDU	1,13	0.01	0.949
TSxWS	1,13	0.01	0.958
TSxAMDU	1,13	0.00	0.984
WSxAMDU	1,13	0.00	1.000
BSCxTSxWS	1,13	0.01	0.951
BSCxTSxAMDU	1,13	0.00	0.995
BSCxWSxAMDU	1,13	0.00	1.000
TSxWSxAMDU	1,13	0.01	0.968
BSCxTSxWSxAMDU	1,13	0.00	0.987

Table 13 PERMANOVA results for the cyanolichen *Peltula* and the phycolichen *Placidium* in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments		*Peltula*		*Placidium*		*Psora*	
	df	F	P	F	P	F	P
BSC	1,13	16.86	**0.001**	17.71	**0.001**	5.68	**0.023**
TS	1,13	0.19	0.844	0.15	0.821	0.08	0.921
WS	1,13	0.10	0.927	0.45	0.564	0.25	0.773
AMDU	1,13	0.09	0.837	0.03	0.978	0.19	0.816
BSCxTS	1,13	0.09	0.941	0.06	0.957	0.07	0.935
BSCxWS	1,13	0.08	0.943	0.45	0.580	0.31	0.725
BSCxAMDU	1,13	0.02	0.995	0.01	0.998	0.16	0.838
TSxWS	1,13	0.06	0.966	0.24	0.745	0.01	0.999
TSxAMDU	1,13	1.85	0.169	0.32	0.673	0.31	0.726
WSxAMDU	1,13	0.23	0.810	0.06	0.948	1.03	0.358
BSCxTSxWS	1,13	0.05	0.984	0.26	0.722	0.01	0.998
BSCxTSxAMDU	1,13	0.46	0.611	0.08	0.928	0.27	0.757
BSCxWSxAMDU	1,13	0.13	0.908	0.04	0.977	1.12	0.337
TSxWSxAMDU	1,13	0.10	0.930	0.22	0.763	0.32	0.712
BSCxTSxWSxAMDU	1,13	0.05	0.972	0.14	0.854	0.35	0.695

Table 14 PERMANOVA results for total moss and macroscopically observed cyanobacteria in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments		Moss		Cyanobacteria	
	df	F	P	F	P
BSC	1,13	9.89	**0.003**	5.73	**0.028**
TS	1,13	0.23	0.801	0.15	0.878
WS	1,13	0.71	0.470	0.51	0.535
AMDU	1,13	0.43	0.677	0.13	0.857
BSCxTS	1,13	0.19	0.839	0.09	0.898
BSCxWS	1,13	1.12	0.337	0.48	0.554
BSCxAMDU	1,13	0.35	0.693	0.20	0.779
TSxWS	1,13	0.18	0.797	1.90	0.184
TSxAMDU	1,13	0.48	0.603	0.60	0.495
WSxAMDU	1,13	0.08	0.937	5.74	**0.022**
BSCxTSxWS	1,13	0.30	0.747	1.80	0.203
BSCxTSxAMDU	1,13	0.39	0.679	0.41	0.606
BSCxWSxAMDU	1,13	0.08	0.937	6.71	**0.021**
TSxWSxAMDU	1,13	0.06	0.964	0.87	0.389
BSCxTSxWSxAMDU	1,13	0.06	0.960	1.02	0.349

Table 15 PERMANOVA results for organic cover in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments		Organic Matter	
	df	F	P
BSC	1,13	0.18	0.920
TS	1,13	4.40	**0.016**
WS	1,13	22.30	**0.001**
AMDU	1,13	0.80	0.485
BSCxTS	1,13	0.25	0.873
BSCxWS	1,13	0.47	0.707
BSCxAMDU	1,13	0.19	0.913
TSxWS	1,13	9.44	**0.001**
TSxAMDU	1,13	0.42	0.748
WSxAMDU	1,13	1.06	0.381
BSCxTSxWS	1,13	1.30	0.286
BSCxTSxAMDU	1,13	0.66	0.579
BSCxWSxAMDU	1,13	0.65	0.586
TSxWSxAMDU	1,13	0.60	0.615
BSCxTSxWSxAMDU	1,13	0.67	0.577

Table 16 PERMANOVA results for total non-native cover in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments	Non-natives		
	df	F	P
BSC	1,13	0.20	0.821
TS	1,13	7.18	**0.009**
WS	1,13	4.88	**0.029**
AMDU	1,13	0.54	0.558
BSCxTS	1,13	0.20	0.821
BSCxWS	1,13	0.29	0.762
BSCxAMDU	1,13	0.38	0.675
TSxWS	1,13	1.95	0.158
TSxAMDU	1,13	0.54	0.558
WSxAMDU	1,13	0.90	0.394
BSCxTSxWS	1,13	0.64	0.494
BSCxTSxAMDU	1,13	0.02	0.995
BSCxWSxAMDU	1,13	0.66	0.487
TSxWSxAMDU	1,13	0.90	0.394
BSCxTSxWSxAMDU	1,13	0.64	0.494

Table 17 PERMANOVA results for the cover of the non-native annual graminoids *Bromus rubens* and *Schismus* in experimental treatment plots in gypsiferous soil in the eastern Mojave Desert analyzing the effects of the main treatments biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatments	*Bromus rubens*		*Schismus* spp		
	df	F	P	F	P
BSC	1,13	18.14	**0.002**	0.14	0.955
TS	1,13	0.01	0.928	3.55	**0.046**
WS	1,13	0.00	0.995	0.16	0.941
AMDU	1,13	0.01	0.956	0.16	0.946
BSCxTS	1,13	0.00	0.990	0.14	0.955
BSCxWS	1,13	0.00	0.995	2.38	0.108
BSCxAMDU	1,13	0.00	0.989	0.17	0.935
TSxWS	1,13	0.00	0.998	0.16	0.941
TSxAMDU	1,13	0.00	1.000	0.16	0.946
WSxAMDU	1,13	0.00	0.987	0.38	0.756
BSCxTSxWS	1,13	0.00	0.997	2.38	0.108
BSCxTSxAMDU	1,13	0.00	1.000	0.17	0.935
BSCxWSxAMDU	1,13	0.00	0.989	0.11	0.972
TSxWSxAMDU	1,13	0.00	0.997	0.38	0.756
BSCxTSxWSxAMDU	1,13	0.00	0.999	0.11	0.972

Table 18 Mean cover of organic matter for undisturbed and experimental treatment field plots in gypsiferous soils in the eastern Mojave Desert. Main treatments include biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU). Wood shaving additions treatment highlighted in bold text.

Treatment	Organic Matter
BSC	2.3
TS	16.0
WS	**64.0**
AMDU	4.4
BSCxTS	12.6
BSCxWS	**58.0**
BSCxAMDU	7.2
TSxWS	**63.6**
TSxAMDU	29.0
WSxAMDU	**68.0**
BSCxTSxWS	**35.2**
BSCxTSxAMDU	16.8
BSCxWSxAMDU	**46.0**
TSxWSxAMDU	14.8
BSCxTSxWSxAMDU	**49.0**
Disturbed, no treatment	3.0
Undisturbed	5.4

Table 19 Mean cover of total non-native annual plant cover for undisturbed and experimental treatment field plots in gypsiferous soils in the eastern Mojave Desert. Main treatments include biological soil crust inoculation (BSC), topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU).

Treatment	Non-Native Cover
BSC	0.00
TS	**0.60**
WS	**0.02**
AMDU	0.00
BSCxTS	0.00
BSCxWS	0.00
BSCxAMDU	0.00
TSxWS	**0.08**
TSxAMDU	**1.02**
WSxAMDU	0.00
BSCxTSxWS	**0.50**
BSCxTSxAMDU	**4.80**
BSCxWSxAMDU	**0.02**
TSxWSxAMDU	**1.40**
BSCxTSxWSxAMDU	**0.70**
Disturbed, no treatment	0.00
Undisturbed	**0.67**

Table 20 Comparisons between the chlorophyll fluorescence mean responses of the cyanolichen *Collema* collected from undisturbed (bold) and experimental treatment field plots in gypsiferous soils in the eastern Mojave Desert with the main effects topsoil (TS), wood shavings (WS), *Ambrosia* (AMDU), and time, and the two-way and three-way interactions between main treatment variables TS, WS, and AMDU. Parameters measured and calculated include dark-adapted chlorophyll fluorescence (F_v/F_m), light-adapted chlorophyll fluorescence (F'_v/F'_m), chlorophyll fluorescence actual quantum yield (Φ_{PSII}), and the proportion of the light absorbed by PSII that is actually used in photochemistry (F'_q/F'_m).

time		F_v/F_m	F'_v/F'_m	Φ_{PSII}	F'_q/F'_m
6	**Undisturbed**	**0.116**	**0.334**	**0.278**	**0.277**
6	BSC	0.250	0.474	0.385	0.390
6	BSCxTS	0.203	0.350	0.277	0.294
6	BSCxWS	0.271	0.506	0.416	0.416
6	BSCxAMDU	0.155	0.372	0.303	0.303
6	BSCxTSxWS	0.351	0.555	0.475	0.475
6	BSCxTSxAMDU	0.288	0.480	0.396	0.397
6	BSCxWSxAMDU	0.200	0.425	0.354	0.354
6	BSCxTSxWSxAMDU	0.225	0.475	0.396	0.396
12	**Undisturbed**	**0.152**	**0.351**	**0.297**	**0.297**
12	BSC	0.333	0.542	0.462	0.462
12	BSCxTS	0.251	0.408	0.345	0.343
12	BSCxWS	0.301	0.523	0.436	0.439
12	BSCxAMDU	0.210	0.443	0.376	0.376
12	BSCxTSxWS	0.393	0.605	0.527	0.527
12	BSCxTSxAMDU	0.340	0.527	0.445	0.445
12	BSCxWSxAMDU	0.270	0.494	0.432	0.432
12	BSCxTSxWSxAMDU	0.355	0.581	0.504	0.504
24	**Undisturbed**	**0.178**	**0.365**	**0.307**	**0.308**
24	BSC	0.343	0.563	0.484	0.484
24	BSCxTS	0.273	0.421	0.362	0.362
24	BSCxWS	0.320	0.532	0.438	0.444
24	BSCxAMDU	0.220	0.419	0.359	0.359
24	BSCxTSxWS	0.365	0.547	0.469	0.471
24	BSCxTSxAMDU	0.298	0.510	0.421	0.421
24	BSCxWSxAMDU	0.281	0.498	0.433	0.436
24	BSCxTSxWSxAMDU	0.327	0.554	0.468	0.468
48	**Undisturbed**	**0.168**	**0.365**	**0.300**	**0.300**
48	BSC	0.345	0.559	0.477	0.477
48	BSCxTS	0.199	0.349	0.282	0.282
48	BSCxWS	0.297	0.490	0.411	0.412
48	BSCxAMDU	0.152	0.351	0.289	0.289
48	BSCxTSxWS	0.340	0.518	0.434	0.419
48	BSCxTSxAMDU	0.286	0.485	0.385	0.394
48	BSCxWSxAMDU	0.195	0.477	0.365	0.366
48	BSCxTSxWSxAMDU	0.285	0.520	0.444	0.444

Table 21 ANOVA results for the dark-adapted chlorophyll fluorescence (F_v/F_m) responses from the cyanolichen *Collema* collected from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert to the main effects of topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Time		F_v/F_m		
(Hrs)		df	F	P
6	TS	10	1.36	0.261
6	WS	5	0.78	0.417
6	AMDU	5	1.65	0.255
6	TSxWS	5	0.00	0.972
6	TSxAMDU	5	1.08	0.347
6	WSxAMDU	5	1.29	0.308
6	TSxWSxAMDU	5	2.16	0.201
12	TS	10	1.61	0.222
12	WS	5	0.99	0.364
12	AMDU	5	0.19	0.684
12	TSxWS	5	0.37	0.568
12	TSxAMDU	5	2.79	0.156
12	WSxAMDU	5	0.00	0.978
12	TSxWSxAMDU	5	1.54	0.269
24	TS	10	0.06	0.810
24	WS	5	0.38	0.566
24	AMDU	5	0.51	0.509
24	TSxWS	5	0.02	0.888
24	TSxAMDU	5	1.59	0.263
24	WSxAMDU	5	0.24	0.647
24	TSxWSxAMDU	5	0.29	0.614
48	TS	10	0.18	0.678
48	WS	5	0.26	0.629
48	AMDU	5	1.60	0.261
48	TSxWS	5	0.32	0.596
48	TSxAMDU	5	4.89	*0.078*
48	WSxAMDU	5	0.00	0.988
48	TSxWSxAMDU	5	1.18	0.327

Table 22 ANOVA results for the light-adapted chlorophyll fluorescence (F'_v/F'_m) responses from the cyanolichen *Collema* collected from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert to the main effects of topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Time			F'_v/F'_m	
(Hrs)		df	F	P
6	TS	10	0.09	0.762
6	WS	5	2.39	0.183
6	AMDU	5	0.38	0.562
6	TSxWS	5	0.26	0.633
6	TSxAMDU	5	2.62	0.166
6	WSxAMDU	5	0.92	0.381
6	TSxWSxAMDU	5	1.47	0.280
12	TS	10	0.38	0.546
12	WS	5	3.02	0.143
12	AMDU	5	0.00	0.982
12	TSxWS	5	1.67	0.253
12	TSxAMDU	5	2.98	0.145
12	WSxAMDU	5	0.10	0.769
12	TSxWSxAMDU	5	1.58	0.264
24	TS	10	0.01	0.925
24	WS	5	1.12	0.339
24	AMDU	5	0.07	0.798
24	TSxWS	5	0.25	0.641
24	TSxAMDU	5	3.30	0.129
24	WSxAMDU	5	0.15	0.719
24	TSxWSxAMDU	5	0.82	0.406
48	TS	10	0.07	0.799
48	WS	5	1.35	0.298
48	AMDU	5	0.04	0.849
48	TSxWS	5	0.30	0.606
48	TSxAMDU	5	4.71	*0.082*
48	WSxAMDU	5	0.32	0.597
48	TSxWSxAMDU	5	2.32	0.188

Table 23 ANOVA results for chlorophyll fluorescence actual quantum yield (Φ_{PSII}) responses from the cyanolichen *Collema* collected from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert to the main effects of topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Time		Φ_{PSII}		
(Hrs)		df	F	P
6	TS	10	0.15	0.706
6	WS	5	2.96	0.146
6	AMDU	5	0.24	0.642
6	TSxWS	5	0.36	0.577
6	TSxAMDU	5	2.25	0.194
6	WSxAMDU	5	1.05	0.353
6	TSxWSxAMDU	5	1.68	0.251
12	TS	10	0.41	0.529
12	WS	5	3.15	0.136
12	AMDU	5	0.01	0.924
12	TSxWS	5	1.79	0.239
12	TSxAMDU	5	1.98	0.218
12	WSxAMDU	5	0.01	0.925
12	TSxWSxAMDU	5	1.67	0.252
24	TS	10	0.03	0.871
24	WS	5	0.87	0.395
24	AMDU	5	0.06	0.818
24	TSxWS	5	0.34	0.587
24	TSxAMDU	5	1.90	0.227
24	WSxAMDU	5	0.34	0.588
24	TSxWSxAMDU	5	0.82	0.408
48	TS	10	0.06	0.815
48	WS	5	1.03	0.357
48	AMDU	5	0.20	0.673
48	TSxWS	5	0.82	0.407
48	TSxAMDU	5	5.11	*0.073*
48	WSxAMDU	5	0.28	0.622
48	TSxWSxAMDU	5	1.21	0.322

Table 24 ANOVA results for the proportion of the light absorbed by PSII that is actually used in photochemistry (F'_q/F'_m) responses from the cyanolichen *Collema* collected from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert to the main effects of topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Time		F'_q/F'_m		
(Hrs)		df	F	P
6	TS	10	0.23	0.638
6	WS	5	2.58	0.169
6	AMDU	5	0.44	0.538
6	TSxWS	5	0.28	0.622
6	TSxAMDU	5	2.10	0.207
6	WSxAMDU	5	0.80	0.412
6	TSxWSxAMDU	5	1.55	0.268
12	TS	10	0.37	0.551
12	WS	5	3.29	0.130
12	AMDU	5	0.01	0.926
12	TSxWS	5	1.79	0.238
12	TSxAMDU	5	2.09	0.208
12	WSxAMDU	5	0.02	0.897
12	TSxWSxAMDU	5	1.68	0.252
24	TS	10	0.04	0.845
24	WS	5	1.01	0.360
24	AMDU	5	0.08	0.791
24	TSxWS	5	0.30	0.609
24	TSxAMDU	5	1.87	0.229
24	WSxAMDU	5	0.29	0.611
24	TSxWSxAMDU	5	0.83	0.404
48	TS	10	0.10	0.761
48	WS	5	0.77	0.420
48	AMDU	5	0.08	0.784
48	TSxWS	5	0.57	0.486
48	TSxAMDU	5	6.02	*0.058*
48	WSxAMDU	5	0.36	0.576
48	TSxWSxAMDU	5	1.14	0.334

Table 25 ANOVA results for dark- (F_v/F_m) and light-adapted fluorescence (F'_v/F'_m), actual quantum yield (Φ_{PSII}), and the proportion of light absorbed by PSII that is actually used in photochemistry (F'_q/F'_m) responses from the cyanolichen *Collema* across the whole hydration time course to the main effects of topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way and three-way interactions.

BSCx	num	den	F_v/F_m		F'_v/F'_m		Φ_{PSII}		F'_q/F'_m	
Treatment	df	df	F	P	F	P	F	P	F	P
TS	1	16	0.64	0.436	0.02	0.904	0.02	0.896	0.01	0.908
WS	1	5	0.63	0.464	2.15	0.203	2.06	0.211	1.92	0.224
AMDU	1	5	0.99	0.366	0.09	0.772	0.09	0.772	0.09	0.771
TSxWS	1	5	0.12	0.740	0.55	0.490	0.83	0.404	0.70	0.442
TSxAMDU	1	5	2.80	0.155	3.99	0.102	3.22	0.133	3.37	0.126
WSxAMDU	1	5	0.02	0.894	0.00	0.961	0.00	0.969	0.01	0.940
TSxWSxAMDU	1	5	1.30	0.305	1.77	0.241	1.51	0.273	1.45	0.283
Time	3	48	12.21	**0.000**	7.24	**0.000**	10.52	**0.000**	11.29	**0.000**
TSxWSxTime	3	15	0.57	0.644	0.45	0.723	0.47	0.704	0.55	0.658
TSxAMDUxTime	3	15	2.12	0.141	0.85	0.487	1.73	0.204	2.52	*0.097*
WSxAMDUxTime	3	15	2.44	0.105	2.45	0.104	2.68	*0.084*	2.54	*0.095*
TSxWSxAMDUxTime	3	15	2.12	0.141	0.85	0.487	1.73	0.204	2.52	*0.097*

Table 26 ANOVA results for the estimated abundance of cyanobacteria and total microorganisms in one gram of soil identified from surface soil samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert, analyzing the effects of the main treatments, biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatment		Filamentous		Colonial		Unicellular		Microorganism	
Description	df	t	P	t	P	t	P	t	P
BSC	16	14.48	**0.000**	13.43	**0.000**	9.83	**0.000**	14.71	**0.000**
TS	16	-2.61	**0.019**	-4.16	**0.001**	-1.55	0.141	-2.95	**0.009**
WS	16	0.49	0.628	2.02	*0.061*	-0.22	0.827	1.09	0.291
AMDU	16	-1.85	*0.082*	1.52	0.147	0.36	0.723	-1.15	0.269
BSCxTS	16	2.34	**0.032**	-0.11	0.913	-0.96	0.350	2.64	**0.018**
BSCxWS	16	-0.78	0.447	2.95	**0.009**	-0.81	0.431	-0.83	0.419
BSCxAMDU	16	1.36	0.192	0.90	0.382	0.95	0.358	1.26	0.225
TSxWS	16	0.24	0.810	2.63	**0.018**	-0.50	0.623	-0.20	0.846
TSxAMDU	16	0.75	0.462	1.13	0.277	3.24	**0.005**	0.75	0.464
WSxAMDU	16	-1.01	0.326	-0.17	0.866	-1.10	0.288	-0.53	0.601
BSCxTSxWS	16	0.01	0.991	1.70	0.109	0.08	0.933	0.27	0.789
BSCxTSxAMDU	16	-0.96	0.354	1.75	*0.099*	2.65	**0.017**	-0.21	0.839
BSCxWSxAMDU	16	0.34	0.741	-2.66	**0.017**	-0.51	0.614	-0.01	0.992
TSxWSxAMDU	16	-0.05	0.958	-2.58	**0.020**	0.27	0.790	-0.49	0.633
BSCxTSxWSxAMDU	16	0.10	0.919	-0.09	0.926	-0.32	0.756	0.44	0.666
No Treatment	16	-6.55	**0.000**	-6.40	**0.000**	-2.67	**0.010**	-6.67	**0.000**

Table 27 ANOVA results for soil stability responses from experiment treatment field plots in gypsiferous soil in the eastern Mojave Desert, analyzing the effects of the main treatments, biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Source	df	F	P
BSC	13	15.96	**0.001**
TS	13	5.76	**0.030**
WS	13	1.33	0.270
AMDU	13	0.14	0.811
BSCxTS	13	2.12	0.153
BSCxWS	13	1.37	0.264
BSCxAMDU	13	0.02	0.980
TSxWS	13	2.18	0.148
TSxAMDU	13	0.08	0.880
WSxAMDU	13	0.84	0.394
BSCxTSxWS	13	2.04	0.159
BSCxTSxAMDU	13	0.01	0.985
BSCxWSxAMDU	13	0.16	0.804
TSxWSxAMDU	13	0.75	0.423
BSCxTSxWSxAMDU	13	1.11	0.321

Table 28 Mean soil stability for experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert. The main treatments include biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU).

Treatment	Soil stability
BSC	6
TS	4
WS	2
AMDU	1
BSCxTS	5
BSCxWS	5
BSCxAMDU	5
TSxWS	2
TSxAMDU	3
WSxAMDU	2
BSCxTSxWS	5
BSCxTSxAMDU	6
BSCxWSxAMDU	6
TSxWSxAMDU	3
BSCxTSxWSxAMDU	5
No Treatment	1
Undisturbed	6

Table 29 Comparisons of soil stability ratings between experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert, analyzing the effects of the main treatments, biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

Treatment		F	P
BSC	Undisturbed	0.07	0.913
TS	Undisturbed	2.49	*0.100*
WS	Undisturbed	9.77	**0.003**
AMDU	Undisturbed	17.46	**0.001**
BSCxTS	Undisturbed	0.32	0.677
BSCxWS	Undisturbed	0.58	0.509
BSCxAMDU	Undisturbed	0.39	0.630
TSxWS	Undisturbed	7.15	**0.007**
TSxAMDU	Undisturbed	5.64	**0.016**
WSxAMDU	Undisturbed	9.77	**0.003**
BSCxTSxWS	Undisturbed	0.24	0.692
BSCxTSxAMDU	Undisturbed	0.03	0.963
BSCxWSxAMDU	Undisturbed	0.03	0.963
TSxWSxAMDU	Undisturbed	3.26	*0.057*
BSCxTSxWSxAMDU	Undisturbed	0.21	0.768
No Treatment	Undisturbed	20.20	**0.001**

Table 30 ANOVA results for nitrate (NO_3-N) and ammonium (NH_4-N) concentration responses of surface soil samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert, analyzing the effects of the main treatments, biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU), and their two-way, three-way, and four-way interactions. Significant values highlighted in bold, alpha 0.05.

		NO3-N		NH4-N	
Source	df	F	P	F	P
BSC	69	0.81	0.3828	5.66	**0.0301**
TS	69	10.63	**0.0049**	0.08	0.7789
WS	69	0.09	0.7720	9.01	**0.0085**
AMDU	69	5.85	**0.0278**	0.01	0.9129
BSCxTS	69	0.20	0.6625	0.00	0.9801
BSCxWS	69	0.87	0.3637	0.29	0.5951
BSCxAMDU	69	0.69	0.4183	1.25	0.2793
TSxWS	69	1.44	0.2470	1.36	0.2602
TSxAMDU	69	8.72	**0.0093**	4.60	**0.0476**
WSxAMDU	69	5.55	**0.0315**	1.30	0.2710
BSCxTSxWS	69	3.82	*0.0684*	0.67	0.4236
BSCxTSxAMDU	69	0.09	0.7707	3.40	*0.0836*
BSCxWSxAMDU	69	0.16	0.6915	0.97	0.3403
TSxWSxAMDU	69	1.45	0.2459	0.84	0.3729
BSCxTSxWSxAMDU	69	1.62	0.2209	0.62	0.4417
No treatment	69	1.35	0.181	-0.98	0.330

Table 31 Mean nitrate (NO_3-N) and ammonium (NH_4-N) concentrations in parts per million (ppm) from experimental treatment field plots and undisturbed field plots in gypsiferous soil in the eastern Mojave Desert. Main treatments include biological soil crust (BSC) inoculation, topsoil (TS), wood shavings (WS), and *Ambrosia* (AMDU).

Treatments	NO_3-N ppm	NH_4-N ppm
BSC	0.52	0.70
TS	0.17	0.69
WS	0.91	0.40
AMDU	0.51	0.91
BSCxTS	0.41	1.14
BSCxWS	2.55	0.45
BSCxAMDU	0.39	1.36
TSxWS	0.27	0.90
TSxAMDU	0.42	0.87
WSxAMDU	0.15	0.31
BSCxTSxWS	0.19	0.83
BSCxTSxAMDU	0.47	0.87
BSCxWSxAMDU	0.26	1.04
TSxWSxAMDU	0.19	0.33
BSCxTSxWSxAMDU	0.17	0.62
No Treatment	0.86	0.98
Undisturbed	0.37	1.30

Table 32 ANOVA results for the light-adapted chlorophyll fluorescence responses (F'_v/F'_m) from the lichen *Collema* over time during an initial hydration period after two years of storage with treatments of either 6% or 10% mannitol or glucose as the initial hydration event. Significant values highlighted in bold, alpha 0.05.

Time (Hours)	df	F'_v/F'_m F	P
2	4	1.48	0.245
6	4	0.80	0.537
12	4	3.48	0.026
24	4	5.42	**0.004**
48	4	5.80	**0.003**

Table 33 ANOVA results for the light-adapted chlorophyll fluorescence (F'_v/F'_m) responses from the lichen *Collema* over time after two years of storage and that had been treated with either 6 % or 10 % mannitol or glucose after 48 hours of hydration with water.

Time (Hours)	df	F'_v/F'_m F	P
2	4	1.45	0.255
12	4	2.58	*0.068*
18	4	2.71	*0.059*
30	4	2.39	*0.085*

Table 34 ANOVA results for the light-adapted chlorophyll fluorescence (F'_v/F'_m) responses from the lichen *Collema* over time during a second hydration period after a treatment with either 6 % or 10 % mannitol or glucose as an initial hydration event during an initial hydration period after two years of storage.

Time (Hours)	df	F'_v/F'_m F	P
2	4	1.32	0.298
6	4	1.20	0.343
12	4	1.09	0.390
24	4	1.40	0.270

Table 35 ANOVA results for the light-adapted chlorophyll fluorescence (F'_v/F'_m) responses from the lichen *Collema* over time during a second hydration event after treatment with either 6 % or 10 % mannitol or glucose after a 48 hours hydration period with just water after two years of storage.

Time (Hours)	df	F'_v/F'_m F	P
2	4	2.27	*0.099*
6	4	2.28	*0.099*
12	4	2.55	*0.073*
24	4	0.80	0.538

Table 36 Macroscopically observed cyanobacteria mean cover eight months after application of slurry treatment and glucose and/or nutrient solution additions in the laboratory on autoclaved native gypsiferous soils acquired from disturbed gypsiferous topsoil piles within Lake Mead National Recreation Area.

Treatment	Mean Cover Cyanobacteria
Control	0
Slurry	30
Slurry & 10% Glucose	52
Slurry & Nutrient	29
Slurry, Glucose, & Nutrient	69

Table 37 ANOVA results for macroscopically observed cyanobacteria cover responses eight months after application of slurry treatment and glucose and/or nutrient solution additions in the laboratory on autoclaved native gypsiferous soils acquired from disturbed gypsiferous topsoil piles within Lake Mead National Recreation Area. Significant values highlighted in bold, alpha 0.05.

Effect	df	F	P
glucose	24	25.4	**0.000**
nutrient	24	1.5	0.227
glucose*nutrient	24	2.4	0.138

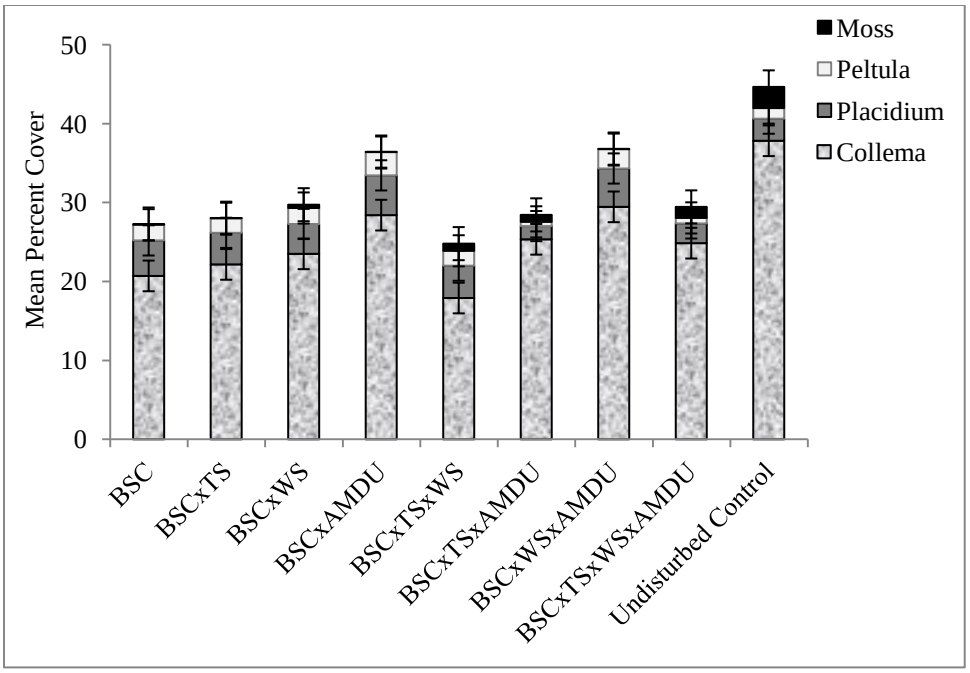


Figure 5 Mean cover with standard error of the lichens *Collema*, *Placidium,* and *Peltula,* and total moss from experimental treatment field plots with biological soil crust inoculants and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

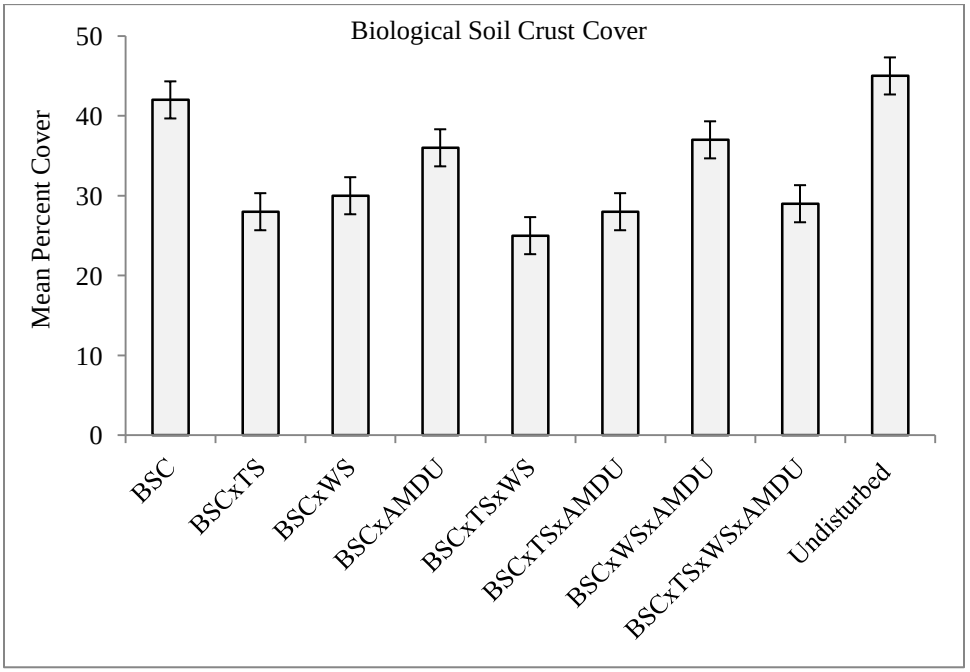


Figure 6 Mean cover with standard error of biological soil crust from experimental treatment field plots with biological soil crust inoculants and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

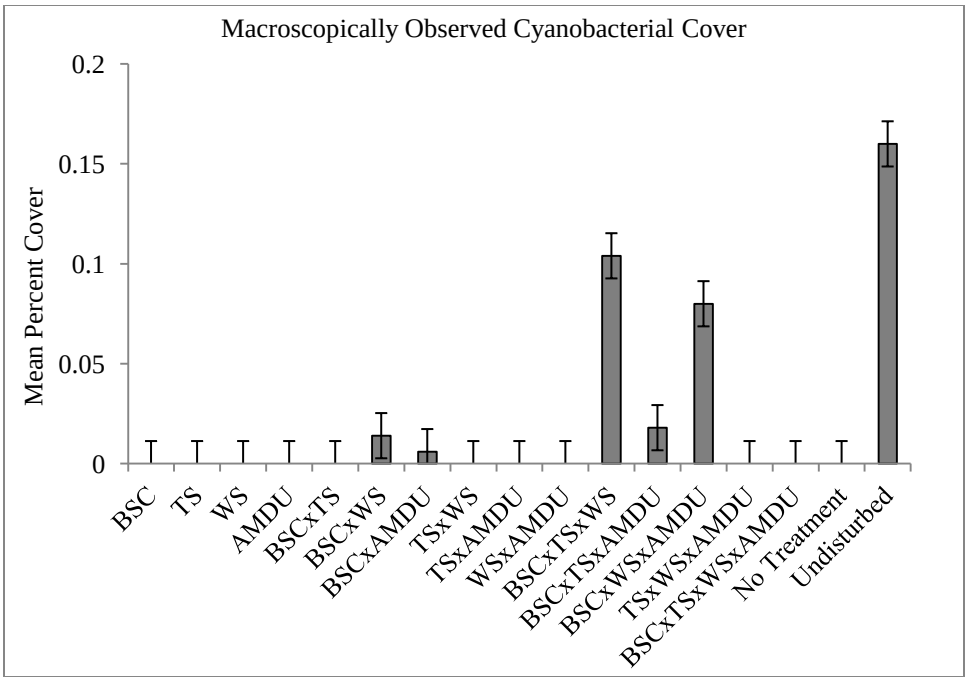


Figure 7 Mean cover with standard error of macroscopically observed cyanobacteria from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present. *Signifies a significant difference between topsoil treatments within AMDU treatment.

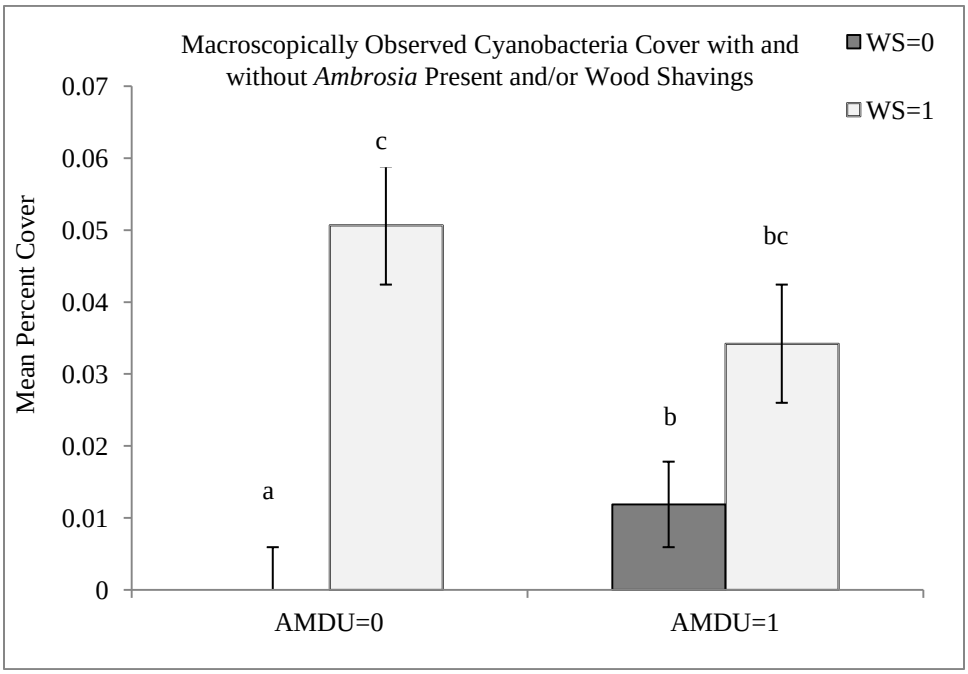


Figure 8 The effects on macroscopically observed cyanobacteria cover of a two-way interaction between the main treatments wood shavings (WS) and *Ambrosia* (AMDU) presence in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Bonferroni adjusted mean values reported. Statistically significant differences denoted by letters.

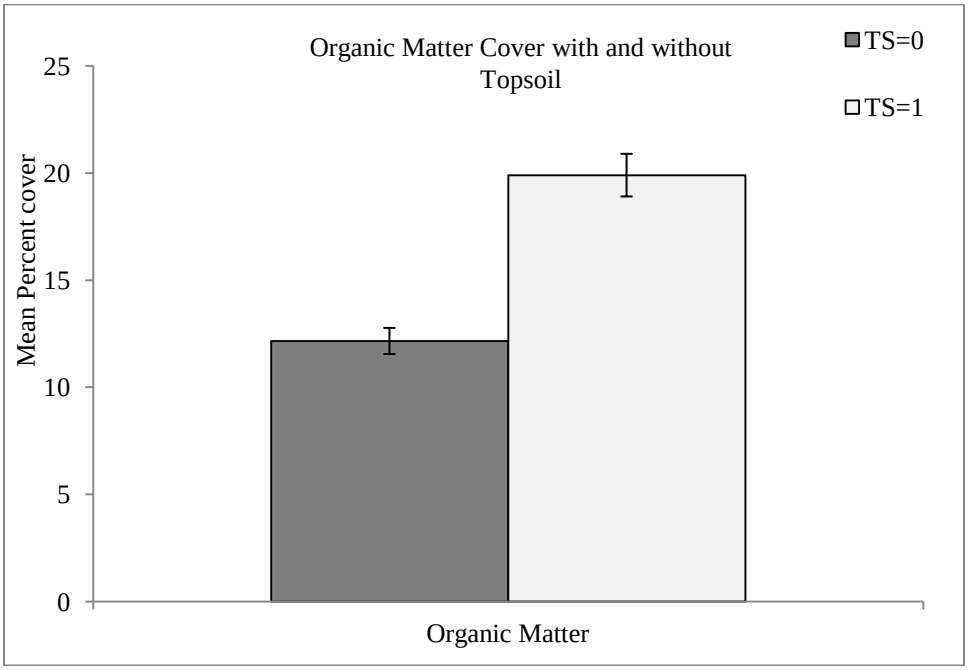


Figure 9 Mean cover with standard error of organic matter with and without topsoil (TS) treatments in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

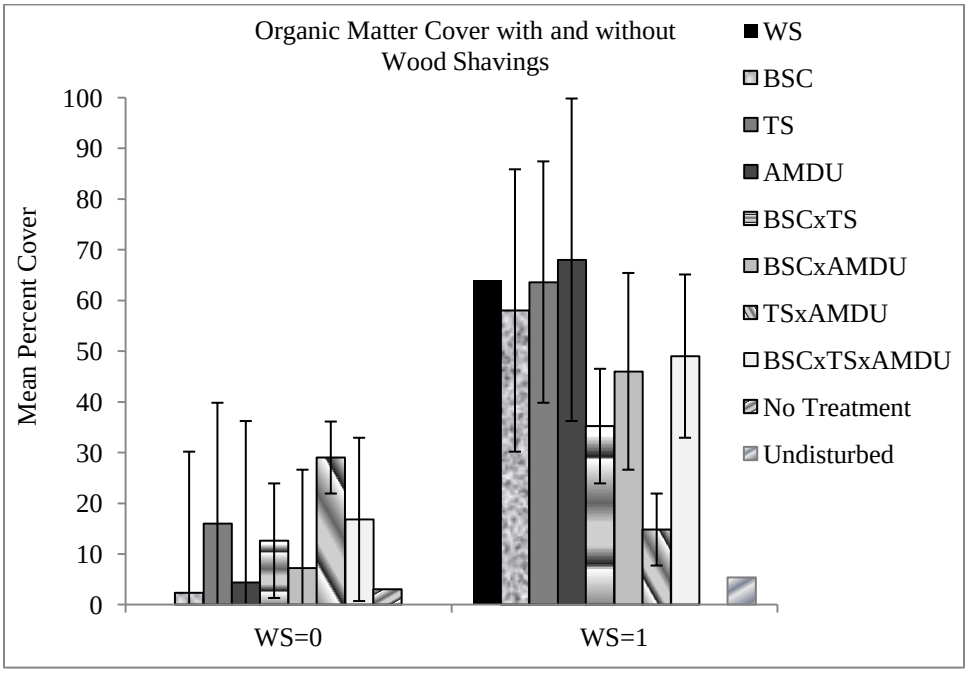


Figure 10 Mean cover with standard error of organic matter with and without the addition of the main treatment wood shavings (WS) in experimental treatment field plots and in undisturbed plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

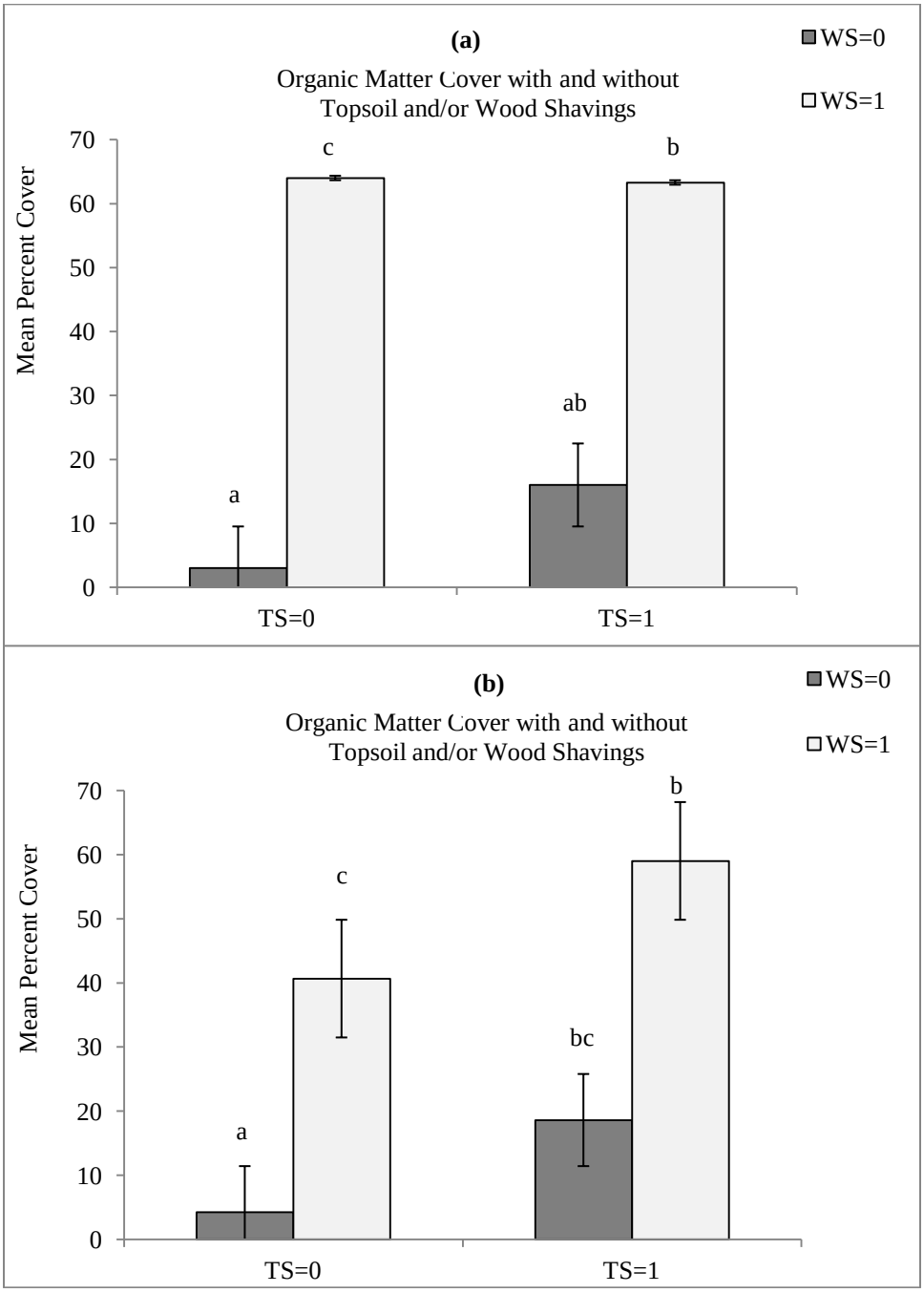


Figure 11 The effects on organic matter from the two-way interaction between the main treatments wood shavings (WS) and topsoil (TS) in experimental treatment field plots **(a)** with only wood shavings and topsoil treatment combinations and **(b)** in all experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Statistically significant differences denoted by letters.

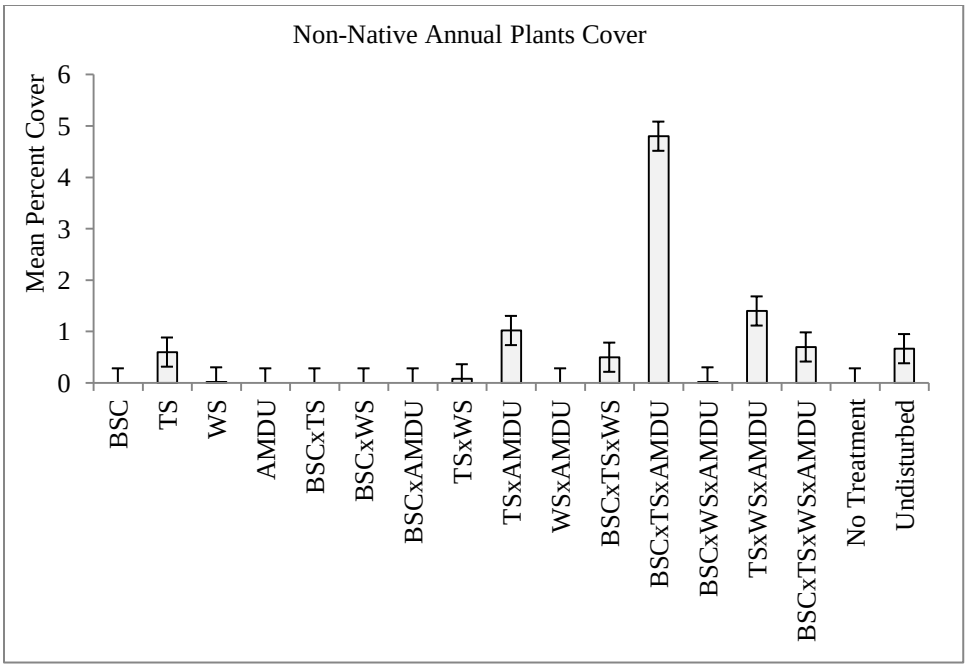


Figure 12 Mean cover with standard error for non-native annual plants in experimental field treatment plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

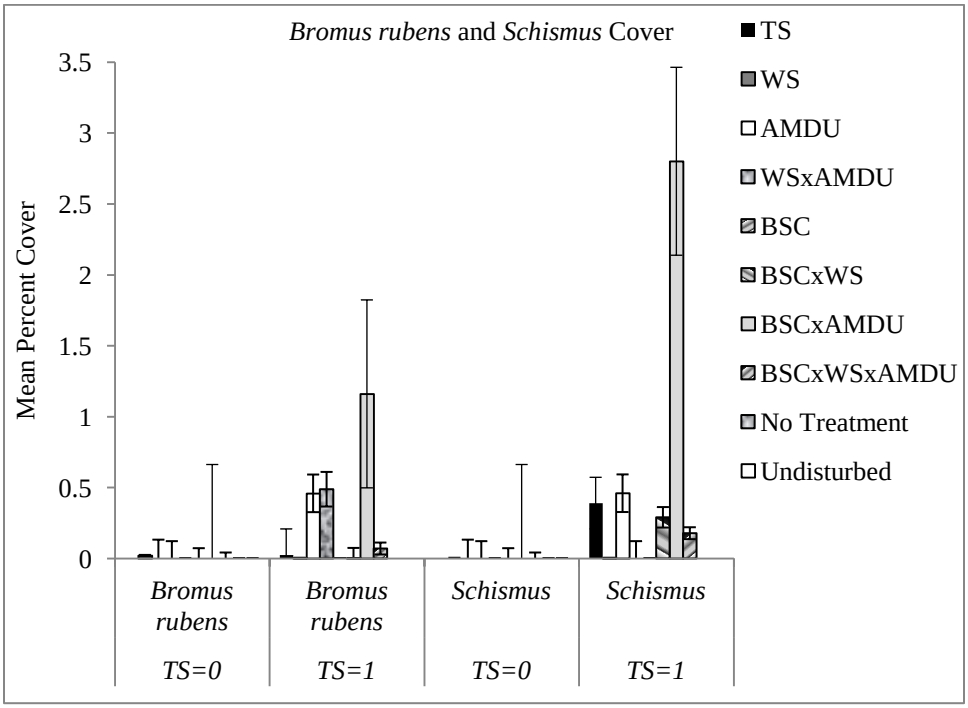


Figure 13 Mean cover with standard error of the non-native annual graminoids *Bromus rubens* and *Schismus* spp. for experimental field and undisturbed treatment plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

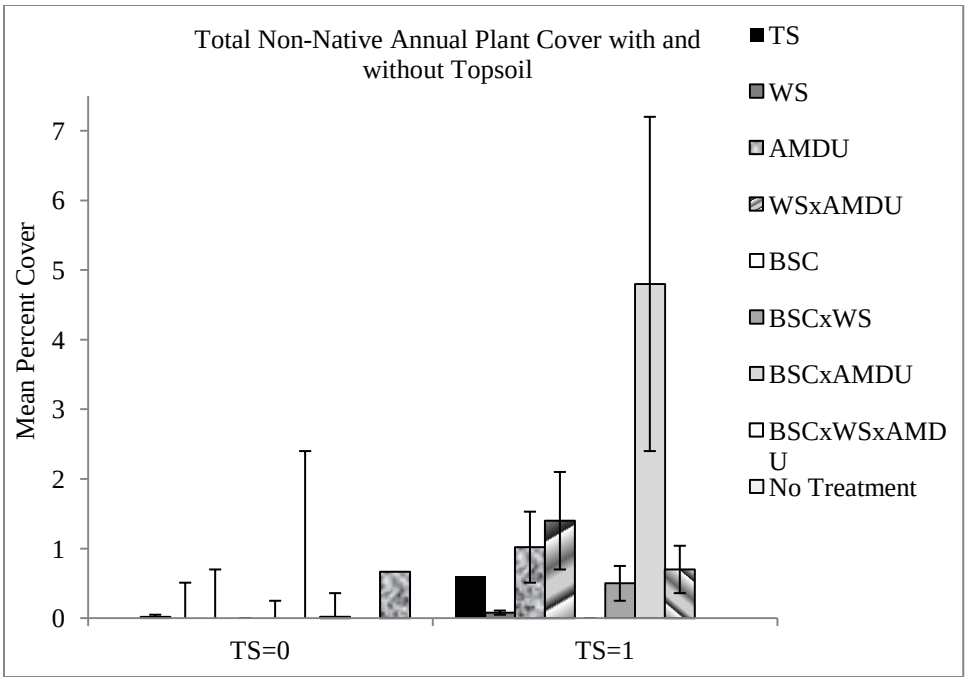


Figure 14 Non-native annual plant cover with standard error with and without topsoil (TS) treatments in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

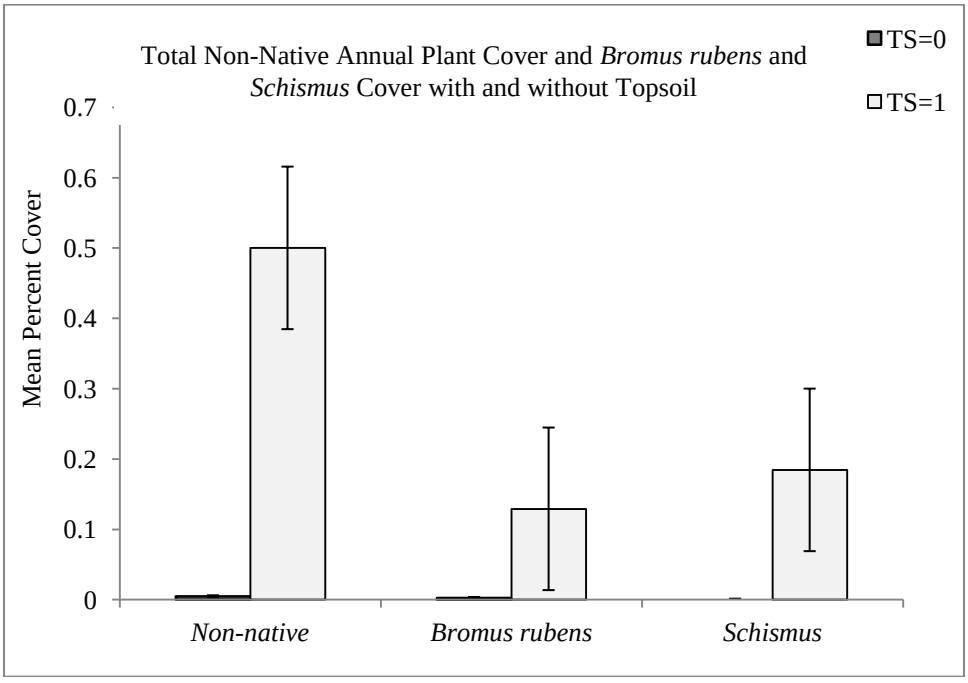


Figure 15 Non-native annual plant cover with standard error and specifically *Bromus rubens* and *Schismus* cover with and without the addition of topsoil (TS) treatment in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

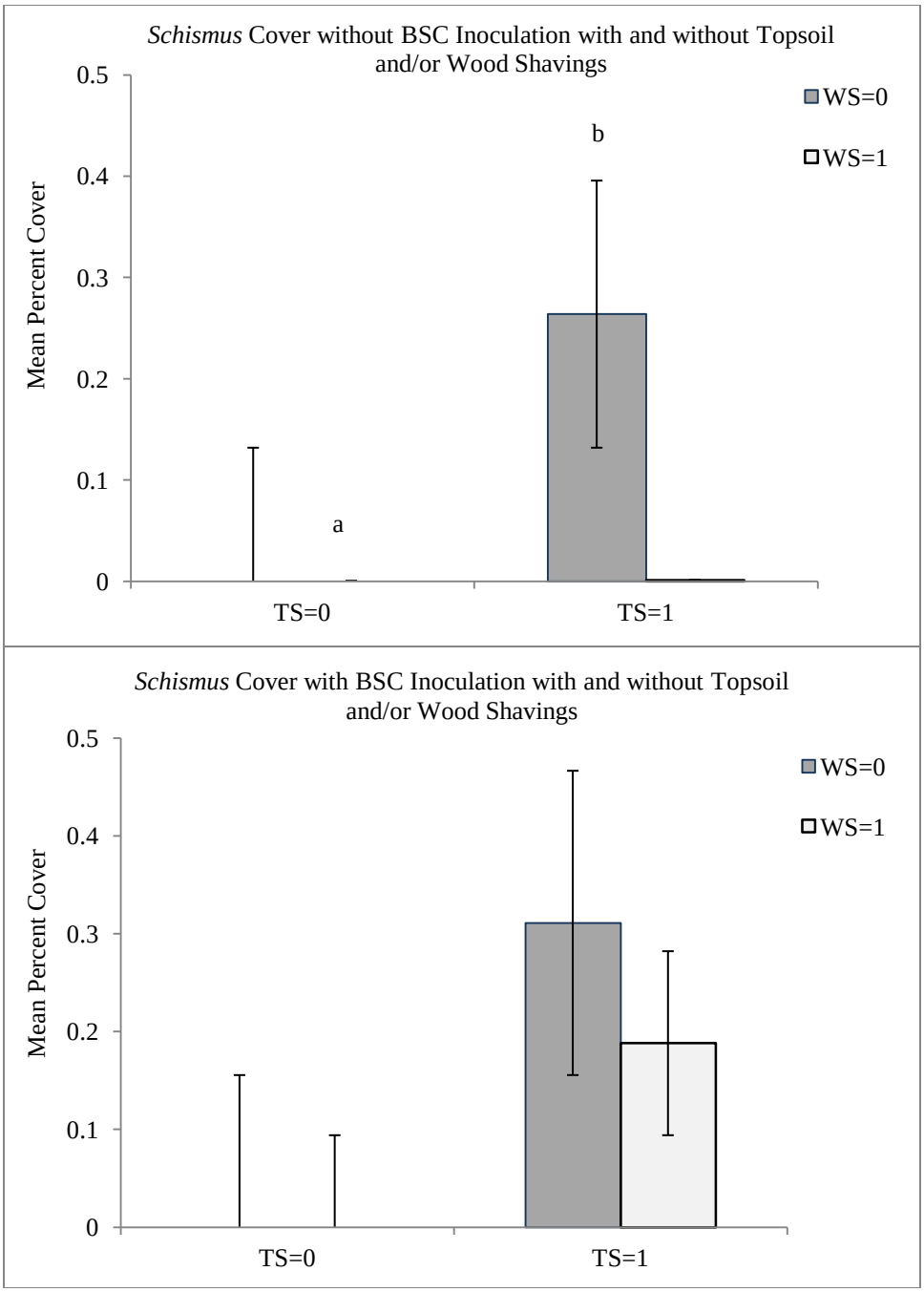


Figure 16 The effects on the cover of the non-native annual graminoid *Schismus* of the three-way interaction between biological soil crust inoculation (BSC), topsoil (TS), and wood shavings (WS) in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Statistically significant differences denoted by letters

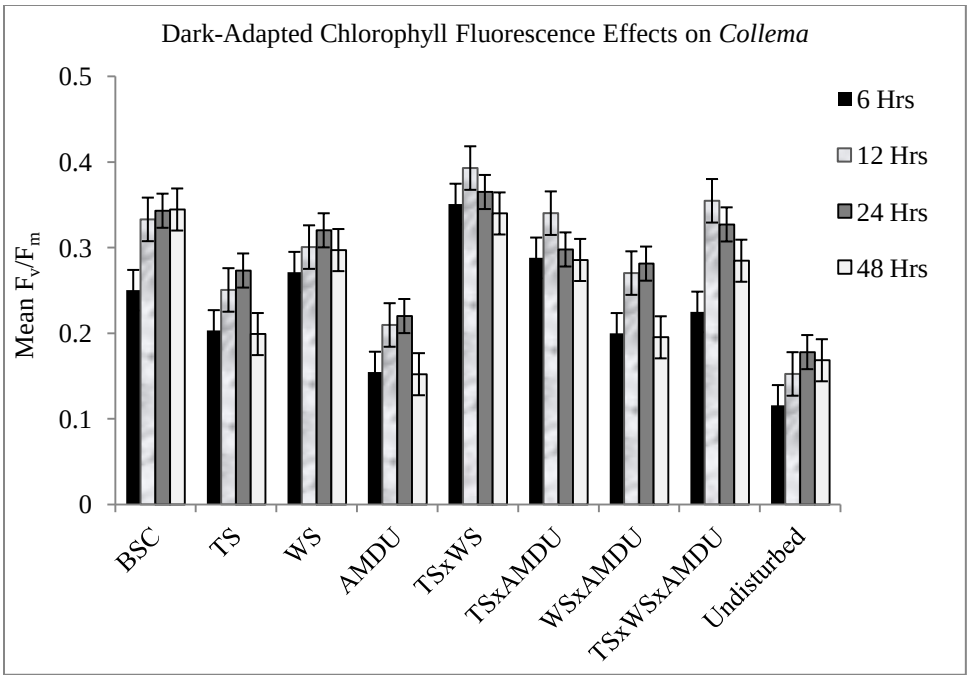


Figure 17 Mean dark-adapted chlorophyll fluorescence (F_v/F_m) with standard error at 6, 12, 24, and 48 hours after hydration for the lichen *Collema* sampled from experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

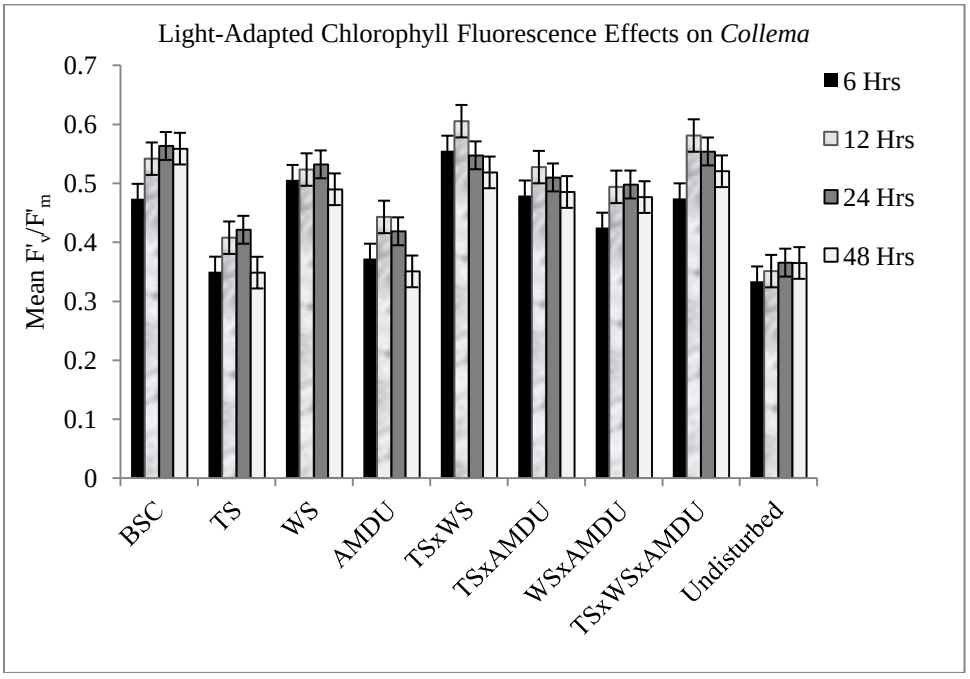


Figure 18 Mean light-adapted chlorophyll fluorescence (F'_v/F'_m) with standard error at 6, 12, 24, and 48 hours after hydration for the lichen *Collema* sampled from experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

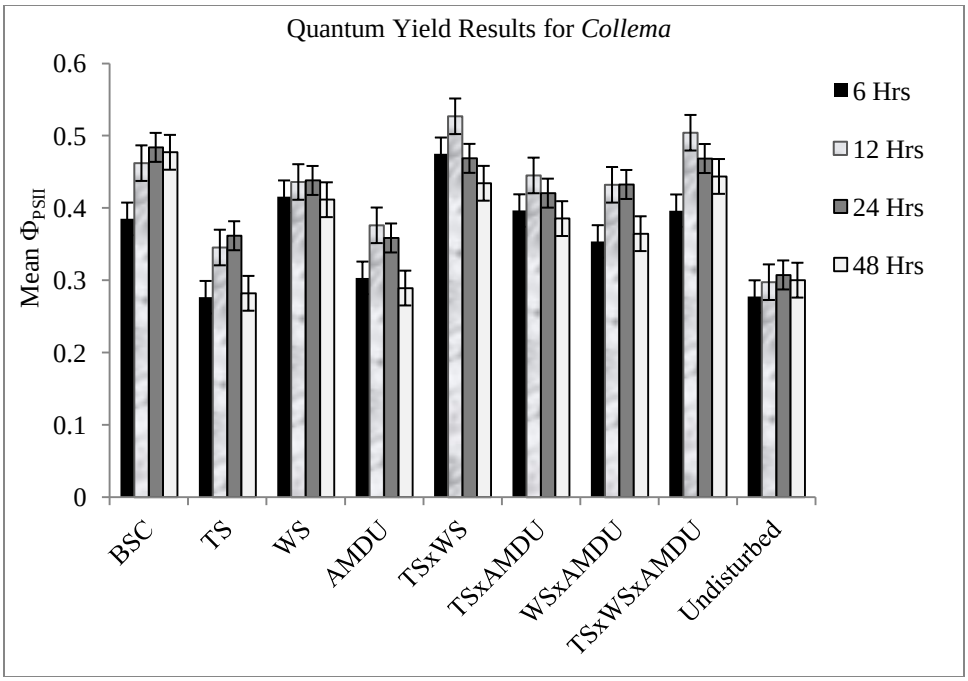


Figure 19 Mean chlorophyll fluorescence actual quantum yield (Φ_{PSII}) with standard error at 6, 12, 24, and 48 hours after hydration for the lichen *Collema* sampled from experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

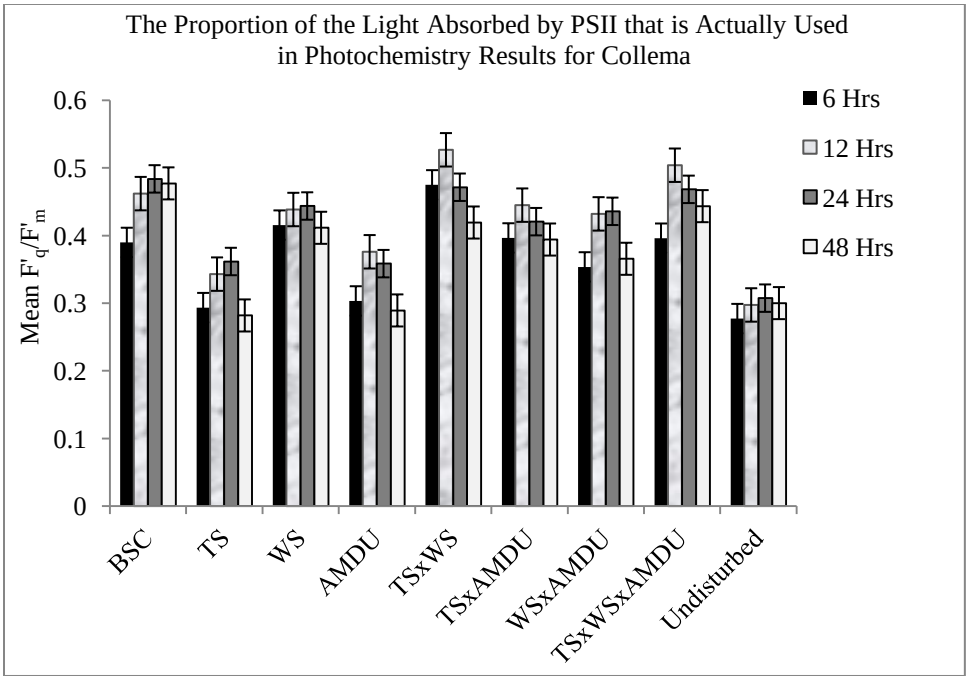


Figure 20 Mean values of the proportion of the light absorbed by PSII that is actually used in photochemistry (F'_q/F'_m) with standard error at 6, 12, 24, and 48 hours after hydration for the lichen *Collema* sampled from experimental treatment field plots and undisturbed plots in gypsiferous soil in the eastern Mojave Desert.

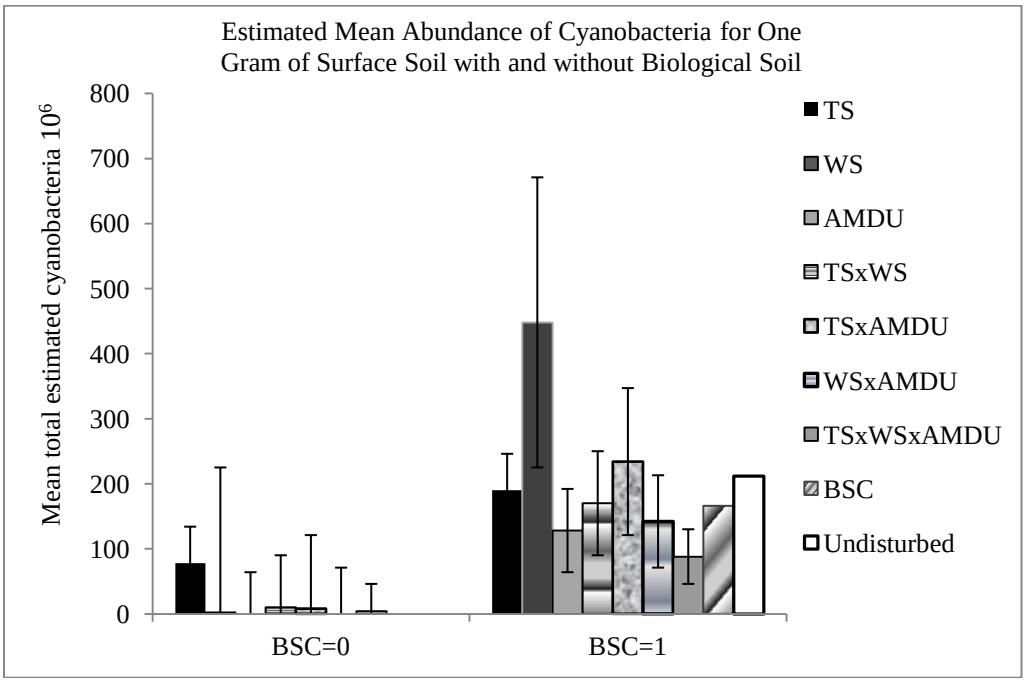


Figure 21 Estimated mean abundance with standard error of cyanobacteria for one gram of surface soil in experimental treatment field plots with and without biological soil crust inoculants and undisturbed plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

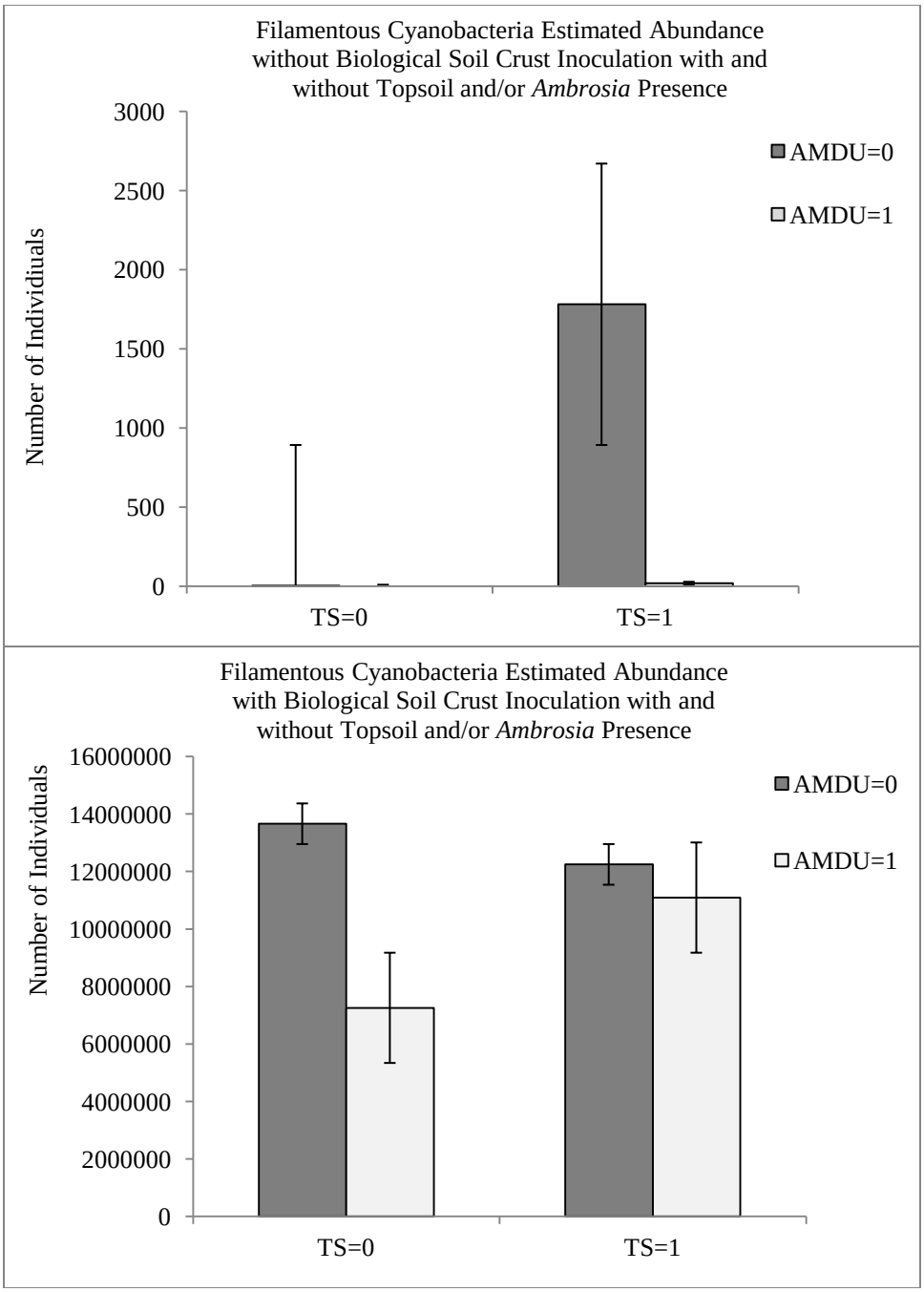


Figure 22 The effects on the estimated mean abundance of filamentous cyanobacteria from one-way, two-way, and three-way treatment interactions between biological soil crust (BSC) inoculation, topsoil (TS), and *Ambrosia* (AMDU) presence in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present.

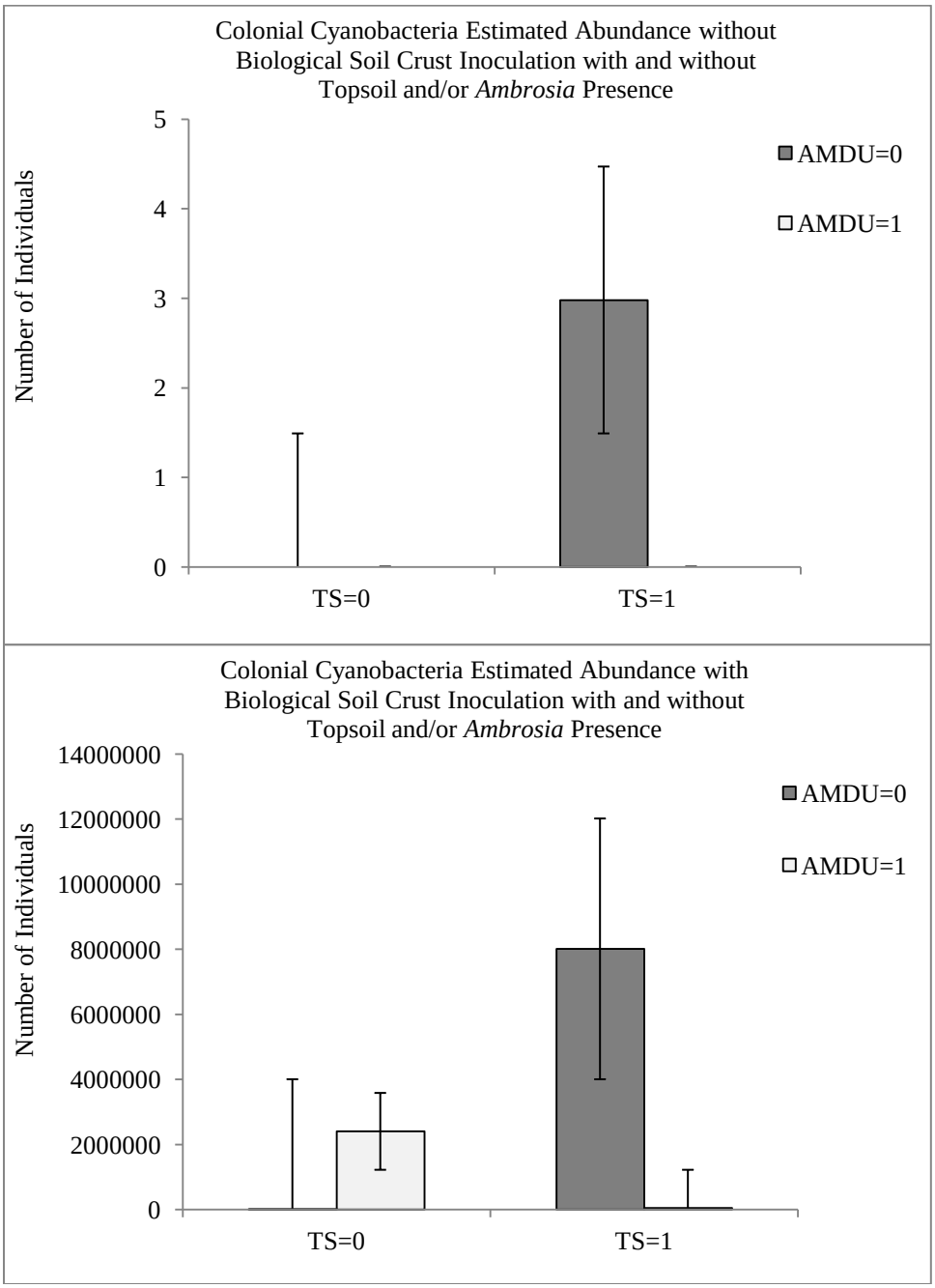


Figure 23 The effects on the estimated mean abundance of colonial cyanobacteria from one-way, two-way, and three-way treatment interactions between biological soil crust (BSC) inoculation, topsoil (TS), and *Ambrosia* (AMDU) presence in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present.

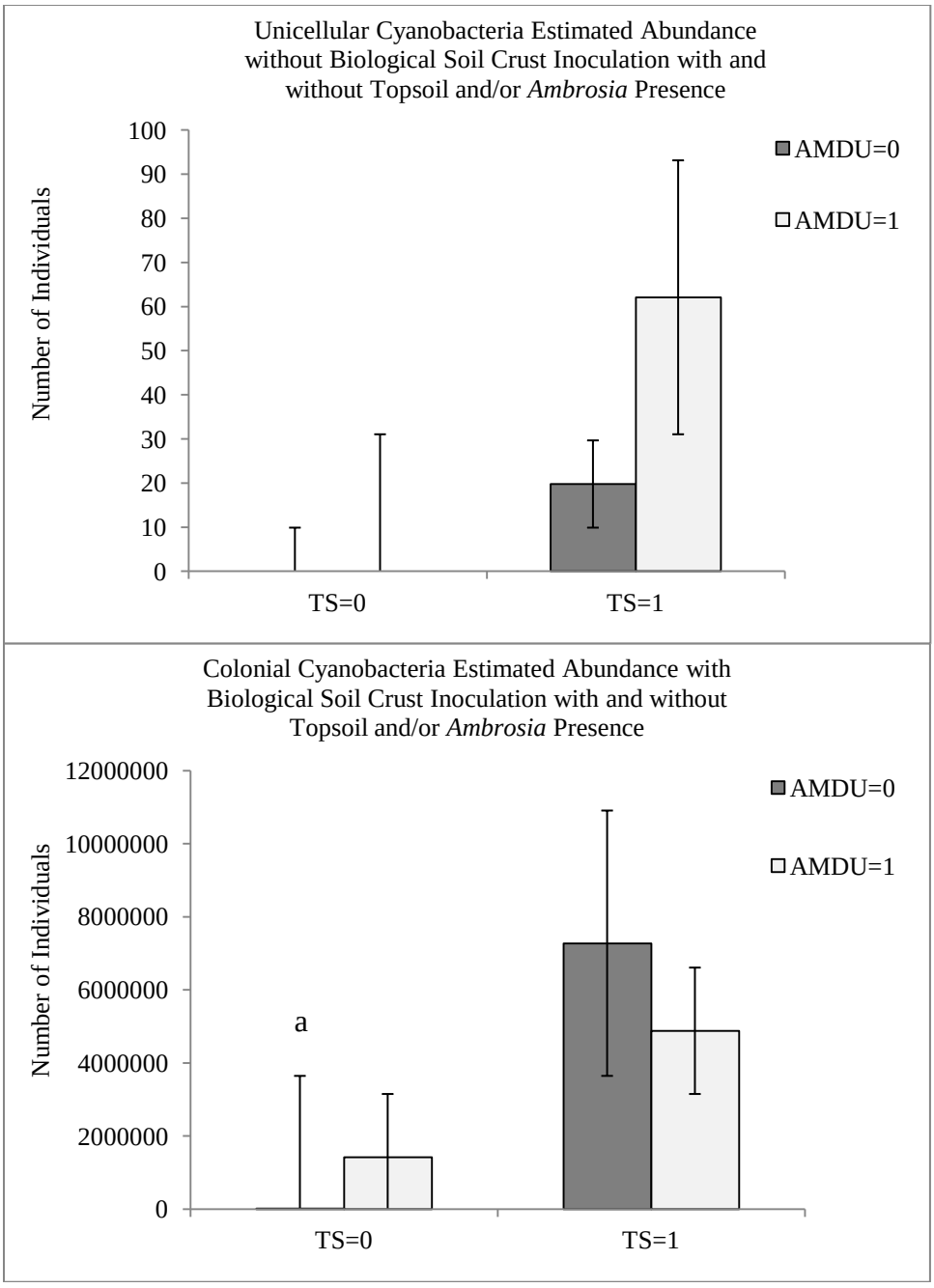


Figure 24 The effects on the estimated mean abundance of unicellular cyanobacteria from one-way, two-way, and three-way treatment interactions between biological soil crust (BSC) inoculation, topsoil (TS), and *Ambrosia* (AMDU) presence in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present.

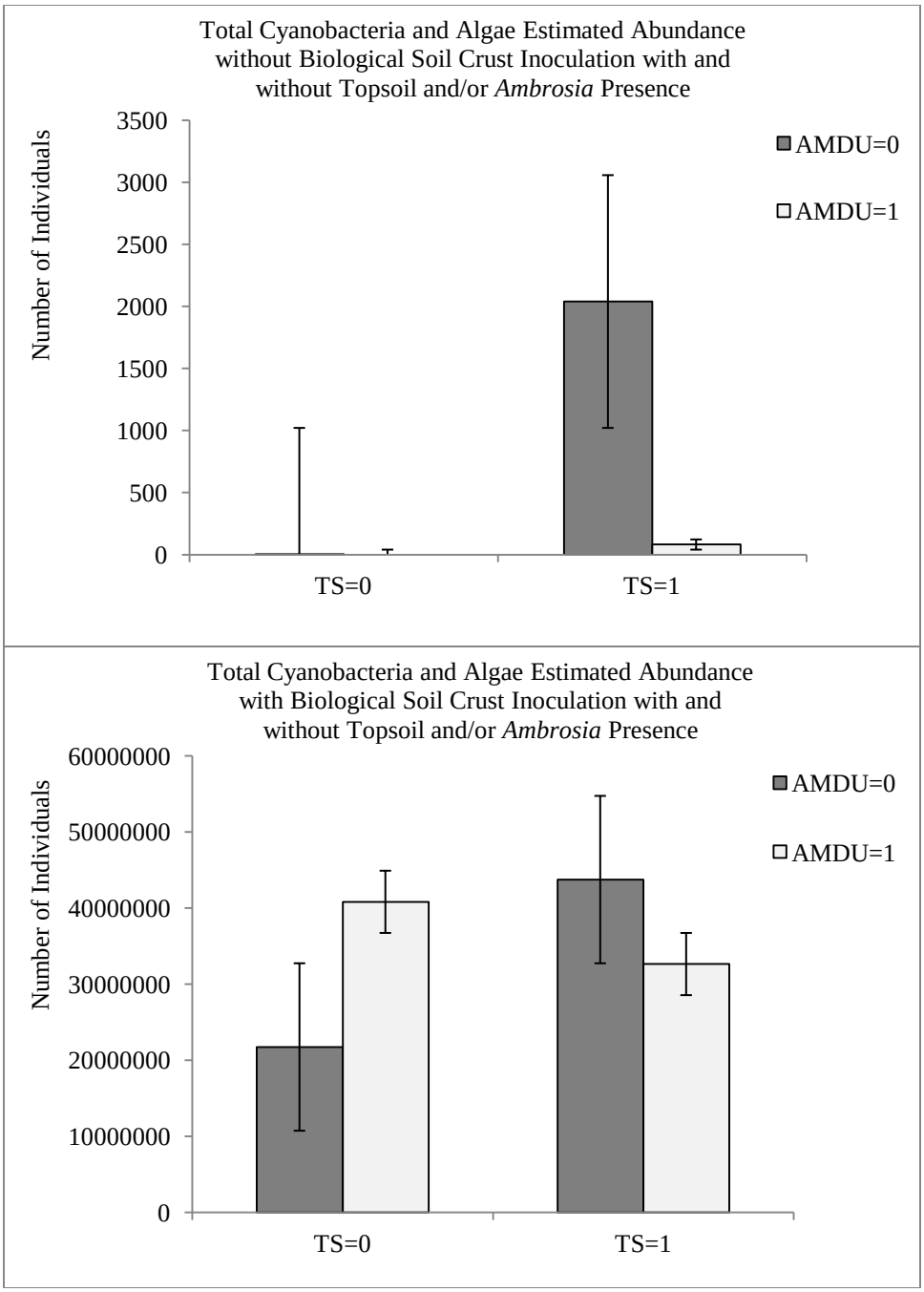


Figure 25 The effects on the estimated mean abundance of total cyanobacteria and algae from one-way, two-way, and three-way treatment interactions between biological soil crust (BSC) inoculation, topsoil (TS), and *Ambrosia* (AMDU) presence in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present.

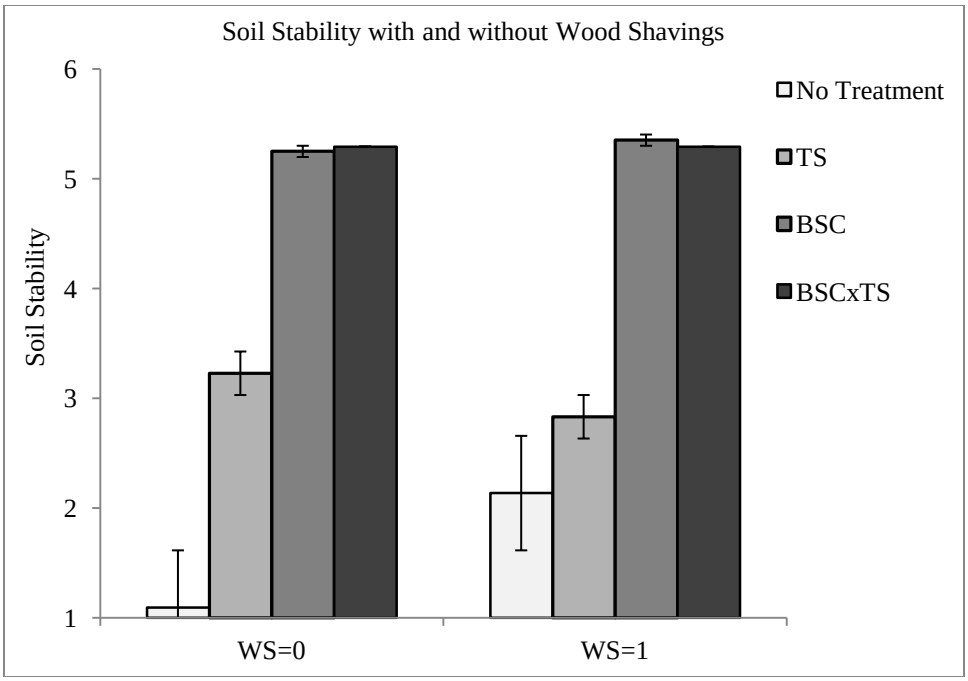


Figure 26 Mean soil stability (ordinal scale 1-6) with standard error for main treatments and two-way and three-way interactions between biological soil crust (BSC) inoculation, topsoil (TS), and wood shavings (WS) in experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

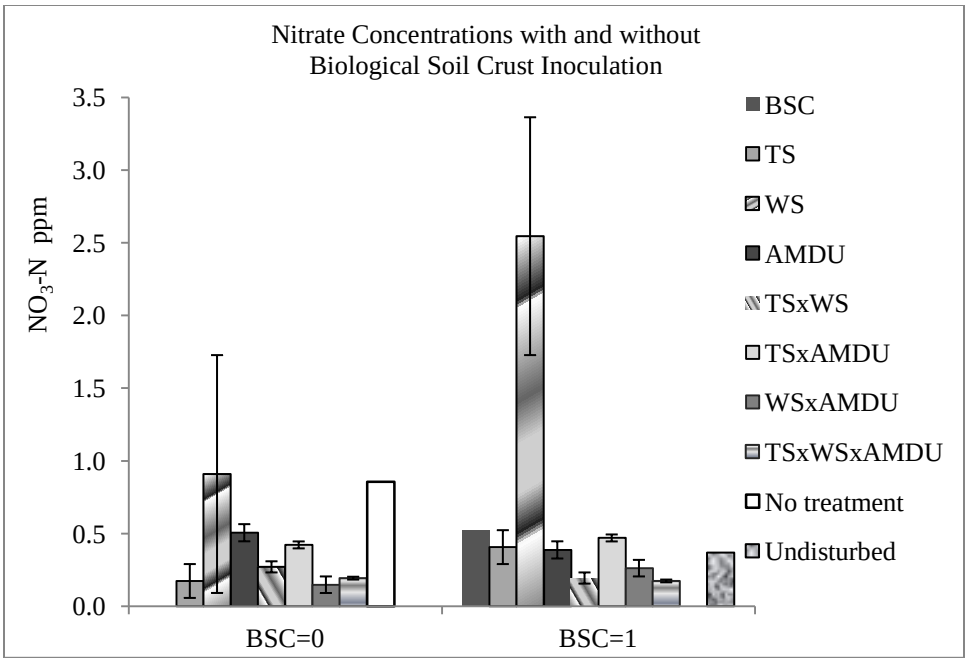


Figure 27 Mean nitrate concentrations in parts per million (ppm) with standard error for samples from undisturbed plots and experimental treatment field plots with and without biological soil crust inoculation in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

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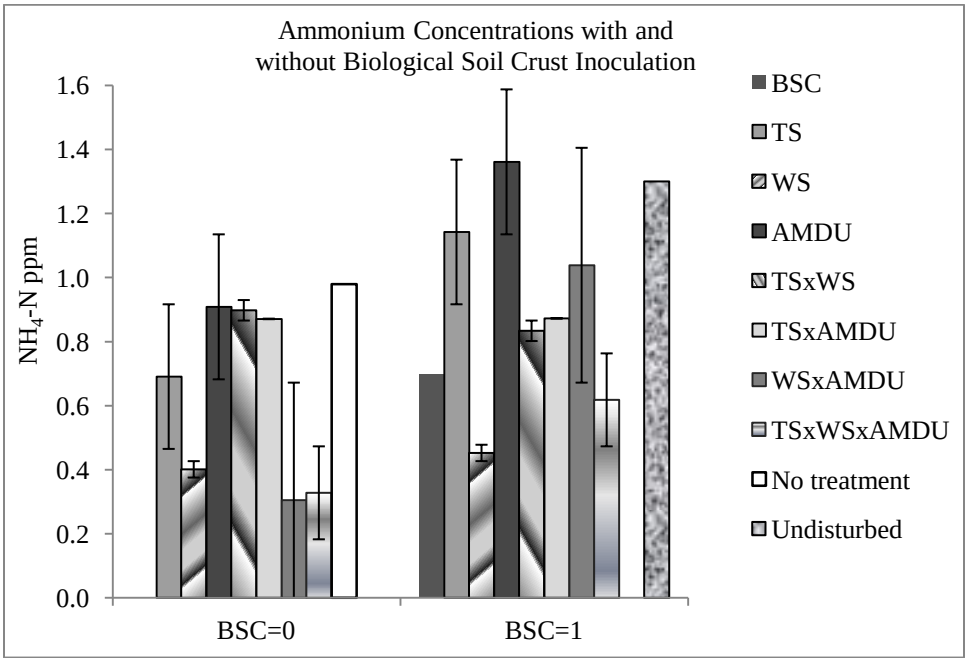


Figure 28 Mean ammonium concentrations in parts per million (ppm) with standard error for samples from undisturbed plots and experimental treatment field plots with and without biological soil crust inoculation in gypsiferous soil in the eastern Mojave Desert; 0 = absent and 1 = present.

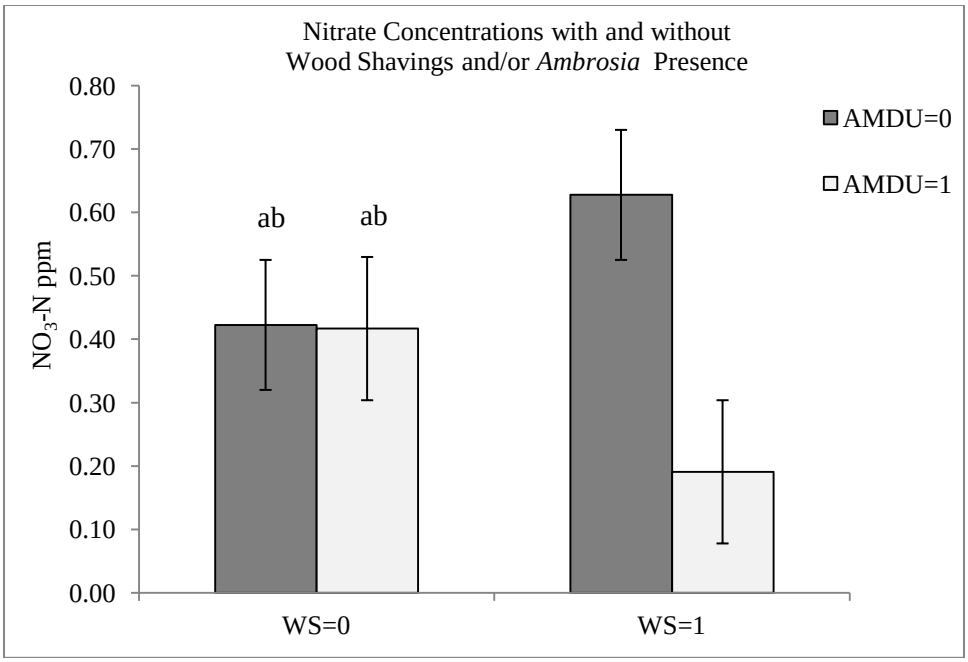


Figure 29 The effects of the two-way interaction between wood shavings (WS) and *Ambrosia* (AMDU) on nitrate concentrations in parts per million (ppm) in samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Letters denote significant differences, alpha 0.05.

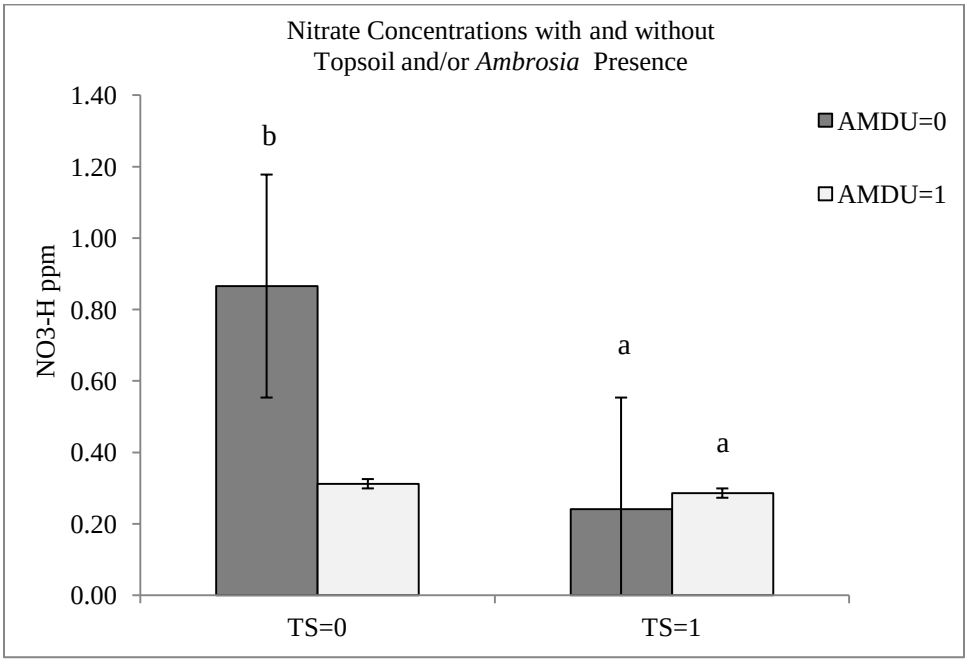


Figure 30 The effects of the two-way interaction between topsoil (TS) and *Ambrosia* (AMDU) on nitrate concentrations in parts per million (ppm) in samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Letters denote significant differences, alpha 0.05.

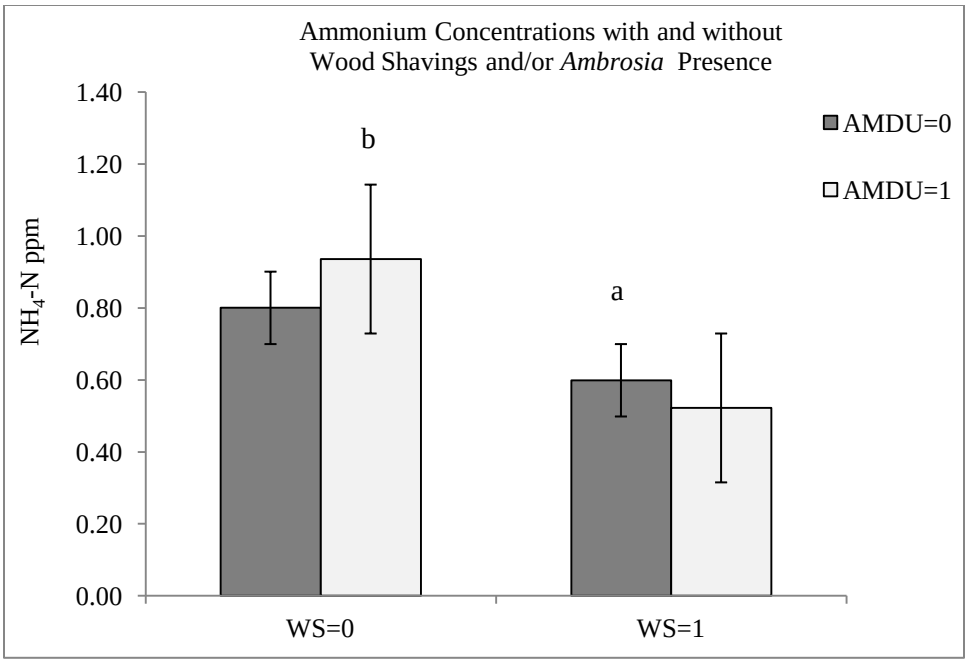


Figure 31 The effects of the two-way interaction between wood shavings (WS) and *Ambrosia* (AMDU) on ammonium concentrations in parts per million in samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Letters denote significant differences, alpha 0.05.

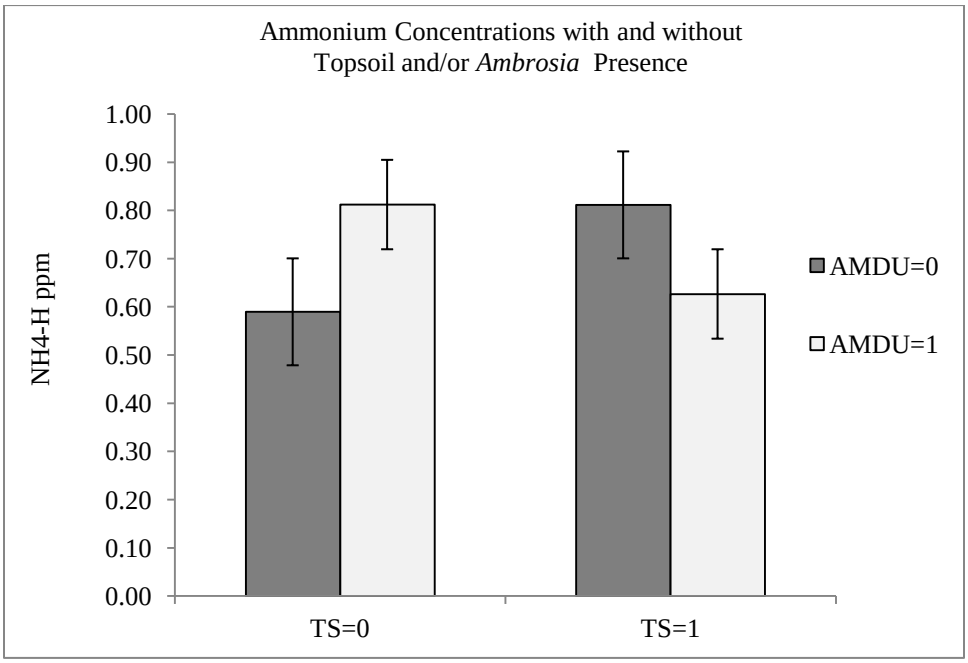


Figure 32 The effects of the two-way interaction between topsoil (TS) and *Ambrosia* (AMDU) on ammonium concentrations in parts per million in samples from experimental treatment field plots in gypsiferous soil in the eastern Mojave Desert. Standard error shown; 0 = absent and 1 = present. Letters denote significant differences, alpha 0.05.

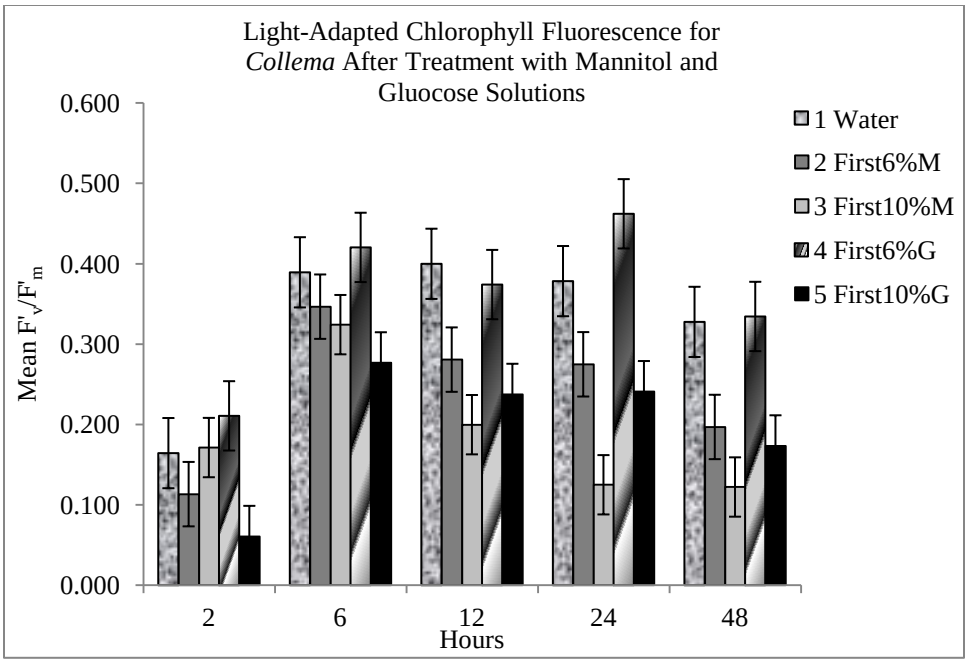


Figure 33 Mean light-adapted chlorophyll fluorescence (F'_v/F'_m) with standard error over time during an initial hydration event after two years of storage with the treatments of either 6% or 10% mannitol (M) or glucose (G) on the lichen *Collema* collected from gypsiferous soil in the eastern Mojave Desert.

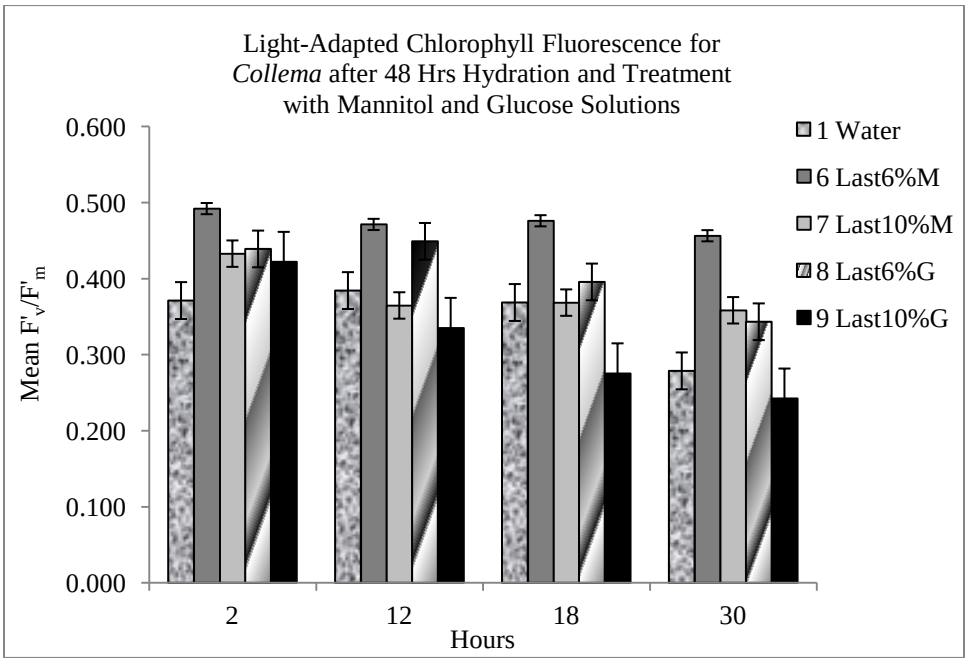


Figure 34 Mean light-adapted chlorophyll fluorescence (F'_v/F'_m) with standard error over time after two years of storage and with treatments of either 6% or 10% mannitol (M) or glucose (G) after 48 hours of hydration with water on the lichen *Collema* collected from gypsiferous soil in the eastern Mojave Desert.

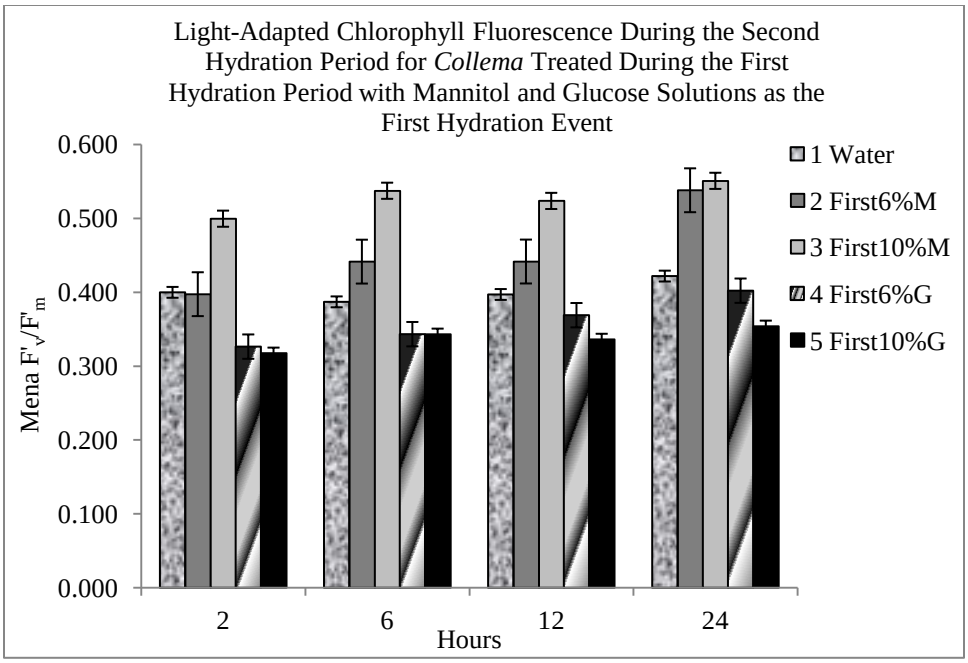


Figure 35 Mean light-adapted chlorophyll fluorescence (F'_v/F'_m) with standard error over time during a second hydration period after during the first hydration period the initial hydration event was with either 6% or 10% mannitol (M) or glucose (G) on the lichen *Collema* collected from gypsiferous soil in the eastern Mojave Desert.

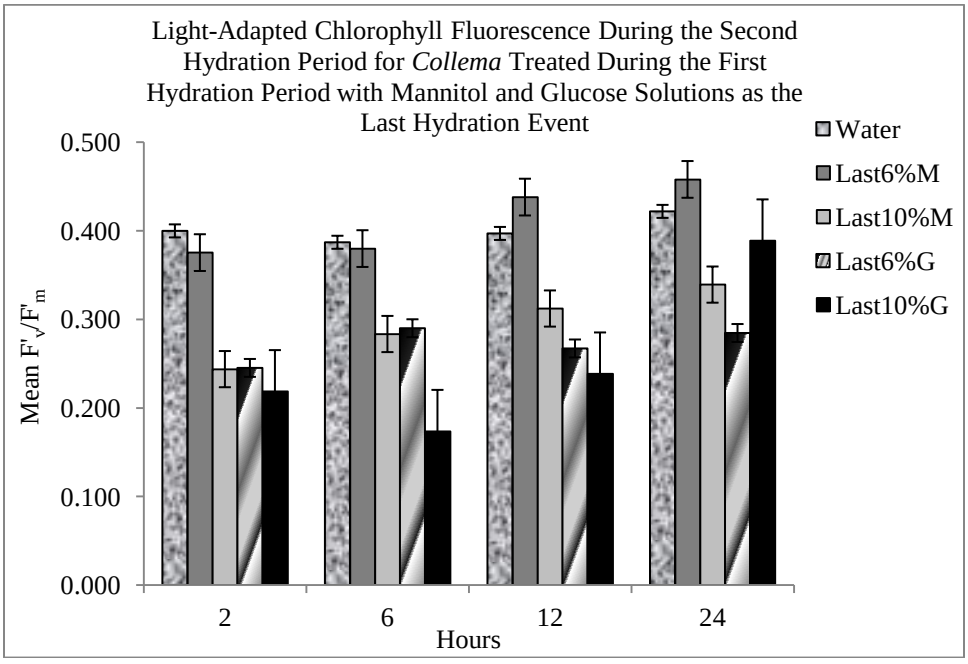


Figure 36 Mean light-adapted chlorophyll fluorescence (F'_v/F'_m) with standard error over time during a second hydration period after during the first hydration period the last hydration event was with either 6% or 10% mannitol (M) or glucose (G) on the lichen *Collema* collected from gypsiferous soil in the eastern Mojave Desert.

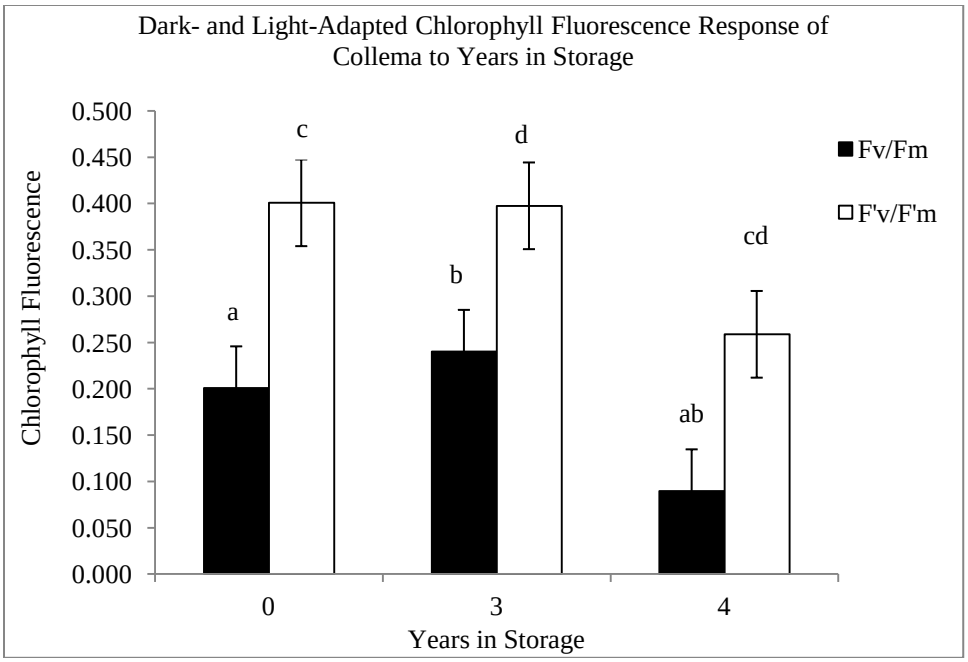


Figure 37 Dark- (F_v/F_m) and light-adapted (F'_v/F'_m) chlorophyll fluorescence responses with standard error from the lichen *Collema* collected August 2012 (0 years) from undisturbed gypsiferous biological soil crust communities in the eastern Mojave Desert and from samples left in storage for 3 and 4 years collected in 2008 from gypsiferous soil in the eastern Mojave Desert. Letters denote significant differences, alpha 0.05.

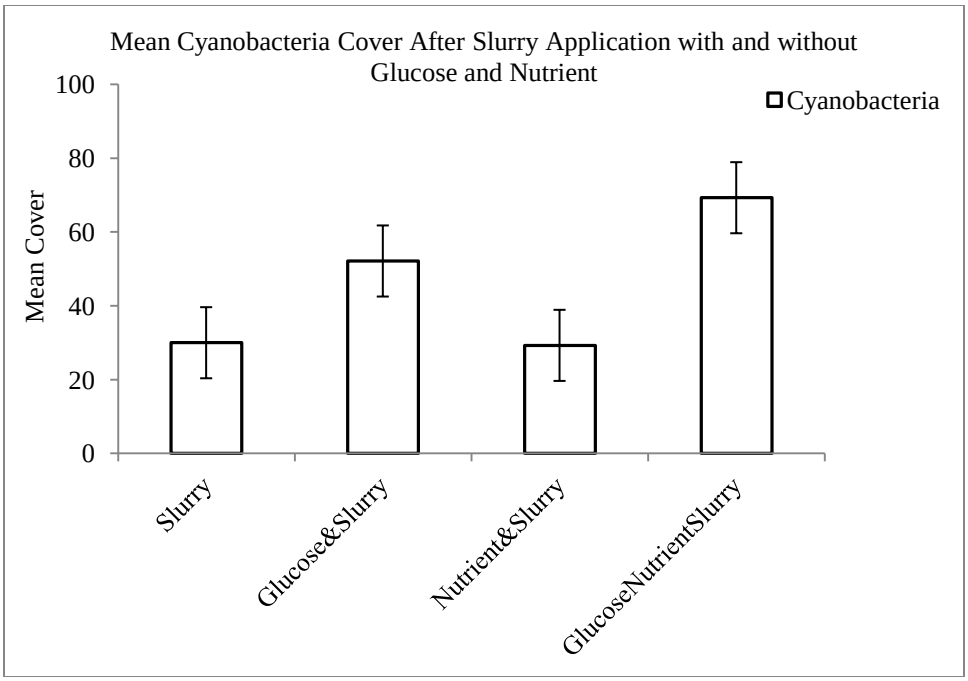


Figure 38 Mean cyanobacteria cover with standard error in nursery flats eight months after application with slurry produced from biological soil crusts collected from gypsiferous soil in the eastern Mojave Desert with and without glucose and/or nutrient solutions.

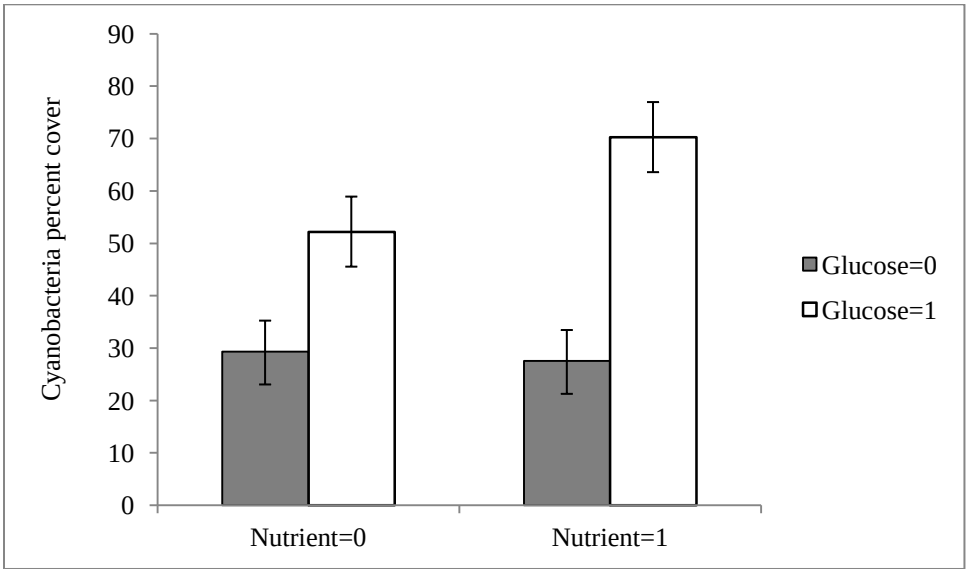


Figure 39 The effects on the cover of cyanobacteria eight months after application of slurry produced from biological soil crusts collected from gypsiferous soil in the eastern Mojave Desert and treatment with nutrient and glucose and their a two-way interactions. Standard error shown; 0 = absent and 1 = present.

CHAPTER 5

CONCLUSION

Given the sensitivity and vulnerability of biological soil crusts, active restoration of crust habitats can be highly beneficial. Stabilizing soils, resource augmentation, and inoculation of native soil crusts can assist with recovery of native soil communities as well as begin to restore native desert ecosystems and assist with sending them along a sustain able trajectory. It is important to utilize native communities that are already adapted to native climate and soil type. These organisms have critical roles in ecosystem sustainability and resilience to such factors as climate change, precipitation events, and wind storms.

This thesis used information related to BSC and restoration research to develop treatment applications for field, greenhouse, and laboratory study. Due to soil properties, gypsiferous soils contain a unique and diverse abiotic soil environment. Lichen species dominant on these soils in the eastern Mojave Desert, which are also prominent in cooler deserts at higher elevations that receive greater yearly precipitation. Other BSC communities in the Mojave Desert are cyanobacteria-dominant, which tolerate low precipitation and high heat. Due to these factors, rehabilitation and/or restoration strategies are likely species and ecosystem specific.

This study examined the potential to salvage, store, and apply BSCs to highly disturbed soils. Results suggest that slurry or direct application may be beneficial along with topsoil reapplication, in the case of topsoil salvaging. If feasible, it is beneficial to use both application techniques in conjunction with addition of a pulverized sanitized organic matrix. A slurry may provide an initial reintroduction of microorganisms, such as

cyanobacteria, to reestablish without competition prior to inoculation in relatively intact BSCs containing lichens and mosses. Slurry inoculation would be most optimal in the fall after the day-time temperatures have cooled. Following several months to a year, direct application by scattering BSC pieced will provide propagules for later successional crust species. Applying an organic matrix will assist with initial soil stability as well as provide a source of carbohydrates directly in soil. This study has demonstrated that application of BSC pieces increases soil stability even at 30% cover and BSCs survive the inoculation process. The restoration goals of LMNRA are to not only to hiding damage and prevent further disturbance but also to restore damaged or degraded areas. Native perennials are often used to mask a disturbed area while attempting to restore vegetation and visual consistency of the landscape. BSC treatments also in conjunction with outplanting treatments will assist with vegetative and visual consistency while rehabilitating ecosystem functions.

Continuing to monitor salvaged stored BSCs and BSC field plots would continue to provide useful and strategic information for future restoration projects. Additionally, conducting a full-factorial study on combination inoculation techniques in a greenhouse, laboratory, and/or field setting would provide additional beneficial information. Additional resource augmentation studies on salvage BSCs would also provide useful information on how rehabilitation may be accelerated or how inoculants may be propagated in a laboratory setting.

APPENDIX 1

BIOLOGICAL SOIL CRUST ORGANISMS: AN INTRODUCTION

Cyanobacteria

Cyanobacteria are photosynthetic prokaryotes that synthesize chlorophyll *a*, the pigment molecule that is essential for most photosynthetic organisms. Cyanobacteria form the phycobilin pigment phycocyanin which causes the bluish color of these organisms (Whitton and Potts 2000). They may occur as unicellular or as colonies, and colonies can be filamentous. A filament is a chain of single cells, called the trichome. Some filamentous cyanobacteria are enclosed in extracellular polysaccharide. Cyanobacteria are also capable of withstanding high temperatures (Mazor et al. 1996). Cyanobacteria are poikilohydric and are inactive while in the dry state, protecting the cellular structures. They can tolerate desiccation due to acute water deficiency by accumulation of compatible solutes at high concentrations to counteract osmotic stresses without a detrimental effect on enzyme efficiency (Potts 1994; Wynn-Williams 2000) and some species are motile which contributes to soil particle aggregation (Anderson et al. 1982) while protecting the cyanobacteria species from excessive radiation (Garcia-Pichel and Pringault 2001). They reproduce by cellular division and subsequent separation of cells. Colonial and filamentous cyanobacteria reproduce by fragmentation of the trichome forming hormogonia, which are motile and can glide through soil media when wet.

Green Algae

Green algae (Chlorophyta and Charophyta) are a diverse group of eukaryotic photosynthetic organisms that occur in as a diversity of organizations: unicellular,

colonial, filamentous, membranous or sheet like, and tubular types. The most prominent organelle in an algal cell is the chloroplast, which contains the sites for the photosynthetic pigments chlorophyll *a* and *b*, as well as several other carotenes and xanthophylls. Some species are motile. Unicellular algae function as gametes and produce special containers or gametangia. These cellular forms may also be motile by means of flagella or non-motile. Multicellular algae also produce gametangia where every gametangial cell is fertile producing a separate gamete.

Lichens

Lichens are highly desiccation tolerant, photosynthetic organisms. They are the symbiosis of a fungi partner, the mycobiont, and a photosynthetic organism, the photobiont, either a green algae or cyanobacterium. A lichen relationship is generally referred to as mutualism; however, since the mycobionts tend to be obligatory and the photobionts can be found both in lichenized and free-living states, lichens are alternatively considered controlled parasitism (Ahmadjian 1993; Nash 1996a). A majority of the lichenized fungi are *Ascomycetes*, with the remaining from the *Basidiomycetes* (Ahmadjian 1993). About 85% of lichens have a green algal symbiont (Tschermak-Woess 1976; Honegger 1986), with about 75% of lichenized relationships with the green algae *Trebouxia* (Tschermak-Woess 1976). Approximately 10% of the photobionts are cyanobacteria, and the remaining lichen relationships have simultaneous associations with a green algae and a cyanobacterium (see Green et al. 2002) (Tschermak-Woess 1976; Honegger 1996).

The thallus is the main vegetative structure of the lichen and is primarily determined by the mycobiont. The lichen thallus can be homoiomerously (symbionts

evenly distributed) or heteromerously (symbionts stratified) arranged and have several morphological groups: crustose, foliose, and fruticose, with crustose and foliose forms having additional gelatinous types (Büdel and Scheidegger 1996). The thallus is developed to supply an adequate amount of light while protecting the photobiont, carbon dioxide diffusion, hydrated conditions and minimizing rapid water loss for positive net photosynthesis (Smith and Douglas 1987).

Lichens are poikilohydric. This characteristic is significant due to the physiology and functioning of lichens during wetting and drying events (Farrar 1976a). Lichens that have a high water-holding capacity (Lange et al. 1998) and can survive extended drought which protects photosynthetic material.

Bryophytes

Bryophytes, such as mosses, occur in BSC communities, although usually in moister habitats (Belnap et al. 2001). Mosses are small plants that utilizing oxidative photosynthesis, do not have internal water-bearing vessels, have their dominate life cycle as a gametophyte, and reproduce with haploid spores. They attach to the soil surface with rhizoids (Belnap et al. 2001). Mosses can be either dioicous (gametophytes only contain sperm or eggs, not both) or monoicous (sperm and eggs are in the same gametophyte). Spores germinate to produce protonema, which appears as a thread-like filament or thalloid.

Bryophytes as a group are desiccation tolerant to different degrees; they tent to equilibrate rapidly with the water potential in their surroundings, desiccate in low humidity and become metabolically inactive, and recover when rehydrated (Proctor et al. 2007). The degree of recovery decreases with the time length of desiccation and is

depending on the temperature and intensity of desiccation (Proctor 2001). Recovery involves the initiation of respiration, protein synthesis, and photosynthesis (Proctor 2001; Proctor et al. 2007), all which can occur within a few minutes to a few hours after hydration (Proctor 2001). Respiration begins soon after hydration and recovery of protein synthesis occurs within a few minutes after rehydration (Oliver 1991). Photosynthesis recovers within a few seconds to minutes (Proctor 2001; Proctor and Smirnoff 2000). The desert moss *Tortula ruralis* rapidly recovers its metabolism during hydration (Oliver and Bewley 1997; Oliver et al. 2005). Cushions or mat growth dry slowly (Zotz et al. 2000), and isolated shoot will dry more quickly.

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Thesis Title: Restoration of Biological Soil Crusts on Disturbed Gypsiferous Soils in Lake Mead National Recreation Area, Eastern Mojave Desert.

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Chairperson, Scott Abella, Ph.D.
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APPENDIX E

Included are additional tables related to the invertebrate study

INVERTEBRATES

Table E.1. Geographic information for all invertebrate study plots in Lake Mead National Recreation Area, eastern Mojave Desert in 2008.

Plot name	**Habitat type**	**UTMx**[a]	**UTMy**[a]	**Elevation (m)**
GYP1	Gypsum	4035966.7	730743.9	459
GYP2	Gypsum	4035897.8	730760.3	460
GYP3	Gypsum	4035851.3	730772.2	471
GYP4	Gypsum	4035664.2	731899.5	428
GYP5	Gypsum	4035669.6	731981.2	428
DP1	Desert pavement	4032464.4	731655.2	426
DP2	Desert pavement	4032411.7	731641.1	426
DP3	Desert pavement	4032346.9	731610.5	424
DP4	Desert pavement	4032247.3	731557.7	431
DP5	Desert pavement	4021245.1	725406.8	441

[a] UTM: Universal Transverse Mercator (m) zone 11, North American Datum 1983.

Table E.2. Coleoptera species list obtained from specimens collected from Lake Mead National Recreation Area, eastern Mojave Desert. Highlighted entries are species new to science.

Taxa	**Suborder**	**Family (common family name)**	**Habitat[a]**	**Count**	**Relative abundance**
Calosoma sp.	Adephaga	Carabidae (ground beetles)	GYP	2	0.05%
Lebiine sp. 1	Adephaga	Carabidae (ground beetles)	DP	6	0.16%
Lebiine sp. *2*	Adephaga	Carabidae (ground beetles)	DP	1	0.03%
Tetragonoderus pallidus	Adephaga	Carabidae (ground beetles)	GYP/DP	67	1.80%
Niptus sp.	Polyphaga	Anobiidae (spider beetles)	GYP	1	0.03%
Ptinus nr. *verticalis*	Polyphaga	Anobiidae (spider beetles)	GYP	2	0.05%
Trogoderma sp.	Polyphaga	Dermestidae (carpet beetles)	GYP/DP	89	2.39%
Cryptorhopalum sp.	Polyphaga	Dermestidae (carpet beetles)	GYP/DP	6	0.16%
Acmaeodera sp.	Polyphaga	Buprestidae (metallic wood boring beetles)	GYP	1	0.03%
Aethecerinus latecinctus	Polyphaga	Cerambycidae (long-horned beetles)	GYP/DP	9	0.24%
Acanthoscelides sp.	Polyphaga	Chrysomelidae (leaf beetles)	GYP	1	0.03%
Algarobius prosopis	Polyphaga	Chrysomelidae (leaf beetles)	GYP	1	0.03%
Altica obliterata	Polyphaga	Chrysomelidae (leaf beetles)	GYP	1	0.03%
Chaetocnema sp.	Polyphaga	Chrysomelidae (leaf beetles)	DP	1	0.03%
Glyptina sp.	Polyphaga	Chrysomelidae (leaf beetles)	DP	3	0.08%
Phyllotreta sp.	Polyphaga	Chrysomelidae (leaf beetles)	GYP/DP	7	0.19%
Stator limbatus	Polyphaga	Chrysomelidae (leaf beetles)	GYP	1	0.03%
Zabrotes sp.	Polyphaga	Chrysomelidae (leaf beetles)	GYP	1	0.03%
Cymatodera sp. 1	Polyphaga	Cleridae (checkered beetles)	DP	1	0.03%
Cymatodera sp. 2	Polyphaga	Cleridae (checkered beetles)	GYP	1	0.03%
Cymatodera sp. 3	Polyphaga	Cleridae (checkered beetles)	DP	1	0.03%
Trichodes ornatus	Polyphaga	Cleridae (checkered beetles)	GYP/DP	8	0.21%
Attalus sp. 1	Polyphaga	Melyridae (soft-winged flower beetles)	GYP/DP	41	1.10%
Attalus sp. 2	Polyphaga	Melyridae (soft-winged flower beetles)	DP	2	0.05%
Attalus sp. 3	Polyphaga	Melyridae (soft-winged flower beetles)	DP	1	0.03%
Dasytastes sp.	Polyphaga	Melyridae (soft-winged flower beetles)	GYP/DP	37	0.99%
Dasytellus sp.	Polyphaga	Melyridae (soft-winged flower beetles)	GYP	1	0.03%
Eudasytes sp.	Polyphaga	Melyridae (soft-winged flower beetles)	GYP/DP	368	9.87%

Eutrichopleurus sp.	Polyphaga	Melyridae (soft-winged flower beetles)	GYP/DP	441	11.82%
Rhadalus testaceus	Polyphaga	Melyridae (soft-winged flower beetles)	GYP	1	0.03%
Trichochrous nr. umbratus	Polyphaga	Melyridae (soft-winged flower beetles)	GYP/DP	49	1.31%
Coccinella septempunctata	Polyphaga	Coccinellidae (lady beetles)	GYP	1	0.03%
Hippodamia convergens	Polyphaga	Coccinellidae (lady beetles)	DP	2	0.05%
Hyperaspis sp. 1	Polyphaga	Coccinellidae (lady beetles)	GYP/DP	3	0.08%
Hyperaspis sp. 2	Polyphaga	Coccinellidae (lady beetles)	GYP	1	0.03%
Carpophilus nr. *ligneus*	Polyphaga	Nitidulidae (sap-feeding beetles)	DP	3	0.08%
Carpophilus pallipennis	Polyphaga	Nitidulidae (sap-feeding beetles)	DP	1	0.03%
Trigonorhinus nr. *tomentosus*	Polyphaga	Anthribidae (fungus weevils)	GYP	2	0.05%
Curculionine sp.	Polyphaga	Curculionidae (snout and bark beetles)	GYP	1	0.03%
Thinoxenus sp. 1	Polyphaga	Curculionidae (snout and bark beetles)	GYP	1	0.03%
Thinoxenus sp. 2	Polyphaga	Curculionidae (snout and bark beetles)	GYP	6	0.16%
Thinoxenus sp. 3	Polyphaga	Curculionidae (snout and bark beetles)	GYP	6	0.16%
Eucyllus nr. *Vagans*	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	20	0.54%
Entimine sp. 5	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	7	0.19%
Mesagroicus sp.	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	34	0.91%
Ophryastes sp. 1	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	24	0.64%
Ophryastes sp. 1a	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	8	0.21%
Ophryastes sp. 2	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	4	0.11%
Ophryastes sp. 3	Polyphaga	Curculionidae (snout and bark beetles)	GYP	2	0.05%
Ophryastes sp. 4	Polyphaga	Curculionidae (snout and bark beetles)	DP	1	0.03%
Ophryastes sp. 5	Polyphaga	Curculionidae (snout and bark beetles)	DP	1	0.03%
Smicronyx sp.	Polyphaga	Curculionidae (snout and bark beetles)	GYP/DP	706	18.93%
Thinoxenus sp.	Polyphaga	Curculionidae (snout and bark beetles)	DP	1	0.03%
Trigonoscuta sp.	Polyphaga	Curculionidae (snout and bark beetles)	GYP	2	0.05%
Horistonotus sp.	Polyphaga	Elateridae (click beetles)	GYP/DP	121	3.24%
Neotrichophorus substriatus	Polyphaga	Elateridae (click beetles)	GYP/DP	10	0.27%
Eremosaprinus sp.	Polyphaga	Histeridae (clown beetles)	GYP	41	1.10%
Euspilotus sp.	Polyphaga	Histeridae (clown beetles)	DP	64	1.72%
Xerosaprinus sp.	Polyphaga	Histeridae (clown beetles)	DP	2	0.05%
Diplotaxis n. sp.	Polyphaga	Scarabaeidae (scarab beetles)	GYP	10	0.27%

Gymnopyge sp.	Polyphaga	Scarabaeidae (scarab beetles)	GYP/DP	194	5.20%
Phyllophaga n. sp.	Polyphaga	Scarabaeidae (scarab beetles)	GYP/DP	99	2.65%
Ptomaphagus sp.	Polyphaga	Leiodidae (round fungus beetles)	GYP/DP	35	0.94%
Omaliine sp. 1	Polyphaga	Staphylinidae (rove beetles)	GYP	1	0.03%
Papusus (?n. sp.*)*	Polyphaga	Staphylinidae (rove beetles)	GYP/DP	15	0.40%
Cyclodinus franciscanus	Polyphaga	Anthicidae (ant-like flower beetles)	DP	251	6.73%
Ischyropalpus sp.	Polyphaga	Anthicidae (ant-like flower beetles)	GYP	1	0.03%
Mastoremus (?n. sp.*)*	Polyphaga	Anthicidae (ant-like flower beetles)	GYP	5	0.13%
Cysteodemus armatus	Polyphaga	Meloidae (blister beetles)	GYP/DP	5	0.13%
Eupompha schwarzi	Polyphaga	Meloidae (blister beetles)	DP	1	0.03%
Lytta magister	Polyphaga	Meloidae (blister beetles)	GYP/DP	20	0.54%
Lytta sp. 1	Polyphaga	Meloidae (blister beetles)	GYP/DP	1	0.03%
Phodaga alticeps	Polyphaga	Meloidae (blister beetles)	DP	1	0.03%
Pleuropasta mirabilis	Polyphaga	Meloidae (blister beetles)	DP	1	0.03%
Typhaea stercorea	Polyphaga	Mycetophagidae (hairy fungus beetles)	GYP	1	0.03%
Oxacis sp. 1	Polyphaga	Oedemeridae (false blister beetles)	GYP	4	0.11%
Oxacis sp. 2	Polyphaga	Oedemeridae (false blister beetles)	DP	2	0.05%
Oxacis sp. 3	Polyphaga	Oedemeridae (false blister beetles)	DP	1	0.03%
Oxacis sp. 4	Polyphaga	Oedemeridae (false blister beetles)	DP	1	0.03%
Allopoda nr. californica	Polyphaga	Scraptiidae (false flower beetles)	GYP/DP	37	0.99%
Diclidia sp.	Polyphaga	Scraptiidae (false flower beetles)	DP	5	0.13%
Pentaria sp.	Polyphaga	Scraptiidae (false flower beetles)	DP	5	0.13%
Alaephus nevadensis	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	261	7.00%
Anepsius brunneus	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	106	2.84%
Araeoschizus sulcicollis	Polyphaga	Tenebrionidae (darkling beetles)	DP	10	0.27%
Argoporis sp.	Polyphaga	Tenebrionidae (darkling beetles)	DP	1	0.03%
Asbolus verrucosus	Polyphaga	Tenebrionidae (darkling beetles)	GYP	6	0.16%
Auchmobius subboreus	Polyphaga	Tenebrionidae (darkling beetles)	GYP	1	0.03%
Batuliodes sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	102	2.73%
Cerenopus concolor	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	6	0.16%
Cheirodes californicus	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	21	0.56%
Chilometopon	Polyphaga	Tenebrionidae (darkling beetles)	GYP	2	0.05%

Cryptoglossa muricata	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	45	1.21%
Eupsophulus castaneus	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	9	0.24%
Eleodes armata	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	56	1.50%
Eleodes sp.	Polyphaga	Tenebrionidae (darkling beetles)	DP	3	0.08%
Eusattus dubius	Polyphaga	Tenebrionidae (darkling beetles)	GYP	2	0.05%
Edrotes ventricosus	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	14	0.38%
Hylocrinus sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP	1	0.03%
Hymenorus sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	18	0.48%
Mecysmus sp.	Polyphaga	Tenebrionidae (darkling beetles)	DP	1	0.03%
Metoponium convexicolle	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	58	1.55%
Metoponium sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	1	0.03%
Miscellaneous tenebrionid	Polyphaga	Tenebrionidae (darkling beetles)	DP	1	0.03%
Nocibiotes sp. 1	Polyphaga	Tenebrionidae (darkling beetles)	DP	15	0.40%
Nocibiotes sp. 2	Polyphaga	Tenebrionidae (darkling beetles)	GYP	1	0.03%
Notibius sp.	Polyphaga	Tenebrionidae (darkling beetles)	DP	9	0.24%
Stenomorpha sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP	4	0.11%
Trichiasida sp.	Polyphaga	Tenebrionidae (darkling beetles)	GYP	4	0.11%
Triorophus laevis	Polyphaga	Tenebrionidae (darkling beetles)	GYP/DP	46	1.23%
Trogloderus costatus	Polyphaga	Tenebrionidae (darkling beetles)	GYP	3	0.08%
			Total	3,730	100.00%

[a] GYP = gypsum, DP = desert pavement (non-gypsum)

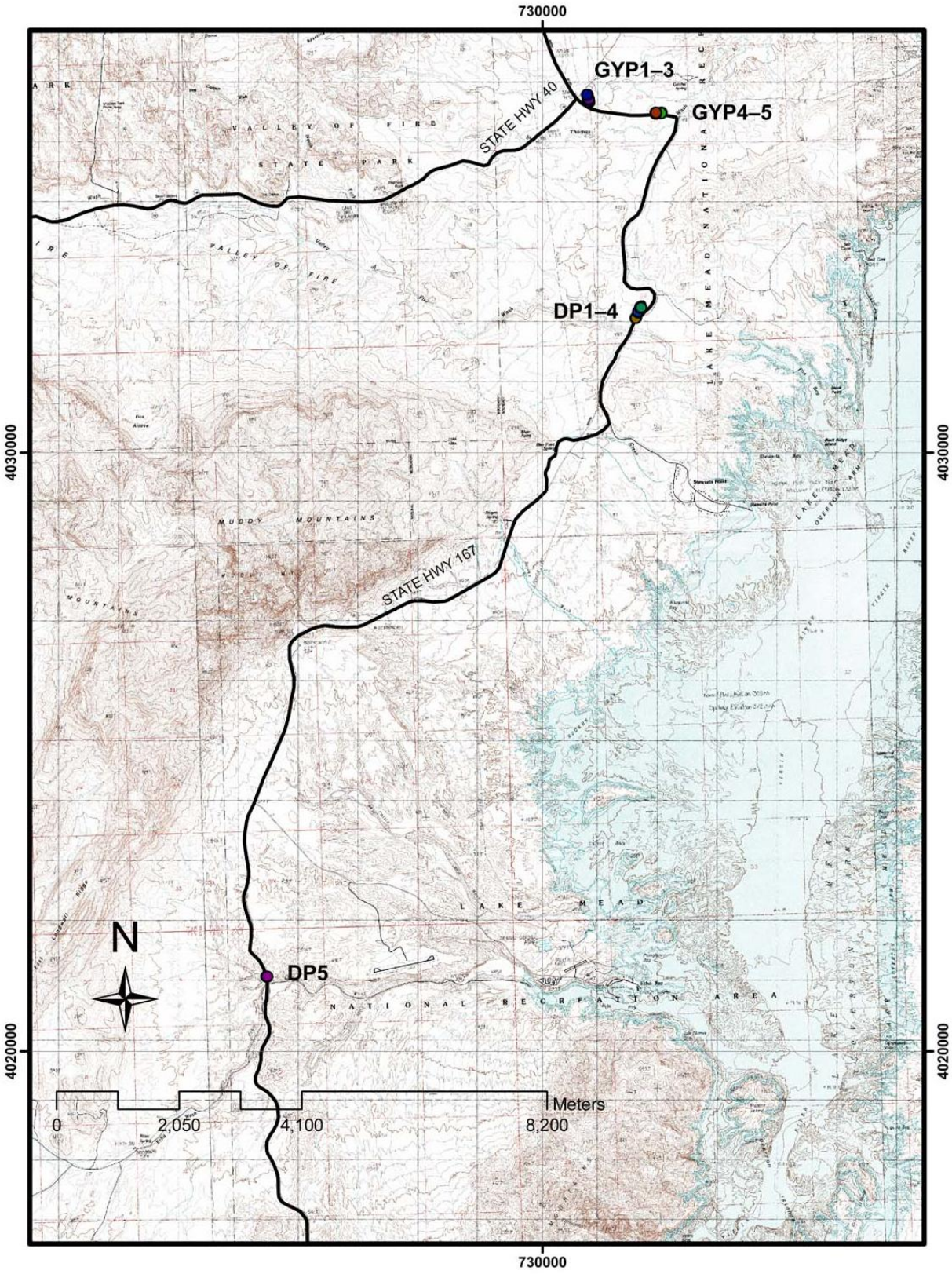


Figure E.1. Study plot locations in gypsum (GYP) and desert pavement (DP) habitats along North Shore Road in Lake Mead National Recreation Area, Clark County, NV, USA.

APPENDIX F

Attached is a field guide to beetles found in gypsiferous soils along Northshore Rd, Lake Mead National Recreation Area, during the Task agreement J8R07090010 period 2009-2012, entitled

Beetle Species: Assemblages in Gypsum and Non-Gypsum Soils in Lake Mead National Recreation Area

Contributed by Ben Jurand (Research Assistant), University of Nevada, Las Vegas.

Beetle Species Assemblages in Gypsum and Non-Gypsum Soils in Lake Mead National Recreation Area



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Report, sample collection, and macro photos by Ben Jurand (UNLV)
Field sampling conducted by Alex Suazo and Ruben Ibarra (UNLV)

This project was funded by task agreement J8R07090010 between the National Park Service (NPS)-Lake Mead National Recreation Area (LMNRA) and University of Nevada, Las Vegas (UNLV) issued against the Great Basin Cooperative Ecosystem Studies Unit Cooperative and Joint Venture Agreement H8R07060001 for the purpose of mutual assistance in conducting a project entitled “Gypsum Soil Restoration and Revegetation in Lake Mead National Recreation Area: Treatments, Monitoring, and Management Activities.”

The sample collection presented here includes 68 of the 111 species sampled during the study. Remaining species were retained by the Department of Entomology at the University of California, Riverside, CA.

Cover photo: *Lytta magister* (Meloidae)


photo: A. Suazo

Introduction

Beetles (Order Coleoptera) perform important ecosystem functions and are one of the most species-rich groups of organisms with some 350,000 species worldwide (Evans and Hogue 2004). Some beetles act as pollinators (Kevan 1999), while others are decomposers and breakdown dead or discarded matter. Ground beetles (Family Carabidae) have been considered useful bioindicators because they perform important ecosystem functions and are also sensitive to environmental changes (Cárdinas and Hidalgo 2007). Similarly, as members of one of the most conspicuous group of terrestrial desert animals (Kramm and Kramm 1972), darkling beetles (Family Tenebrionidae) are excellent candidates for studies that investigate local population size and species distribution across habitats In deserts, beetles may be particularly important by acting as pollinators or seed distributors, helping to sustain populations of rare plant species.

Lake Mead National Recreation Area (LMNRA) contains areas of unique gypsum soils, which support rare plant species such as the Las Vegas bearpoppy (*Arctomecon californica*). Gypsiferous sites also support a well-developed biological crust where a host of symbiotic relationships occur (Lovinch and Bainbridge 1999). Biological soil crust can be easily destroyed by certain human activities; therefore, investigations in such habitats are limited. Because so much gypsum habitat has been lost to urban development and degradation by off-road vehicles and other land uses in the Las Vegas Valley, these unique habitats and their associated biota within LMNRA are extremely important to the ecology of the region.

The purpose of this study was to provide observational and experimental data concerning species composition, distribution, relative abundance, and microhabitat use of beetle assemblages in gypsum and non-gypsum desert pavement soils at LMNRA.

Our objectives were to:

(1) establish baseline data sets of local beetles in Mojave Desert habitats;
(2) investigate patterns of species abundance and distribution in gypsum and non-gypsum desert pavement soil types; and
(3) evaluate the effects of vegetation structure and environmental factors on distribution, abundance and species composition.

Sampling Methods

LMNRA is located in southeastern Clark County, Nevada USA within an area greater than 1.5 million ha in the Mojave Desert. At LMNRA, predominant plant communities include desert scrub, gypsum benches, and gypsum uplands.

Five 10 m × 10 m plots each were established in both gypsum and non-gypsum desert pavement habitat types. Habitat types were selected based on existing soil maps and chemical analyses for gypsum content. Gypsum soils consisted of loamy, gypsic, hyperthermic, shallow typic petrogypsids with parent material consisting of alluvium derived from gypsum. Desert pavement soils consisted of loamy-skeletal, mixed, superactive, hyperthermic, shallow typic haplodurids with parent material consisting of alluvium derived from fanglomerate.

Within each plot, the spatial position of five randomly selected creosote bushes (*Larrea tridentata*) was recorded using a handheld GPS unit. To evaluate effects of microhabitat types on beetle abundance, five interspaces between shrubs were established based on a randomly chosen cardinal direction, positioned approximately 2 m away from a creosote bush. Ambient and soil temperatures were collected using HOBO temp data loggers located at each microhabitat, both under a creosote bush and in an interspace.

At each microhabitat site, four pitfall traps were used to sample invertebrates (Figure 1). One trap was positioned in each cardinal direction. Pitfall traps consisted of a plastic cup (190 mm diameter, 120 mm deep) buried flush with the ground surface. Propylene glycol was used as a killing agent. Field sampling was conducted in April, August, and November of 2008 in conjunction with the realignment of approximately 2.5 km of Northshore Road in LMNRA. Traps were open for four consecutive days at each sampling time.

After collection, specimens were rinsed and stored in alcohol. The specimens were sorted, first by order, then by genus and species, where possible. Beetles were identified and vouchered by the Department of Entomology at the University of California, Riverside, CA.



Figure 1. Pitfall traps were comprised of four cups buried flush with the ground surface and were located in open interspaces and under shrub canopies at all sites.

Results

In total, 3,730 beetles were identified, representing 111 species in 23 families (Table 1). Soft-winged flower beetles (Family Melyridae, pages 69–74), snout and bark beetles (Family Curculionidae, pages 60–68), and darkling beetles (Family Tenebrionidae, pages 18–38) were most abundant and comprised 75% of the sampled individuals. Darkling beetles represented the greatest species richness by far with 29 total species and while most species were variably distributed, at least one species of darkling beetle was present in every sample (i.e., soil habitat, microsite, and sampling time). Scarab beetles (pages 57–59) and ant-like flower beetles (page 7) were also abundant. Significantly, there were two confirmed species new to science of flightless scarab beetles (Family Scarabaeidae) in the genera *Diplotaxis* (page 57) and *Phyllophaga* (page 59).

Table 1. Abundance and species richness of beetle families identified in samples from gypsum (GYP) and desert pavement (DP) habitats.

			Individual counts			Relative abundance		
Family	**Common name**	**Species richness**	**DP**	**GYP**	**Total**	**DP**	**GYP**	**Total**
Melyridae	Soft-winged flower beetles	9	695	246	941	33%	15%	25%
Curculionidae	Snout and bark beetles	16	331	493	824	16%	30%	22%
Tenebrionidae	Darkling beetles	29	353	454	807	17%	28%	22%
Scarabaeidae	Scarab beetles	3	187	116	303	9%	7.1%	8.1%
Anthicidae	Antlike flower beetles	3	251	6	257	12%	0.4%	6.9%
Elateridae	Click beetles	2	24	107	131	1.1%	6.5%	3.5%
Histeridae	Clown beetles	3	66	41	107	3.2%	2.5%	2.9%
Dermestidae	Carpet beetles	2	62	33	95	3.0%	2.0%	2.5%
Carabidae	Ground beetles	4	29	47	76	1.4%	2.9%	2.0%
Scraptiidae	False flower beetles	7	15	32	47	0.7%	2.0%	1.3%
Leiodidae	Round fungus beetles	1	21	14	35	1.0%	0.9%	0.9%
Meloidae	Blister beetles	6	22	7	29	1.1%	0.4%	0.8%
Chrysomelidae	Leaf beetles	8	4	12	16	0.2%	0.7%	0.4%
Staphylinidae	Rove beetles	2	11	5	16	0.5%	0.3%	0.4%
Cleridae	Checkered beetles	4	4	7	11	0.2%	0.4%	0.3%
Cerambycidae	Long-horned beetles	1	3	6	9	0.1%	0.4%	0.2%
Oedemeridae	False blister beetles	4	4	4	8	0.2%	0.2%	0.2%
Coccinellidae	Lady beetles	4	3	4	7	0.1%	0.2%	0.2%
Nitidulidae	Sap-feeding beetles	2	4	0	4	0.2%	0.0%	0.1%
Anobiidae	Death-watch, spider beetles	2	0	3	3	0.0%	0.2%	0.1%
Anthribidae	Fungus weevils	1	0	2	2	0.0%	0.1%	0.1%
Buprestidae	Metallic wood boring beetles	1	0	1	1	0.0%	0.1%	0.0%
Mycetophagidae	Hairy fungus beetles	1	0	1	1	0.0%	0.1%	0.0%
	Total	**111**	**2,089**	**1,641**	**3,730**			

Beetle Abundance Over Time

Overall, beetles in most families were most abundant in the April sampling. In August, darkling beetles and click beetles were the most abundant families and had both increased since April. Ground beetles were also present in August, but were much less abundant. The November sampling did not include all plots used in April and August but rather only included three sites from gypsum soils; no non-gypsum desert pavement plots were sampled in November.

Beetle Abundance in Gypsum and Desert Pavement Soils

The most abundant of the 23 beetle families were sampled in both gypsum and desert pavement habitats (Table 1). Ant-like flower beetles were much more abundant in desert pavement than gypsum habitats. Soft-winged flower beetles, scarab beetles, clown beetles, carpet beetles, and blister beetles were only relatively more abundant in desert pavement habitats (Fig. 1). Sap-feeding beetles, while low in abundance, were exclusively sampled on desert pavement soils.

Click beetles, false flower beetles, and ground beetles were present in both habitats but were relatively more abundant in gypsum soils. Death-watch and spider beetles, fungus weevils, metallic wood boring beetles, and hairy fungus beetles were sampled in small numbers, but were exclusive to gypsum soils (Fig. 2).

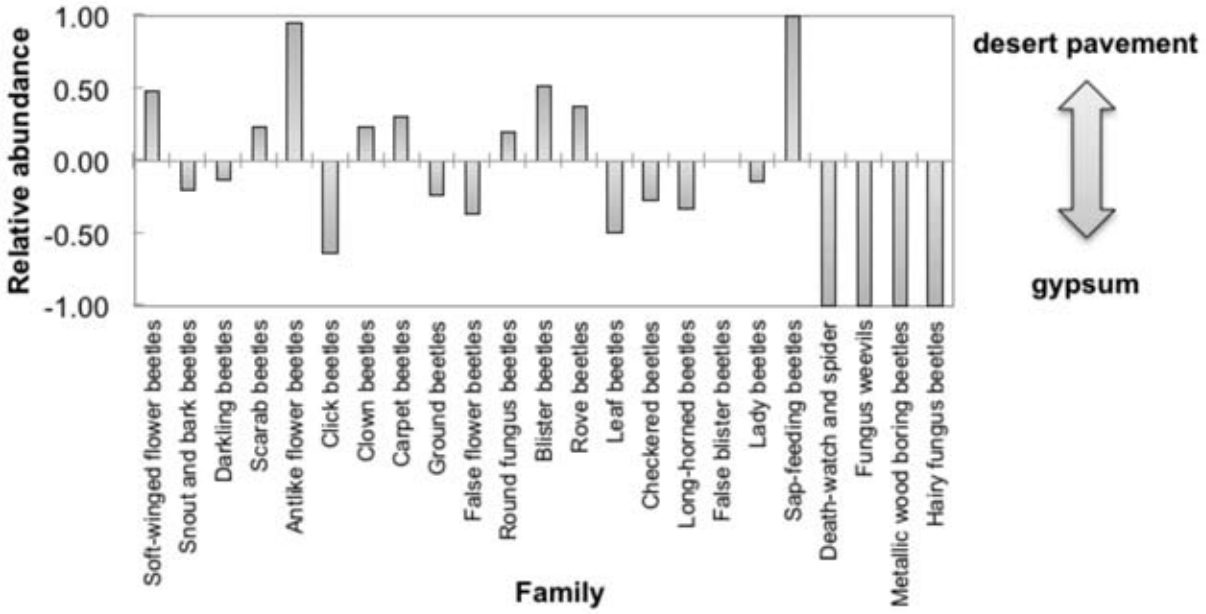


Figure 2. Relative abundance of beetle families in desert pavement and gypsum soils. A standardized value on a scale ranging from -1 to 1 was calculated within each family as the difference between proportions of individuals in desert pavement and gypsum habitats. Positive values represent a tendency toward greater relative abundance of the genus in desert pavement habitats (1.0 indicates exclusive presence in desert pavement habitats); negative values represent a tendency toward greater relative abundance in gypsum habitats. Families decrease in overall abundance from left to right.

Beetle Abundance in Microsites

The most abundant family, soft-winged flower beetles, had greater abundance in interspaces than under shrubs (Fig. 3). Round fungus beetles and lady beetles, while low in abundance, had much greater abundance in interspace samples. In contrast, snout and bark beetles and ground beetles tended to have greater abundance under shrubs. Click beetles, clown beetles, and carpet beetles also tended to have greater abundant under shrubs but were common in under shrubs as well. Fungus weevils, metallic wood boring beetles, and hairy fungus beetles were sampled in small numbers, but were only found under shrubs.

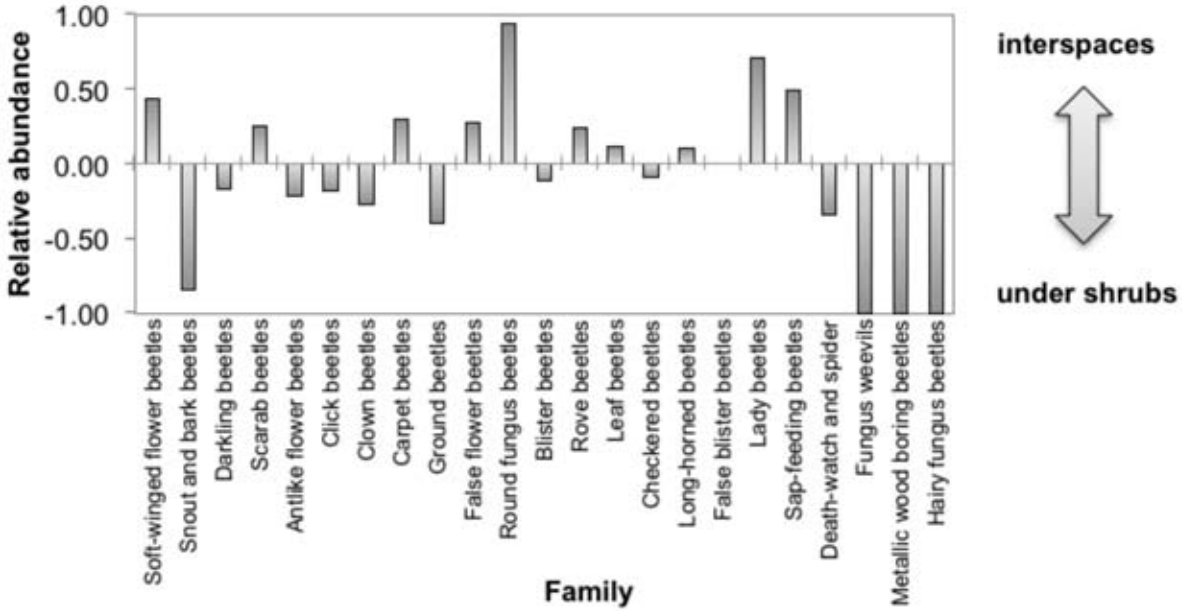


Figure 3. Relative abundance of beetle families in interspace and under shrub microsites. A standardized value on a scale ranging from -1 to 1 was calculated within each family as the difference between proportions of individuals in interspace and under shrub microsites. Positive values represent a tendency toward greater relative abundance of the family in open interspace microsites; negative values a tendency toward greater relative abundance under shrubs. Families decrease in overall abundance from left to right.

Sample Collection

Antlike Flower Beetles (Anthicidae) 7
Cyclodinus franciscanus 7

Blister Beetles (Meloidae) 8
Cysteodemus armatus 8
Lytta magister 9
Pleuropasta mirabilis 10

Carpet Beetles (Dermestidae) 11
Cryptorhopalum sp. 11
Trogoderma sp. 12

Checkered Beetles (Cleridae) 13
Trichodes ornatus 13

Click Beetles (Elateridae) 14
Horistonotus sp. 14
Neotrichophorus substriatus 15

Clown Beetles (Histeridae) 16
Eremosaprinus sp. 16
Euspilotus sp. 17

Darkling Beetles (Tenebrionidae) 18
Alaephus nevadensis 18
Anepius brunneus 19
Araeoschizus sulcicollis 20
Asbolus verrucosus 21
Batuliodes sp. 22
Cerenopus concolor 23
Cheirodes californicus 24
Cryptoglossa muricata 25
Edrotes ventricosus 26
Eleodes armata 27
Eleodes sp. 28
Eupsophulus castaneus 29
Eusattus dubius 30
Hymenorus sp. 31
Metoponium convexicolle 32
Nocibiotes sp. 1 33
Notibius sp. 34
Stenomorpha sp. 35
Trichiasida sp. 36
Triorophus laevis 37
Trogloderus costatus 38

Death-watch & Spider Beetles (Anobiidae) .. 39
Ptinus nr. *verticalis* 39

False Blister Beetles (Oedemeridae) 40
Oxacis sp. 1 40
Oxacis sp. 2 41

False Flower Beetles (Scraptiidae) 42
Diclidia sp. 42
Pentaria sp. 43

Ground Beetles (Carabidae) 44
Calosoma sp. 44
Lebiine sp. 1 45
Tetragonoderus pallidus 46

Lady Beetles (Coccinellidae) 47
Coccinella septempunctata 47
Hippodamia convergens 48
Hyperaspis sp. 1 49
Hyperaspis sp. 2 50

Leaf Beetles (Chrysomelidae) 51
Glyptina sp. 51
Phyllotreta sp. 52

Long-horned Beetles (Cerambycidae) 53
Aethecerinus latecinctus 53

Round Fungus Beetles (Leiodidae) 54
Ptomaphagus sp. 54

Rove Beetles (Staphylinidae) 55
Papusus (?n. sp.) 55

Sap-feeding Beetles (Nitidulidae) 56
Carpophilus nr. *ligneus* 56

Scarab Beetles (Scarabaeidae) 57
Diplotaxis n. sp. 57
Gymnopyge sp. 58
Phyllophaga n. sp. 59

Snout and Bark Beetles (Curculionidae) 60
Entimine sp. 5 60
Eucyllus nr. *vagans* 61
Mesagroicus sp. 62
Ophryastes sp. 1 63
Ophryastes sp. 2 64
Smicronyx sp. 65
Thinoxenus sp. 2 66
Thinoxenus sp. 3 67
Trigonoscuta sp. 68

Soft-winged Flower Beetles (Melyridae) 69
Attalus sp. 1 69
Attalus sp. 2 70
Dasytastes sp. 71
Eudasytes sp. 72
Eutrichopleurus sp. 73
Trichochrous nr. *umbratus* 74

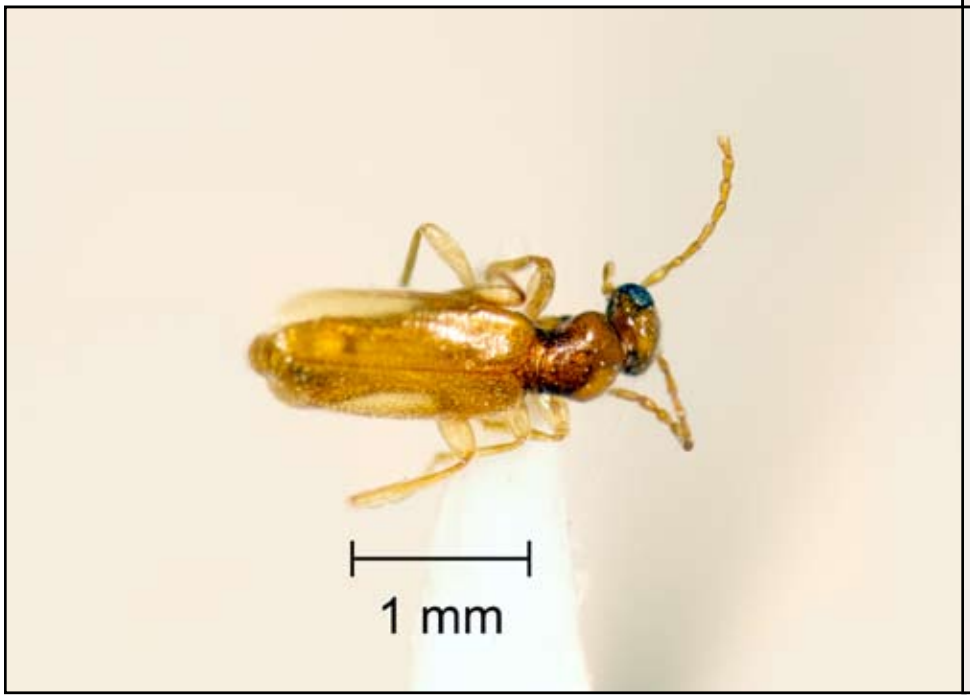
Antlike Flower Beetles (Anthicidae)

Cyclodinus franciscanus

Order: Coleoptera
Suborder: Polyphaga
Family: Anthicidae (Antlike flower beetles)
Subfamily: Anthicinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 6.73%
Sampled in April and August







Blister Beetles (Meloidae)

Cysteodemus armatus

Order: Coleoptera
Suborder: Polyphaga
Family: Meloidae (Blister beetles)
Subfamily: Meloinae
Tribe: Eupomphini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.13%
Sampled in April













Lytta magister

Order: Coleoptera
Suborder: Polyphaga
Family: Meloidae (Blister beetles)
Subfamily: Meloinae
Tribe: n/a

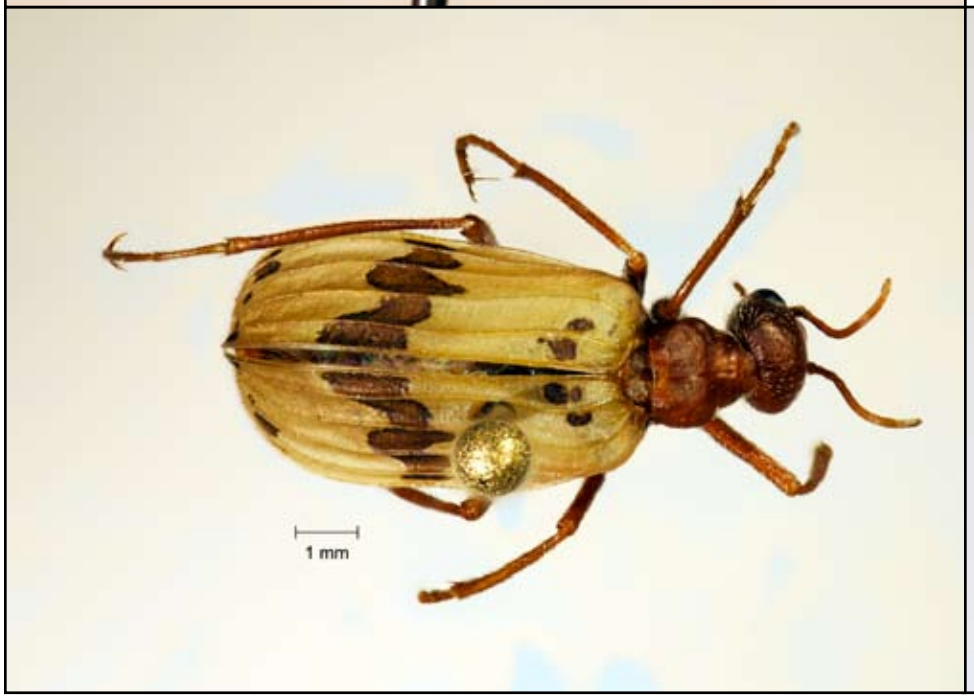
Sampled in gypsum and desert pavement habitats
Relative abundance: 0.54%
Sampled in April



Pleuropasta mirabilis

Order: Coleoptera
Suborder: Polyphaga
Family: Meloidae (Blister beetles)
Subfamily: Meloinae
Tribe: Eupomphini

Sampled in desert pavement habitats
Relative abundance: 0.03%
Sampled in April





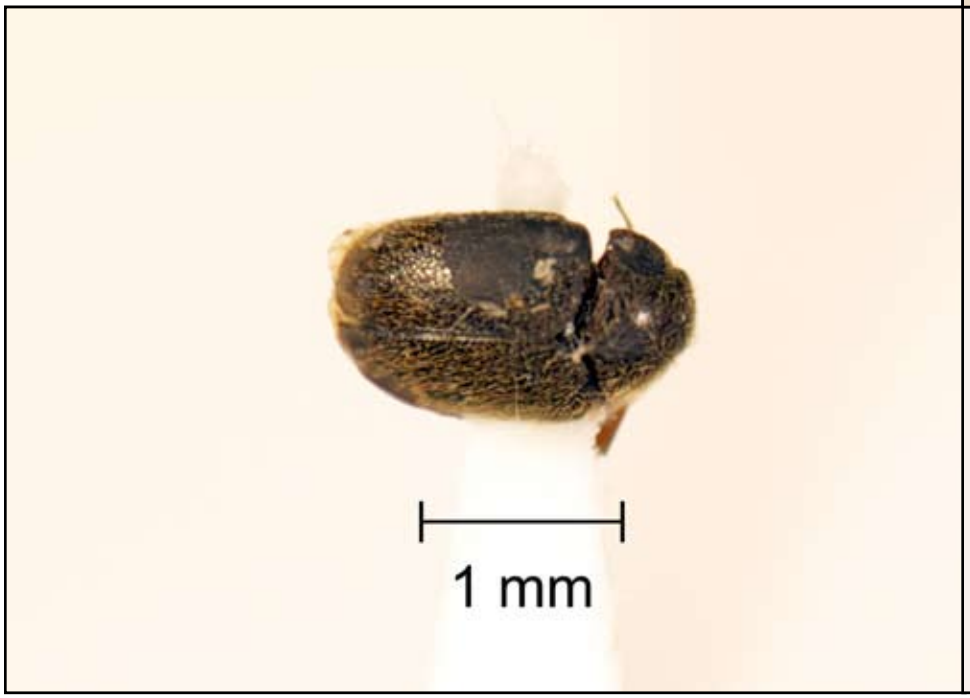
Carpet Beetles (Dermestidae)

Cryptorhopalum sp.

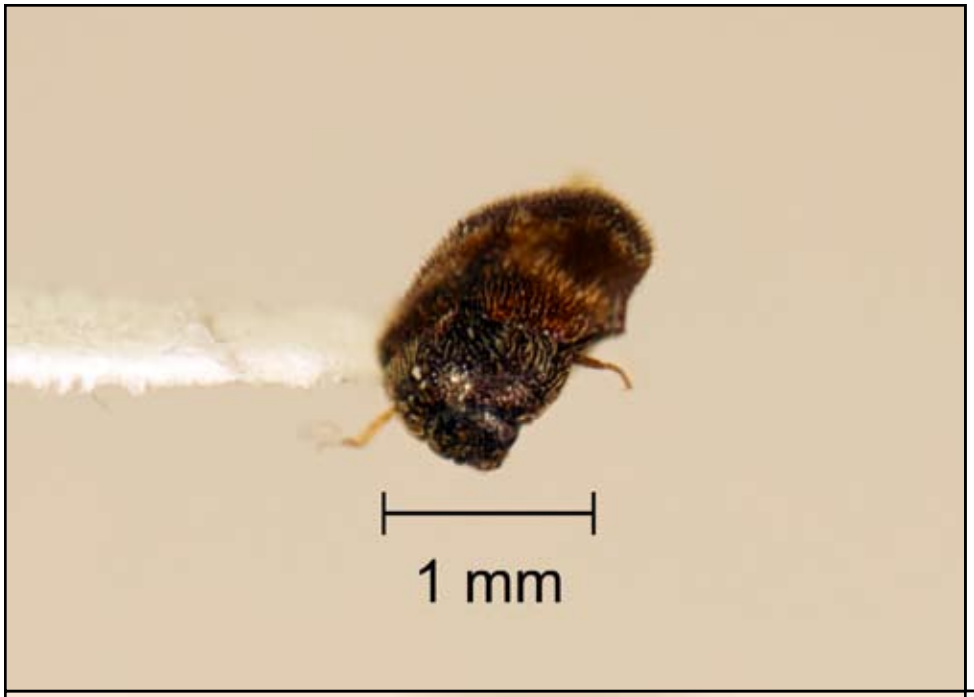
Order: Coleoptera
Suborder: Polyphaga
Family: Dermestidae (Carpet beetles)
Subfamily: Anthrenini
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.16%
Sampled in April









Trogoderma sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Dermestidae (Carpet beetles)
Subfamily: n/a
Tribe: Anthrenini

Sampled in gypsum and desert pavement habitats
Relative abundance: 2.39%
Sampled in April



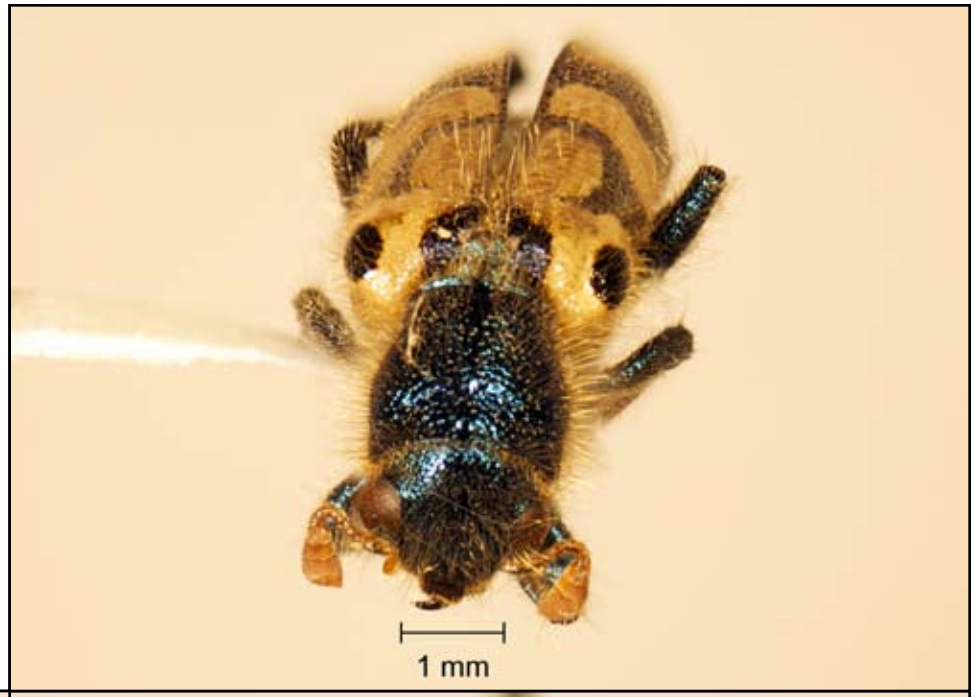


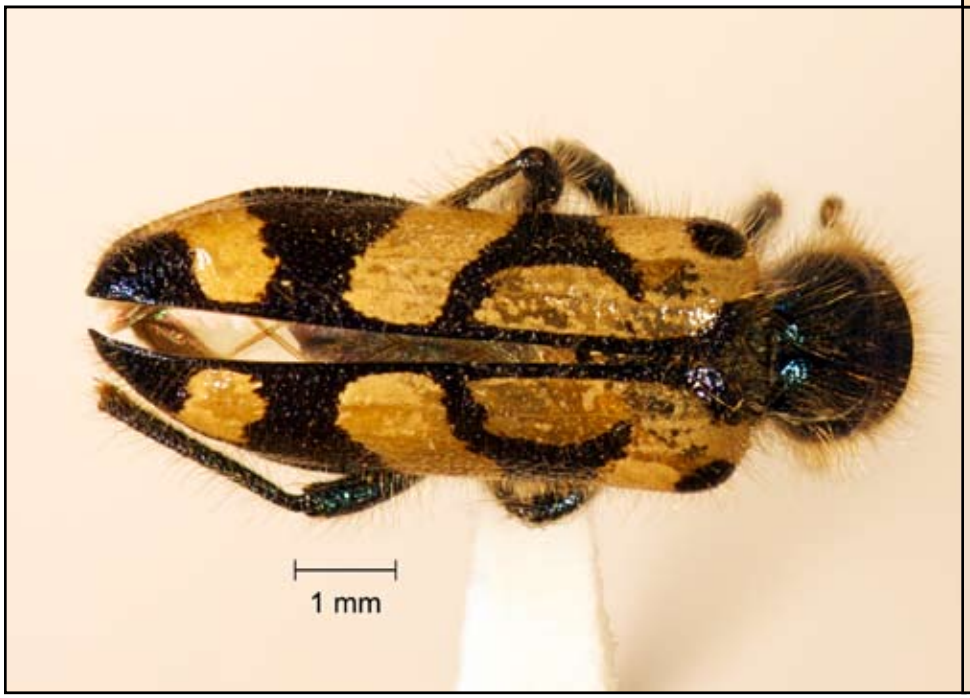
Checkered Beetles (Cleridae)

Trichodes ornatus

Order: Coleoptera
Suborder: Polyphaga
Family: Cleridae (Checkered beetles)
Subfamily: Clerinae
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.21%
Sampled in April







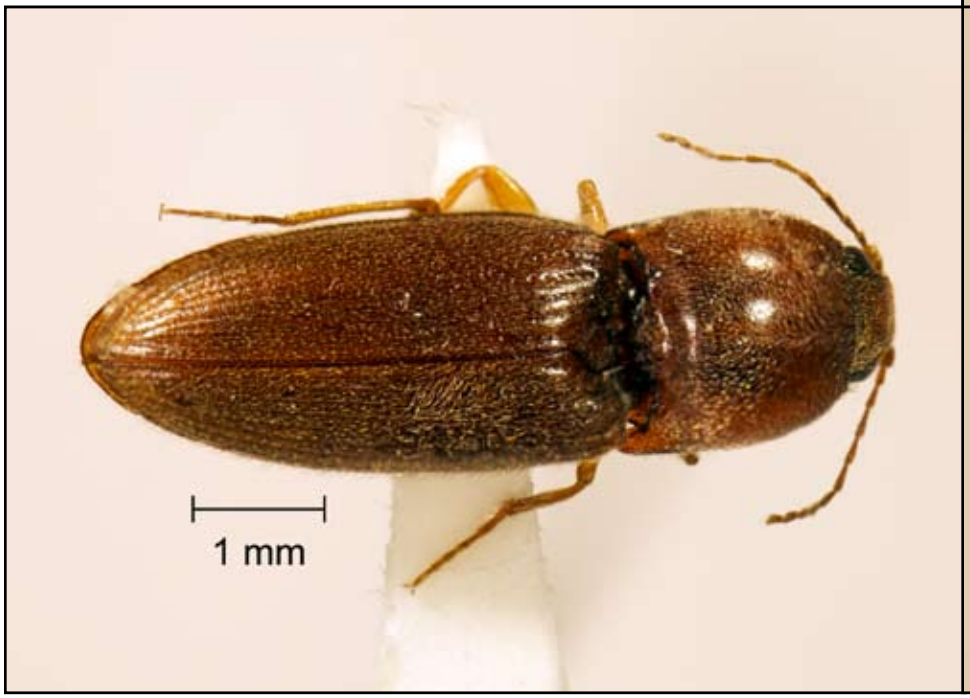
Click Beetles (Elateridae)

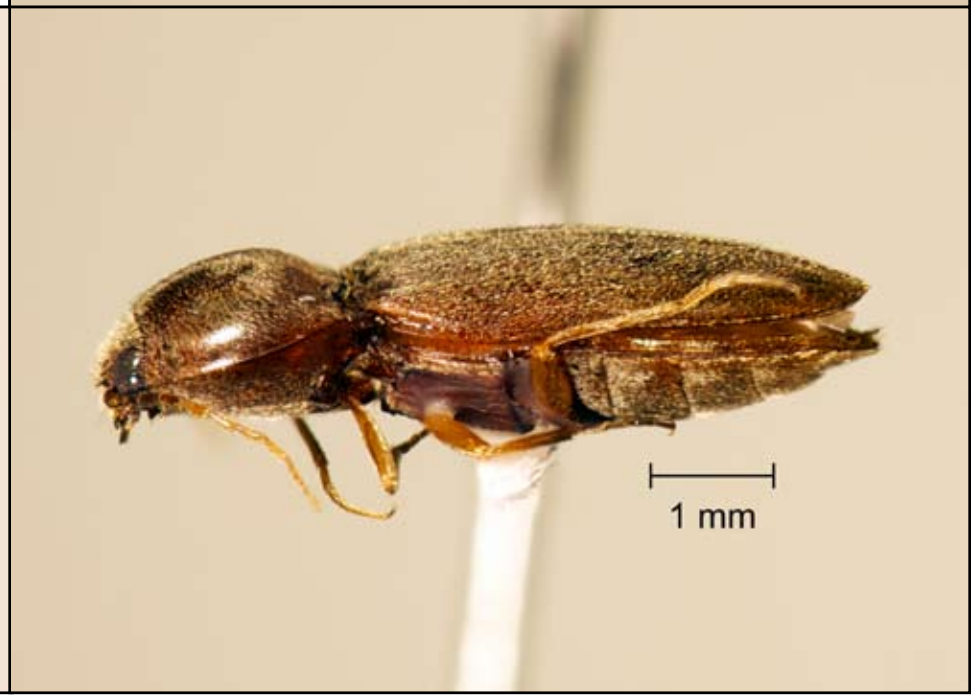
Horistonotus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Elateridae (Click beetles)
Subfamily: Cardiophorinae
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 3.24%
Sampled in August









Neotrichophorus substriatus

Order: Coleoptera
Suborder: Polyphaga
Family: Elateridae (Click beetles)
Subfamily: n/a
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.27%
Sampled in August



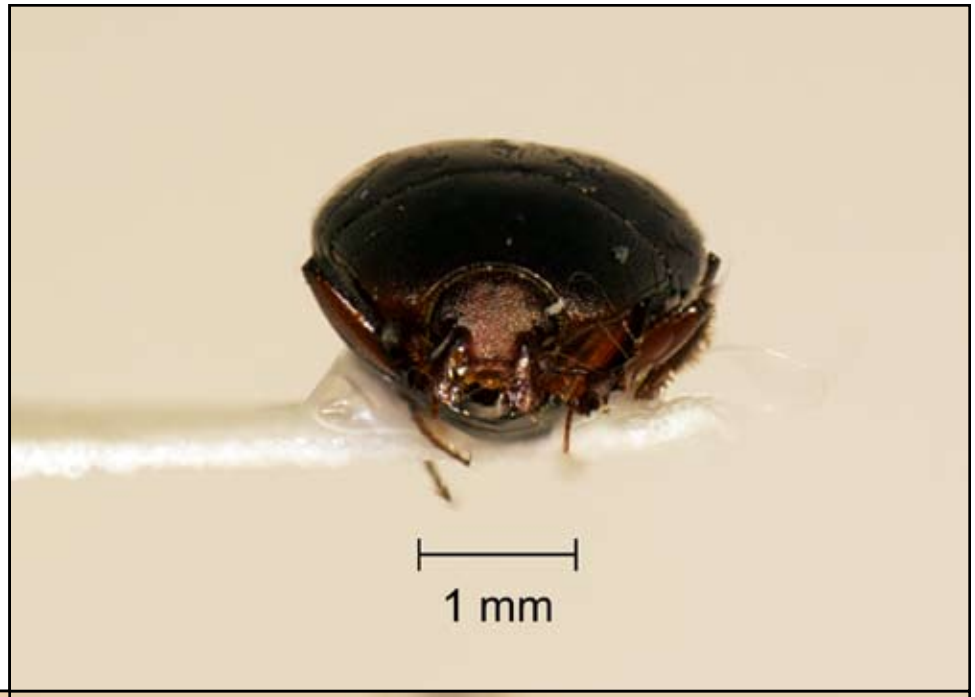


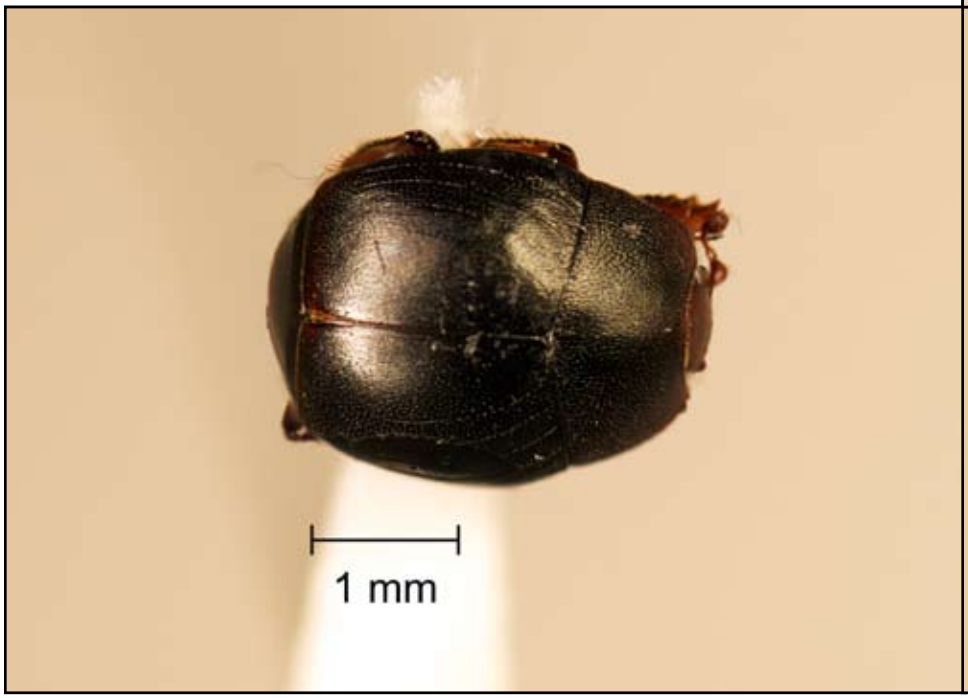
Clown Beetles (Histeridae)

Eremosaprinus sp.

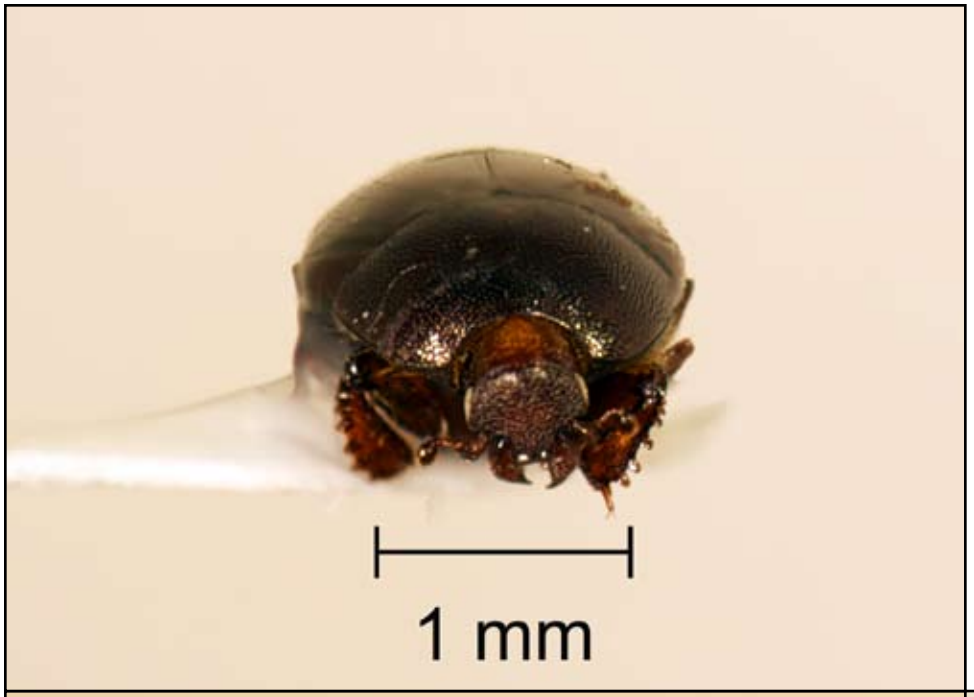
Order: Coleoptera
Suborder: Polyphaga
Family: Histeridae (Clown beetles)
Subfamily: Saprininae
Tribe: n/a

Sampled in gypsum habitats
Relative abundance: 1.10%
Sampled in November









Euspilotus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Histeridae (Clown beetles)
Subfamily: Saprininae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 1.72%
Sampled in April





Darkling Beetles (Tenebrionidae)

Alaephus nevadensis

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Anepsiini

Sampled gypsum and desert pavement habitats
Relative abundance: 7%
Sampled in August









Anepsius brunneus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Stenosini

Sampled in gypsum and desert pavement habitats
Relative abundance: 2.84%
Sampled in April and August





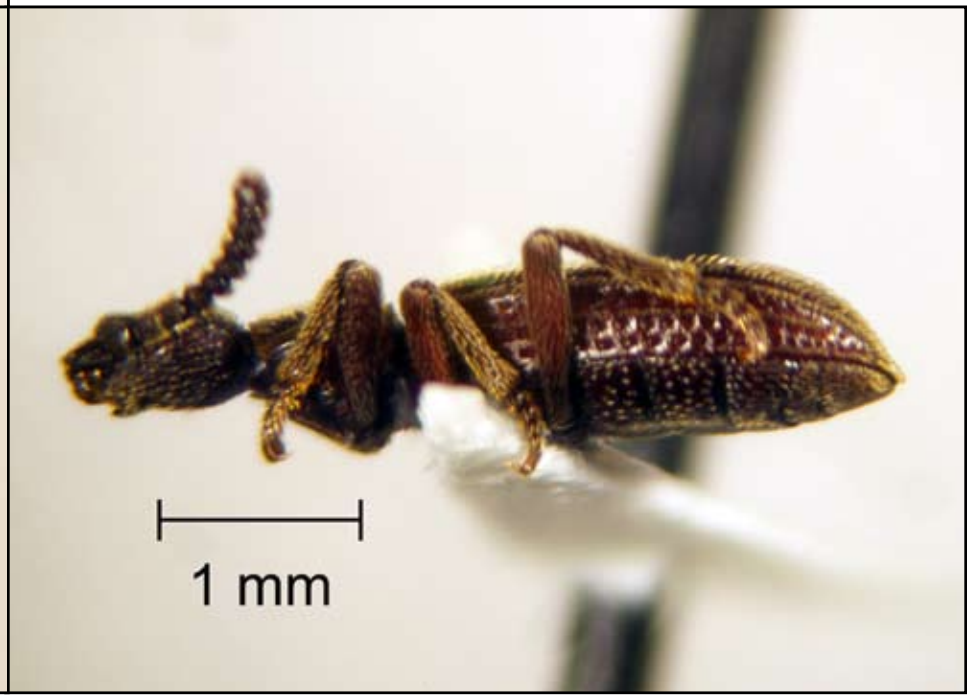


Araeoschizus sulcicollis

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Stenosini

Sampled in desert pavement habitats
Relative abundance: 0.27%
Sampled in April and August







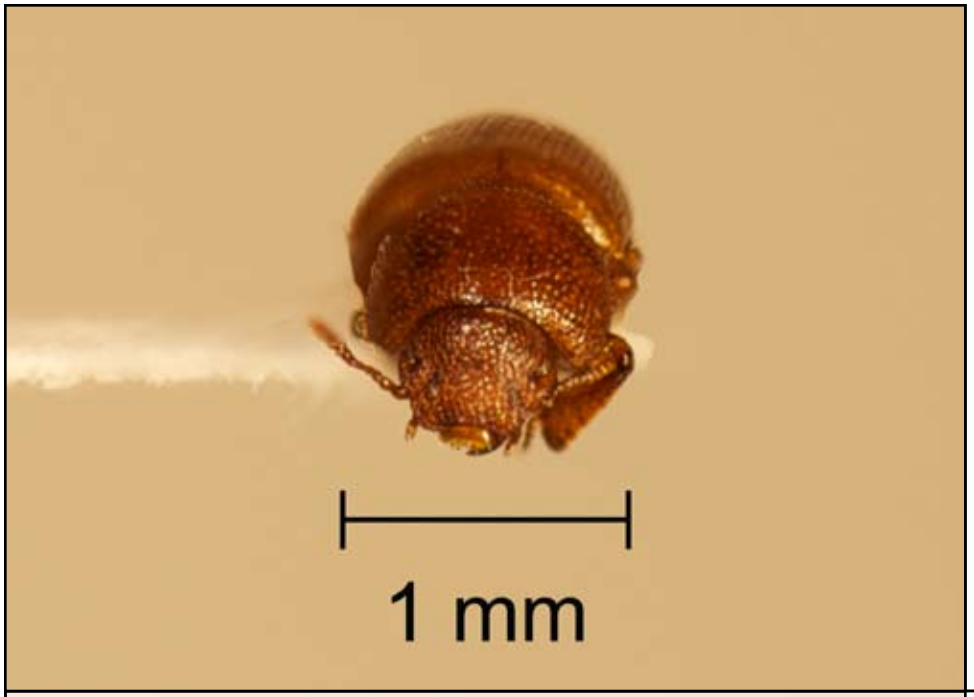




Asbolus verrucosus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Centriopterini

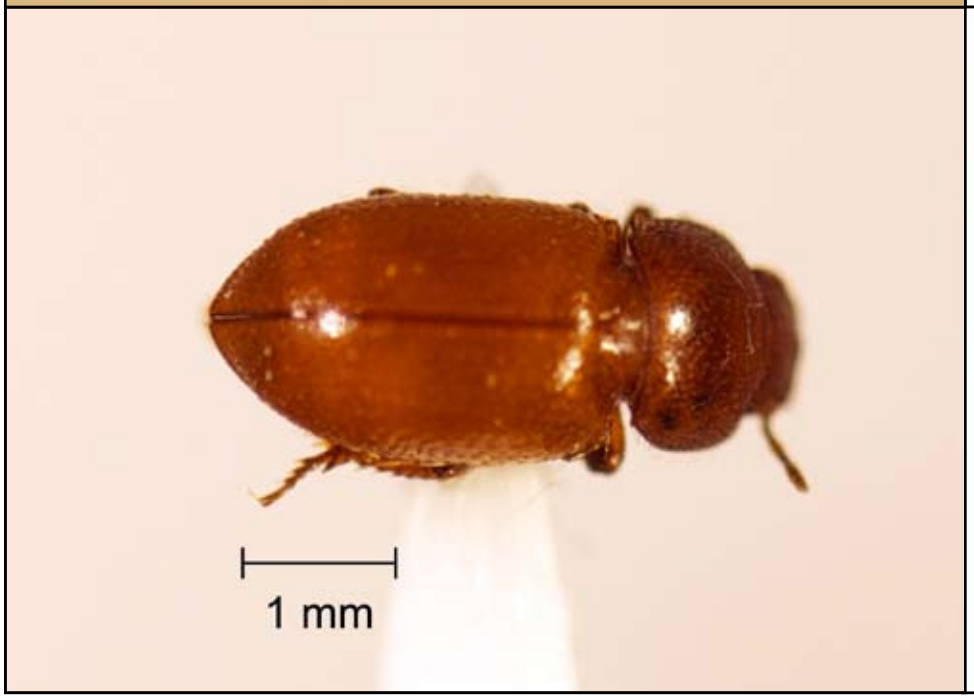
Sampled in gypsum habitats
Relative abundance: 0.16%
Sampled in April and August



*Batuliode*s sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Anepsiini

Sampled in gypsum and desert pavement habitats
Relative abundance: 2.73%
Sampled in April and August





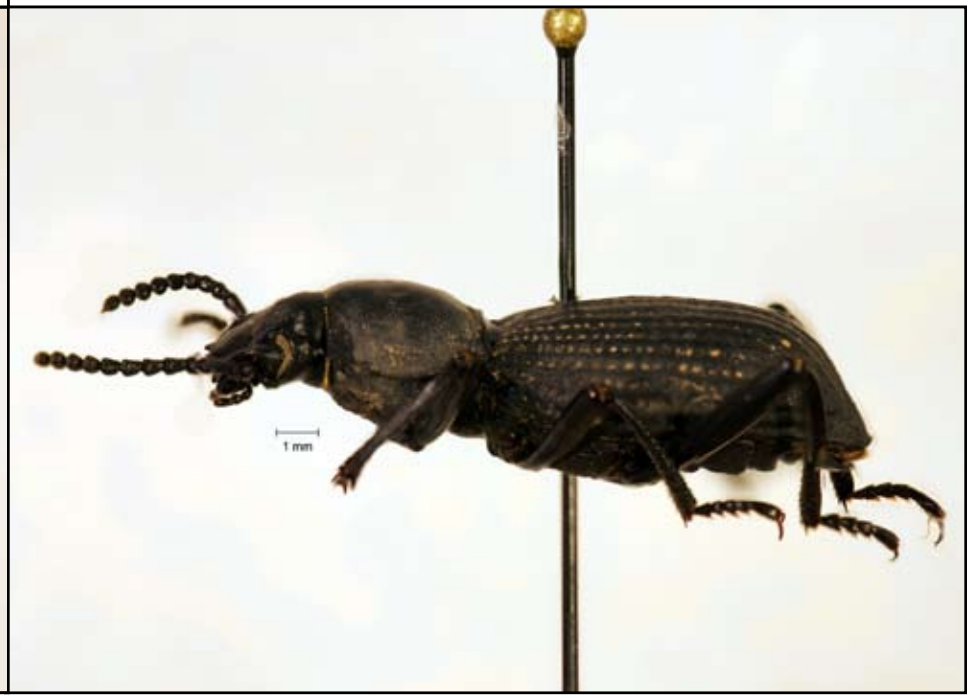


Cerenopus concolor

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Vacronini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.16%
Sampled in April and August







Cheirodes californicus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Melanimini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.56%
Sampled in April and August





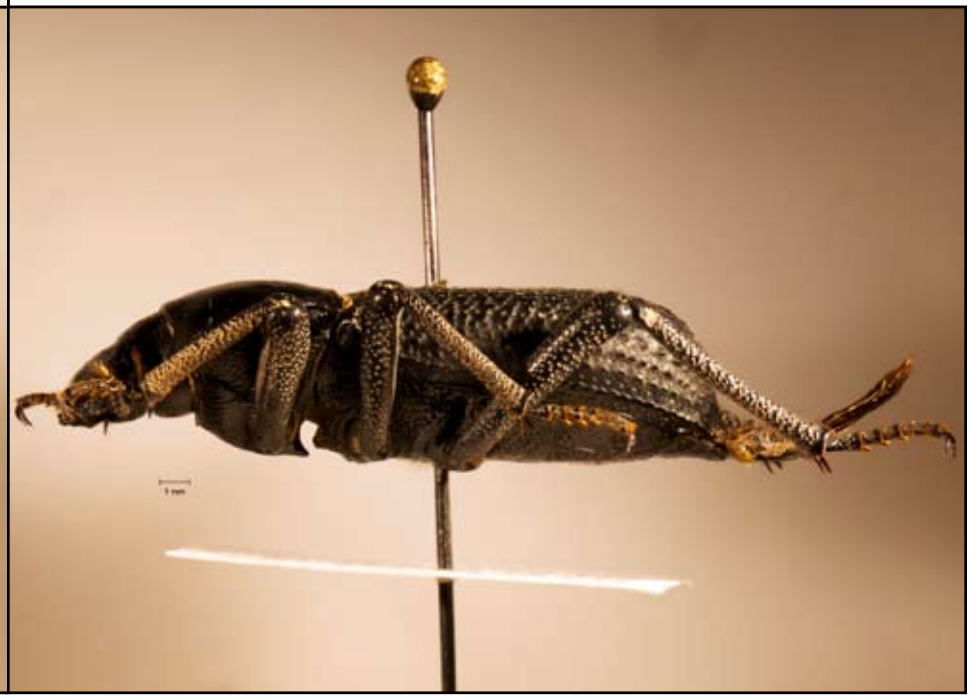


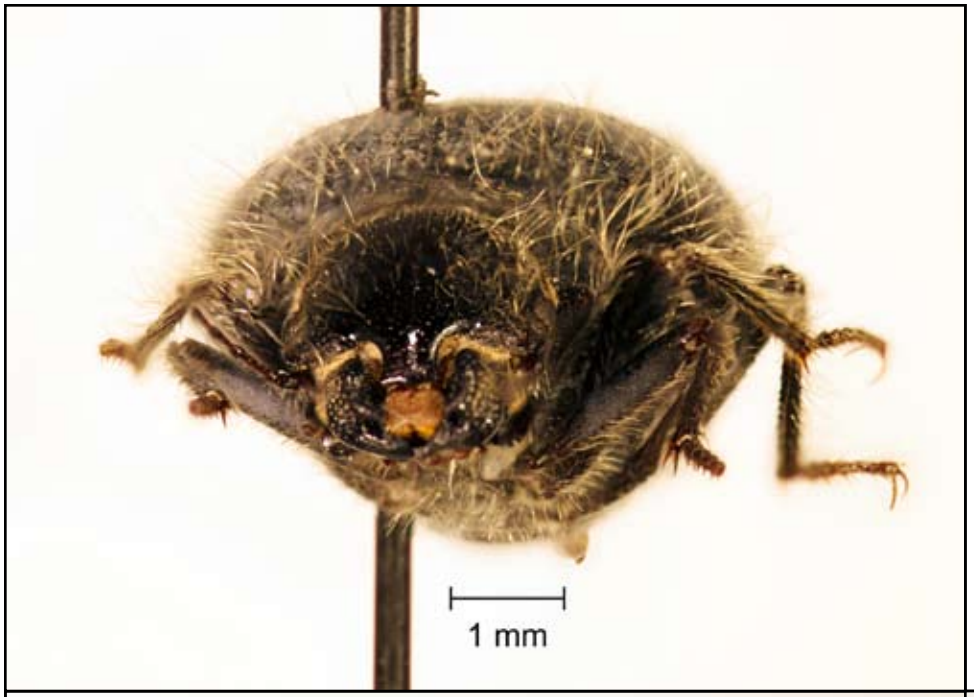
Cryptoglossa muricata

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Centriopterini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.21%
Sampled in April and August







Edrotes ventricosus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Edrotini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.38%
Sampled in April, August, and November











Eleodes armata

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Amphidorini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.50%
Sampled in April, August, and November



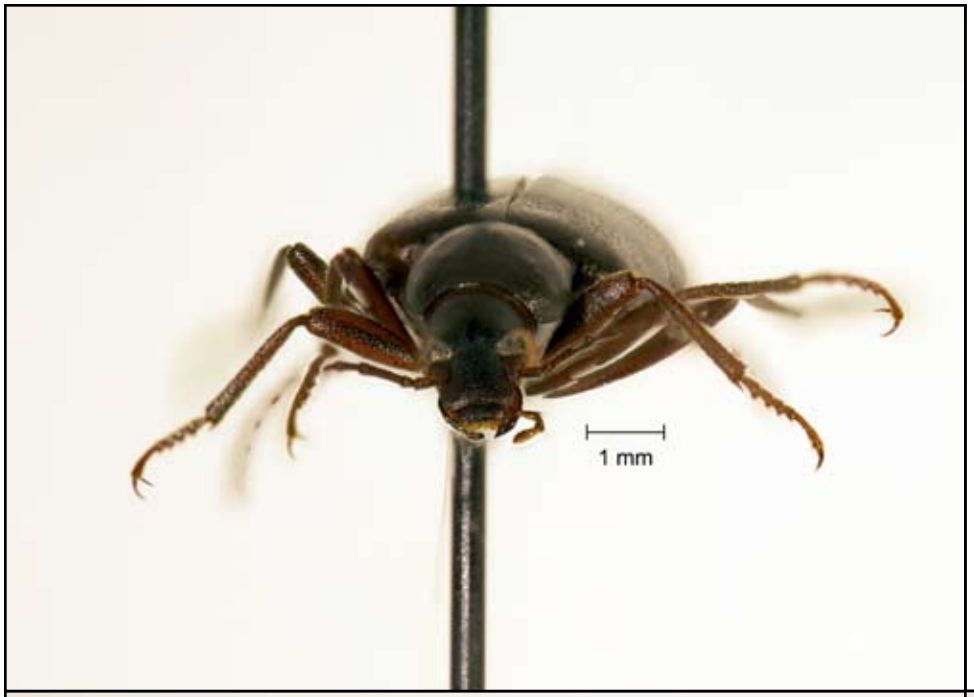
Eleodes sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Amphidorini

Sampled in desert pavement habitats
Relative abundance: 0.08%
Sampled in August







Eupsophulus castaneus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Vacronini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.24%
Sampled in April







Eusattus dubius

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Coniontini

Sampled in gypsum habitats
Relative abundance: 0.05%
Sampled in April







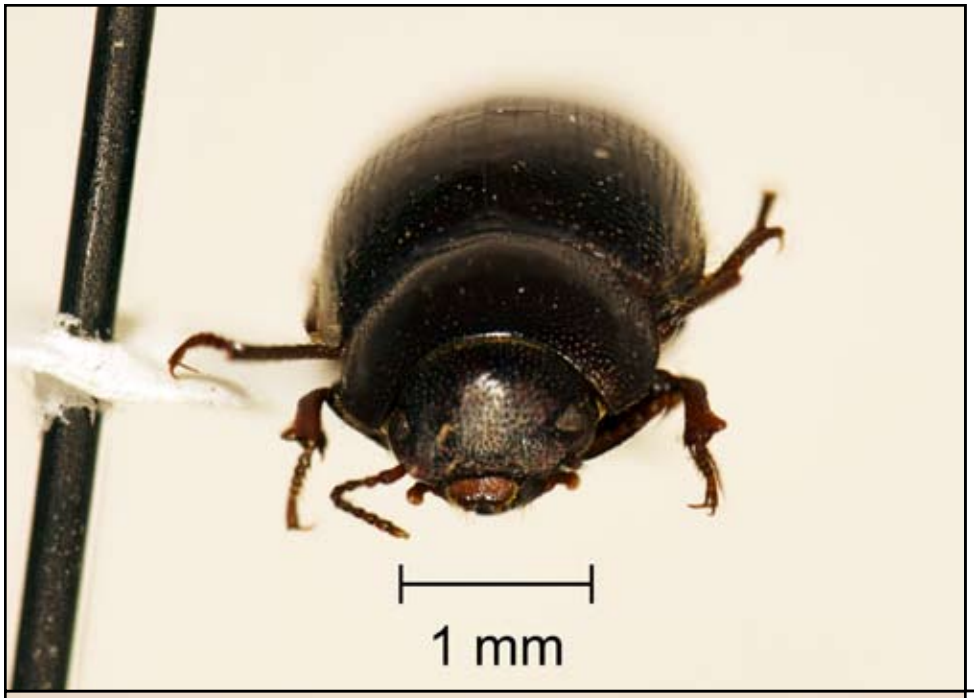
Hymenorus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Alleculinae
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.48%
Sampled in August







Metoponium convexicolle

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Edrotini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.55%
Sampled in April







Nocibiotes sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Opatrini

Sampled in desert pavement habitats
Relative abundance: 0.40%
Sampled in April







Notibius sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Opatrini

Sampled in desert pavement habitats
Relative abundance: 0.24%
Sampled in April











Stenomorpha sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Asidini

Sampled in gypsum habitats
Relative abundance: 0.11%
Sampled in April and November



Trichiasida sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Asidini

Sampled in gypsum habitats
Relative abundance: 0.11%
Sampled in August and November







Triorophus laevis

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Pimeliinae
Tribe: Edrotini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.23%
Sampled in April and August







Trogloderus costatus

Order: Coleoptera
Suborder: Polyphaga
Family: Tenebrionidae (Darkling beetles)
Subfamily: Tenebrioninae
Tribe: Amphidorini

Sampled in gypsum habitats
Relative abundance: 0.08%
Sampled in April and August



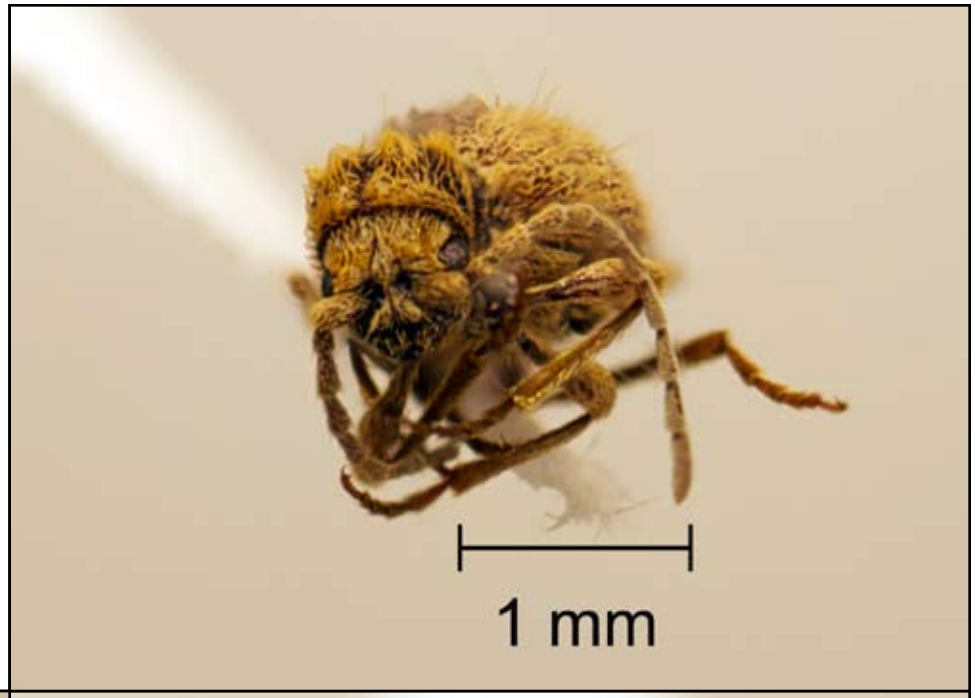


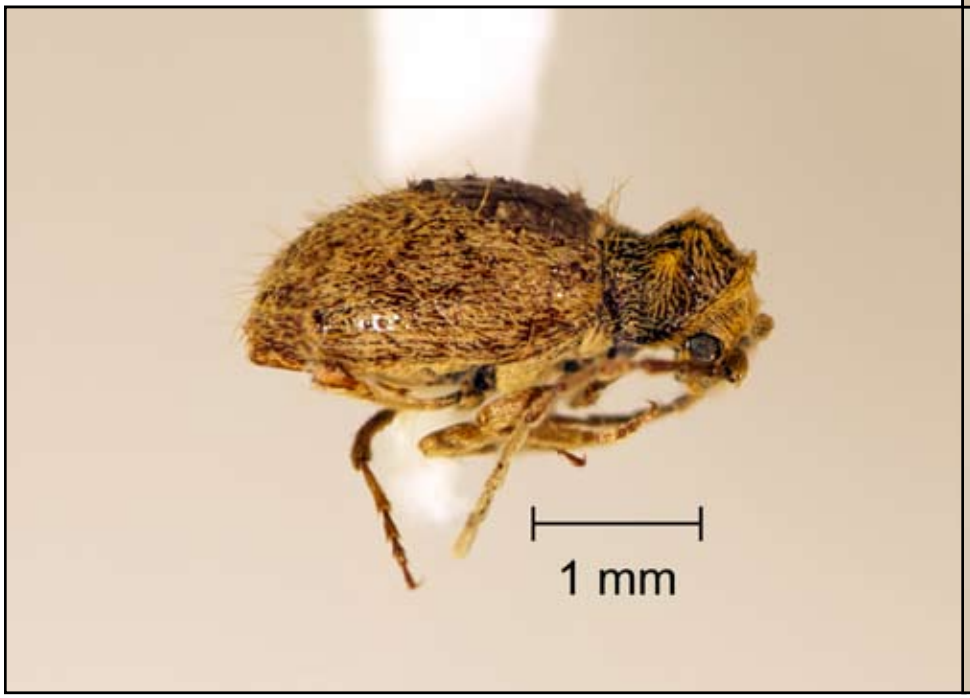
Death Watch and Spider Beetles (Anobiidae)

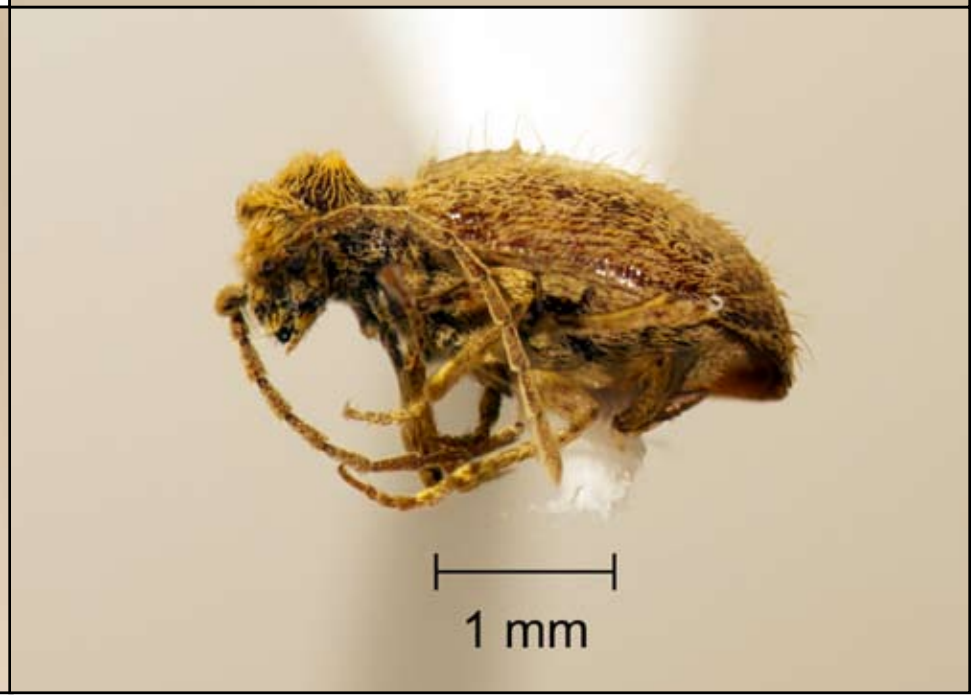
Ptinus nr. *verticalis*

Order: Coleoptera
Suborder: Polyphaga
Family: Anobiidae (Death-watch and spider beetles)
Subfamily: Ptininae (Spider Beetles)
Tribe: n/a

Sampled in gypsum habitats
Relative abundance: 0.05%
Sampled in April







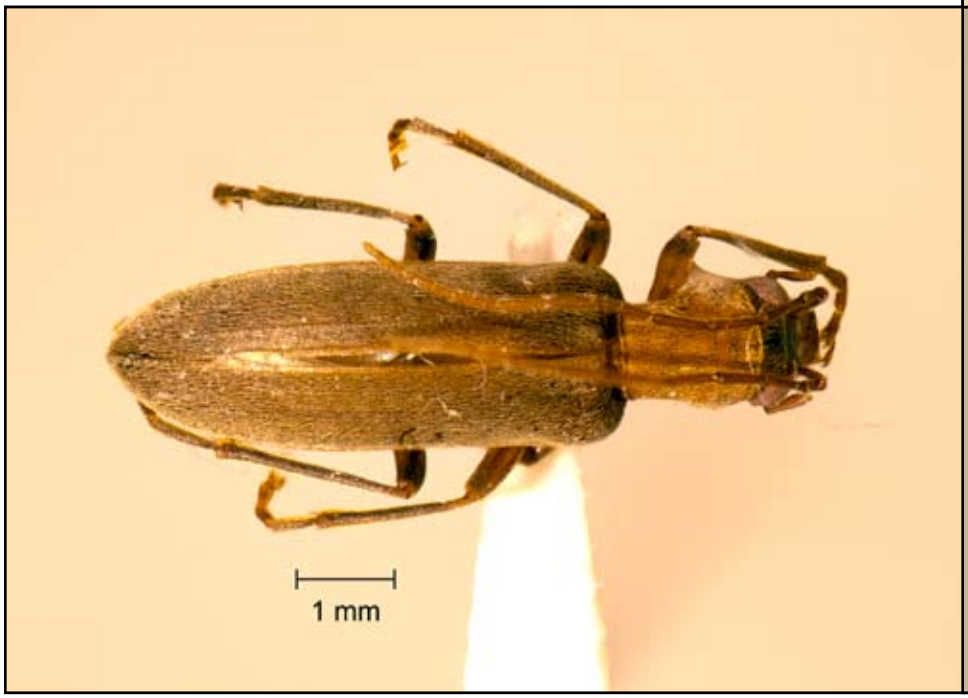
False Blister Beetles (Oedemeridae)

Oxacis sp. 1

Order: Coleoptera
Suborder: Polyphaga
Family: Oedemeridae (False blister beetles)
Subfamily: Oedemerinae
Tribe: Asclerini

Sampled in gypsum habitats
Relative abundance: 0.11%
Sampled in April and August









Oxacis sp. 2

Order: Coleoptera
Suborder: Polyphaga
Family: Oedemeridae (False blister beetles)
Subfamily: Oedemerinae
Tribe: Asclerini

Sampled in desert pavement habitats
Relative abundance: 0.05%
Sampled in August





False Flower Beetles (Scraptiidae)

Diclidia sp.

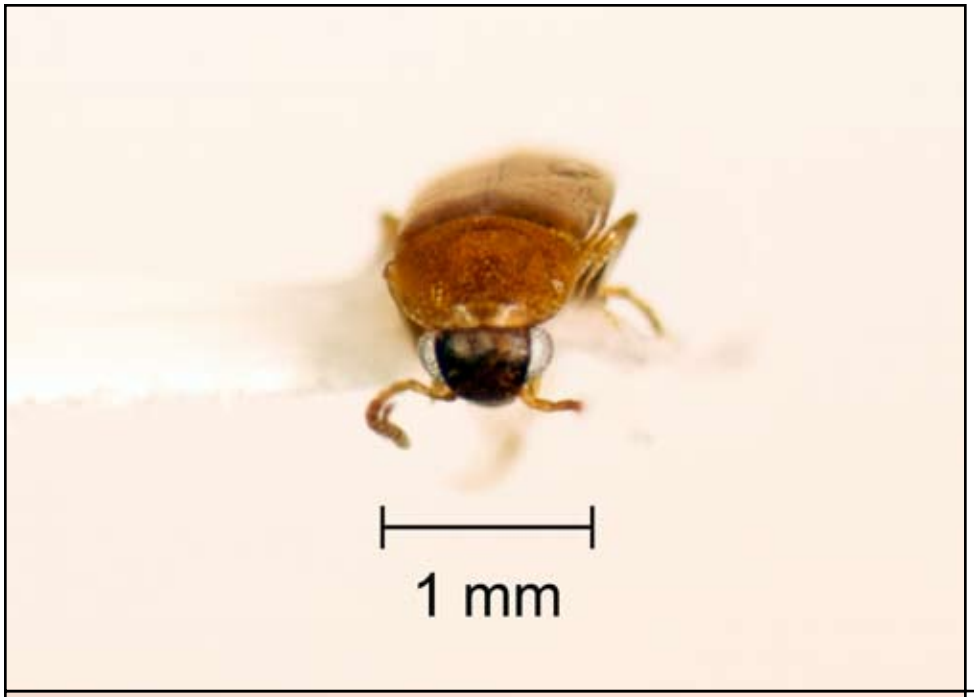
Order: Coleoptera
Suborder: Polyphaga
Family: Scraptiidae (False flower beetles)
Subfamily: Anaspidinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 0.13%
Sampled in April





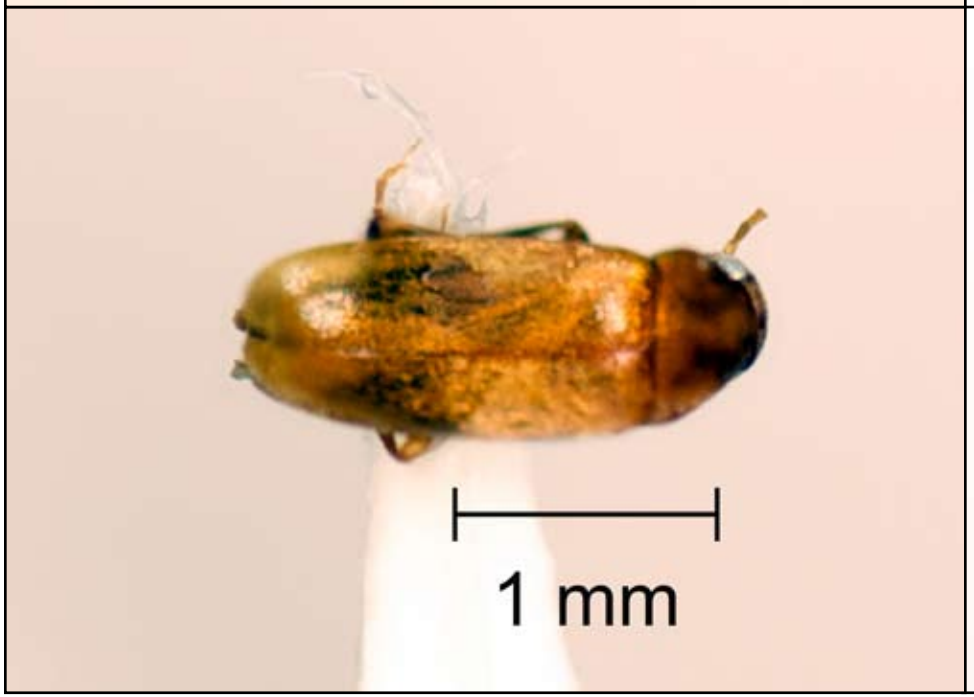


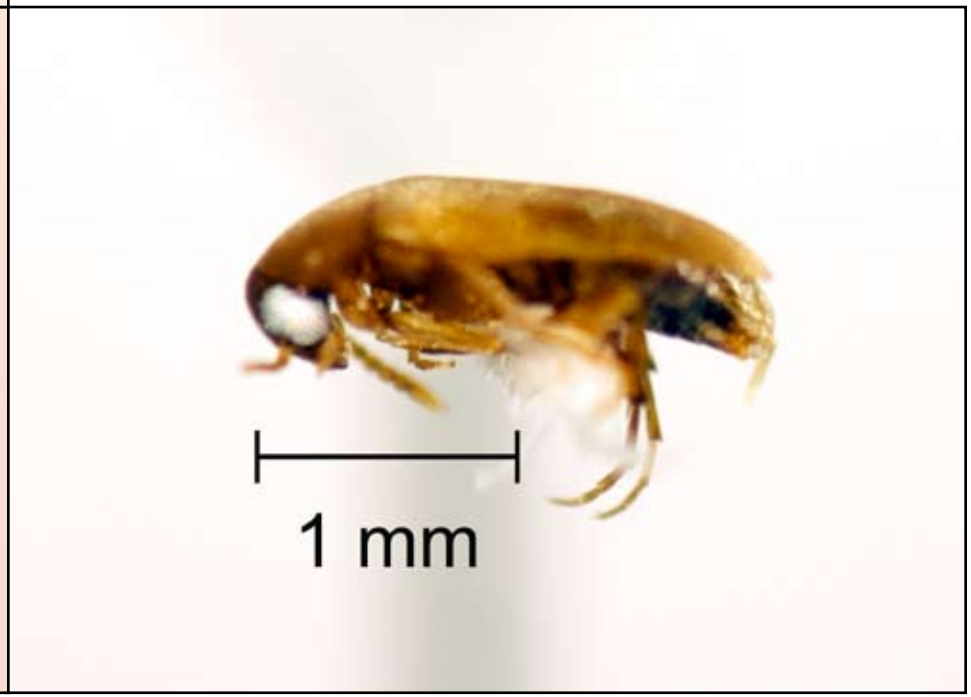


Pentaria sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Scraptiidae (False flower beetles)
Subfamily: Anaspidinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 0.13%
Sampled in April and August





Ground Beetles (Carabidae)

Calosoma sp.

Order: Coleoptera
Suborder: Adephaga
Family: Carabidae (Ground beetles)
Subfamily: Carabinae
Tribe: Carabini

Sampled in gypsum habitats
Relative abundance: 0.05%
Sampled in April









Lebiine sp.

Order: Coleoptera
Suborder: Adephaga
Family: Carabidae (Ground beetles)
Subfamily: Harpalinae
Tribe: Lebiini

Sampled in desert pavement habitats
Relative abundance: 0.16%
Sampled in August







Tetragonoderus pallidus

Order: Coleoptera
Suborder: Adephaga
Family: Carabidae (Ground beetles)
Subfamily: Harpalinae
Tribe: Cyclosomini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.80%
Sampled in April and August





Lady Beetles (Coccinellidae)

Coccinella septempunctata

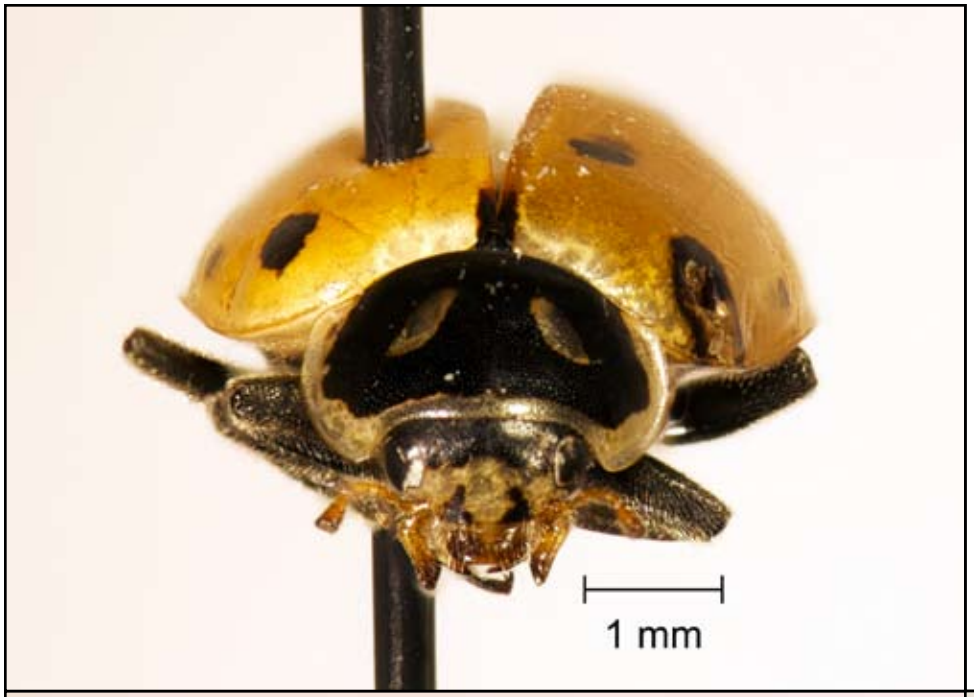
Order: Coleoptera
Suborder: Polyphaga
Family: Coccinellidae (Lady beetles)
Subfamily: Coccinellinae
Tribe: n/a

Sampled in gypsum habitats
Relative abundance: 0.03%
Sampled in August









Hippodamia convergens

Order: Coleoptera
Suborder: Polyphaga
Family: Coccinellidae (Lady beetles)
Subfamily: Coccinellinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 0.05%
Sampled in April



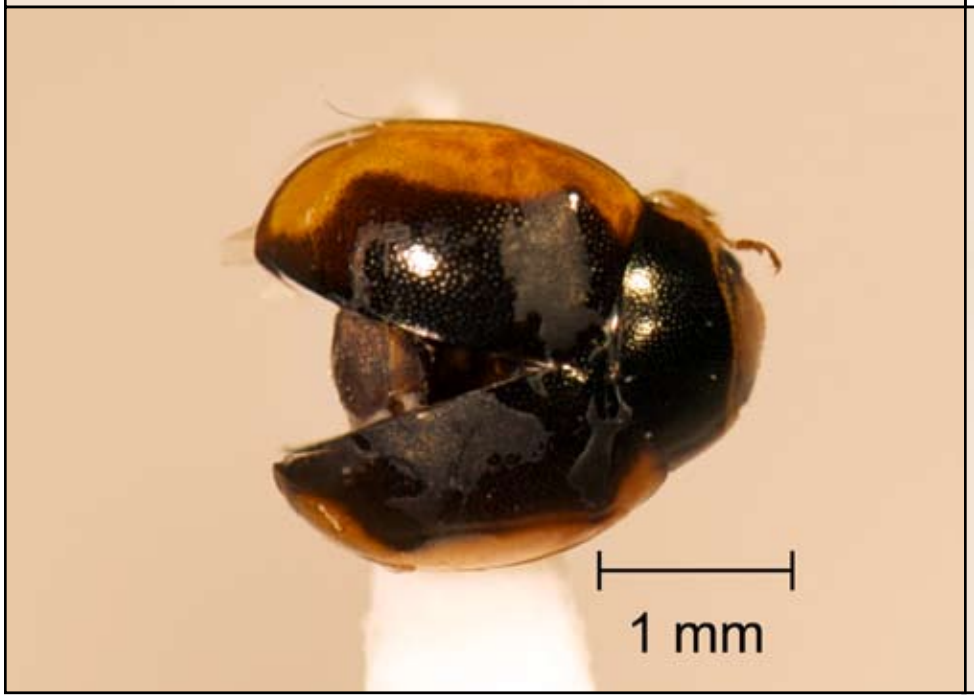




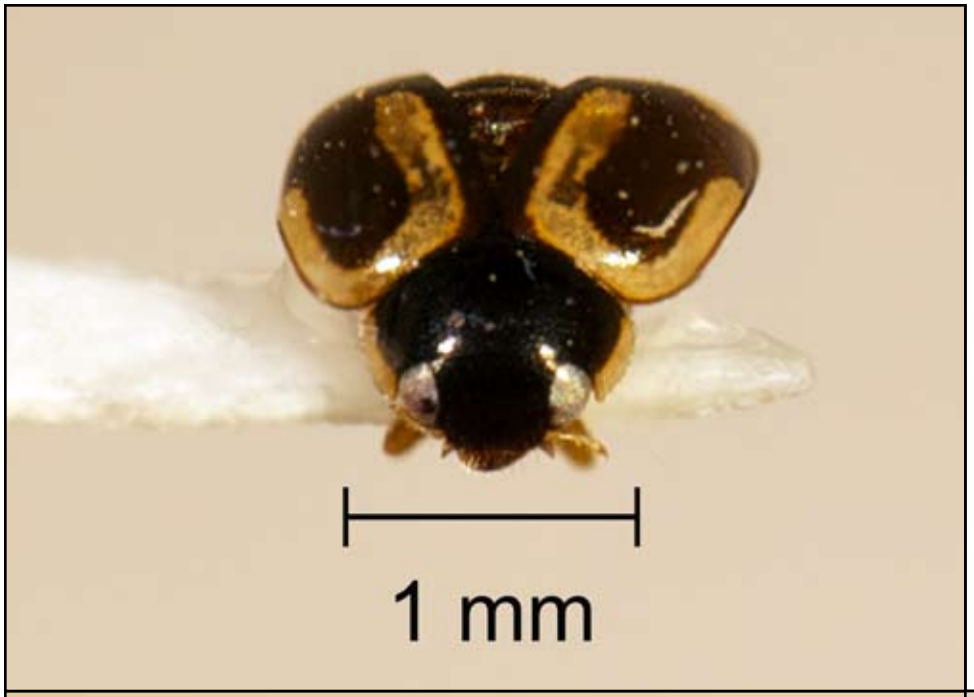
Hyperaspis sp. 1

Order: Coleoptera
Suborder: Polyphaga
Family: Coccinellidae (Lady beetles)
Subfamily: Scymninae
Tribe: Hyperaspidini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.08%
Sampled in April and August







Hyperaspis sp. 2

Order: Coleoptera
Suborder: Polyphaga
Family: Coccinellidae (Lady beetles)
Subfamily: Scymninae
Tribe: Hyperaspidini

Sampled in gypsum habitats
Relative abundance: 0.03%
Sampled in April





Leaf Beetles (Chrysomelidae)

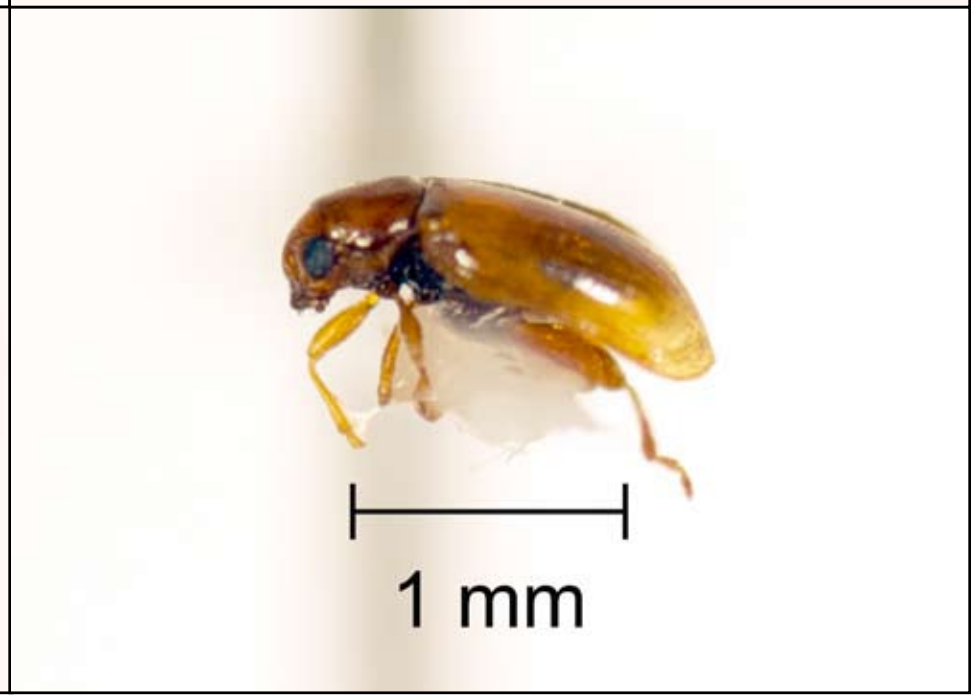
Glyptina sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Chrysomelidae (Leaf beetles)
Subfamily: Galerucinae
Tribe: Alticini (Flea Beetles)

Sampled in desert pavement habitats
Relative abundance: 0.08%
Sampled in April





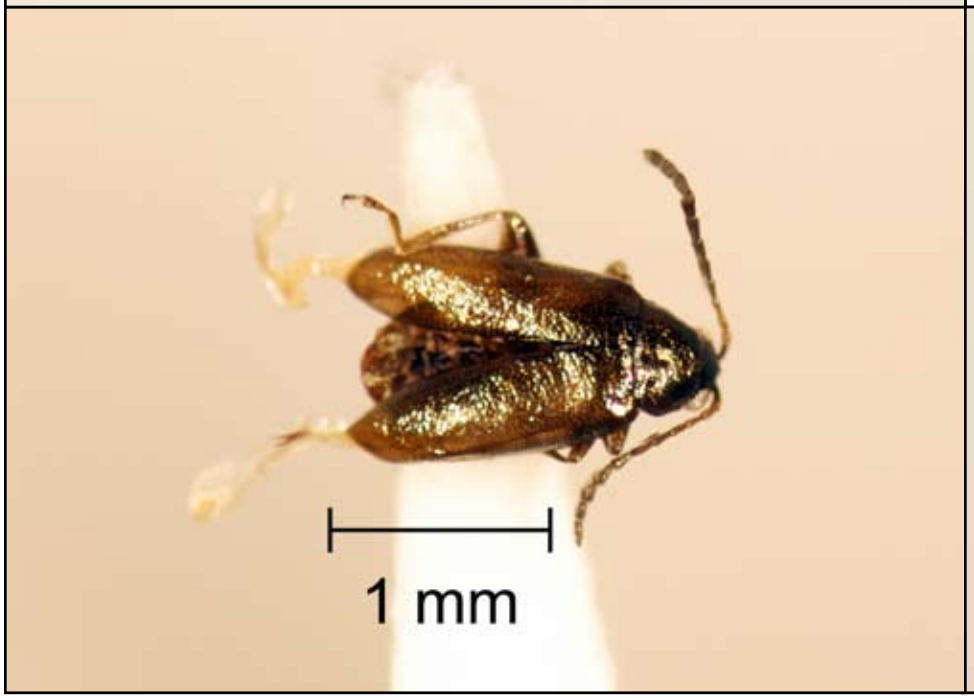


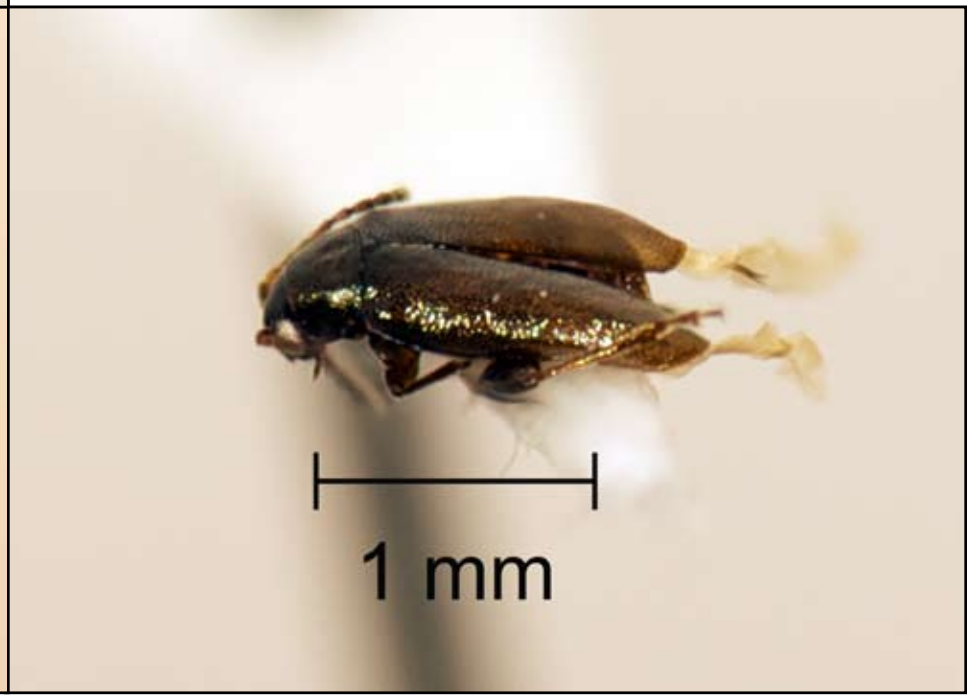


Phyllotreta sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Chrysomelidae (Leaf beetles)
Subfamily: Galerucinae
Tribe: Alticini (Flea Beetles)

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.19%
Sampled in April





Long-horned Beetles (Cerambycidae)

Aethecerinus latecinctus

Order: Coleoptera
Suborder: Polyphaga
Family: Cerambycidae (Long-horned beetles)
Subfamily: Cerambycinae
Tribe: Trachyderini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.24%
Sampled in August





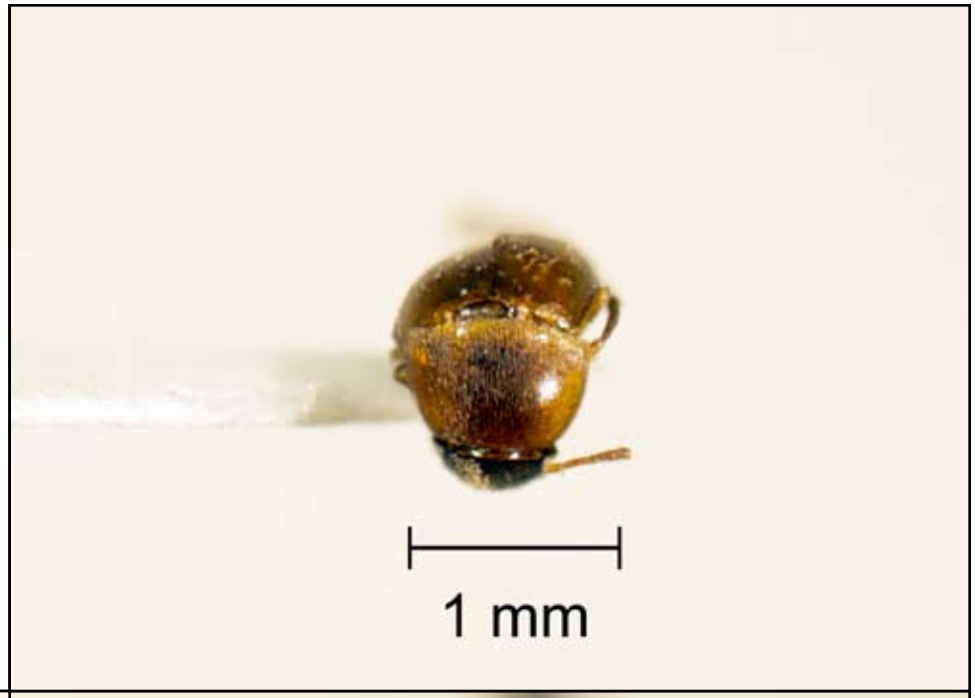


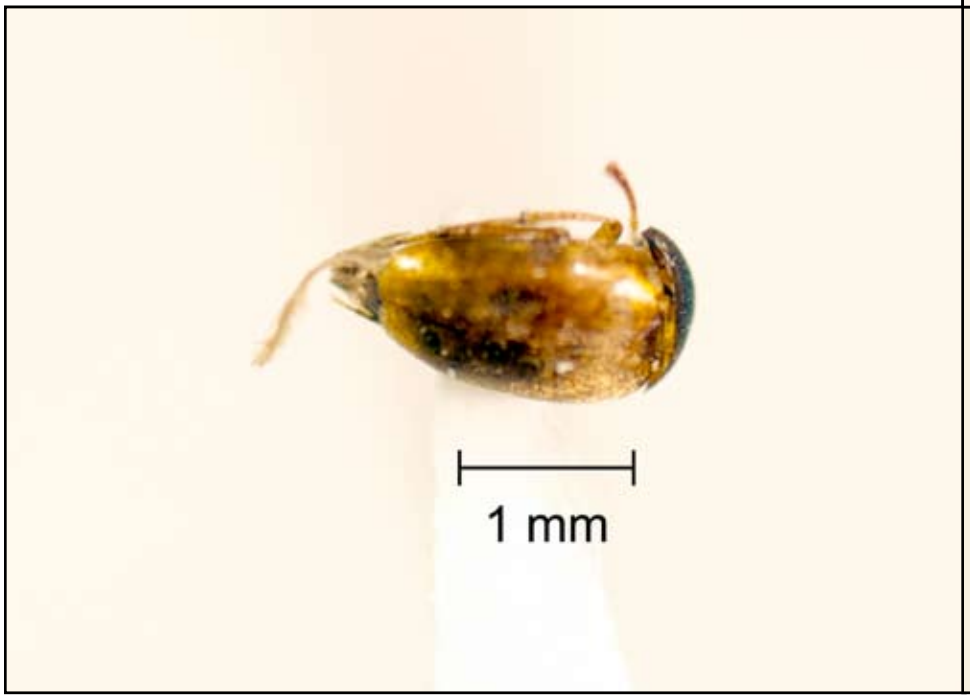
Round Fungus Beetles (Leiodidae)

Ptomaphagus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Leiodidae (Round fungus beetles)
Subfamily: Cholevinae (Small carrion beetles)
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.94%
Sampled in April and November





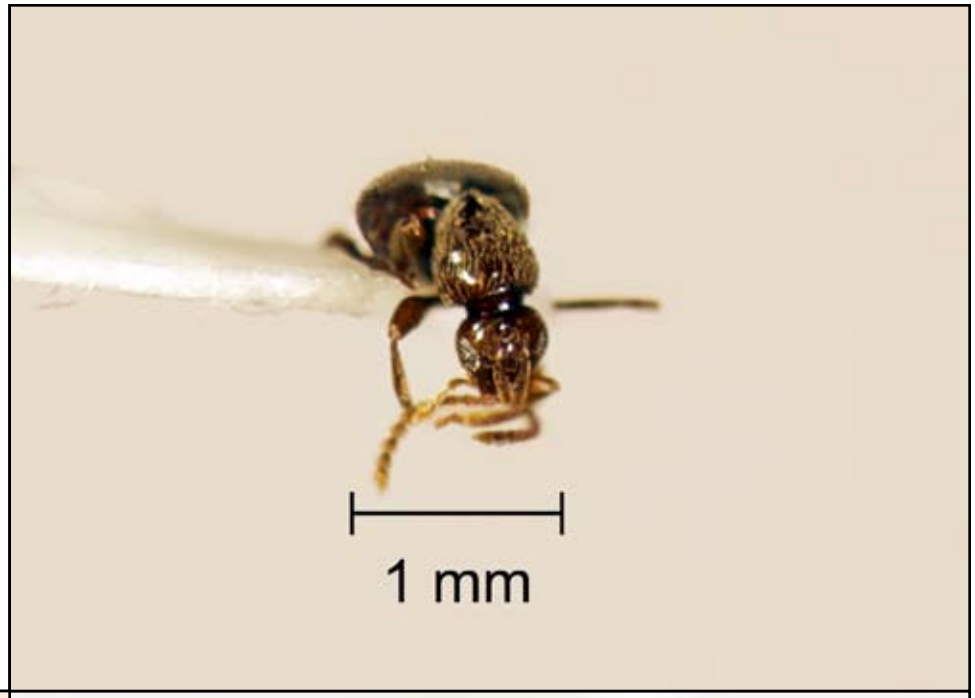


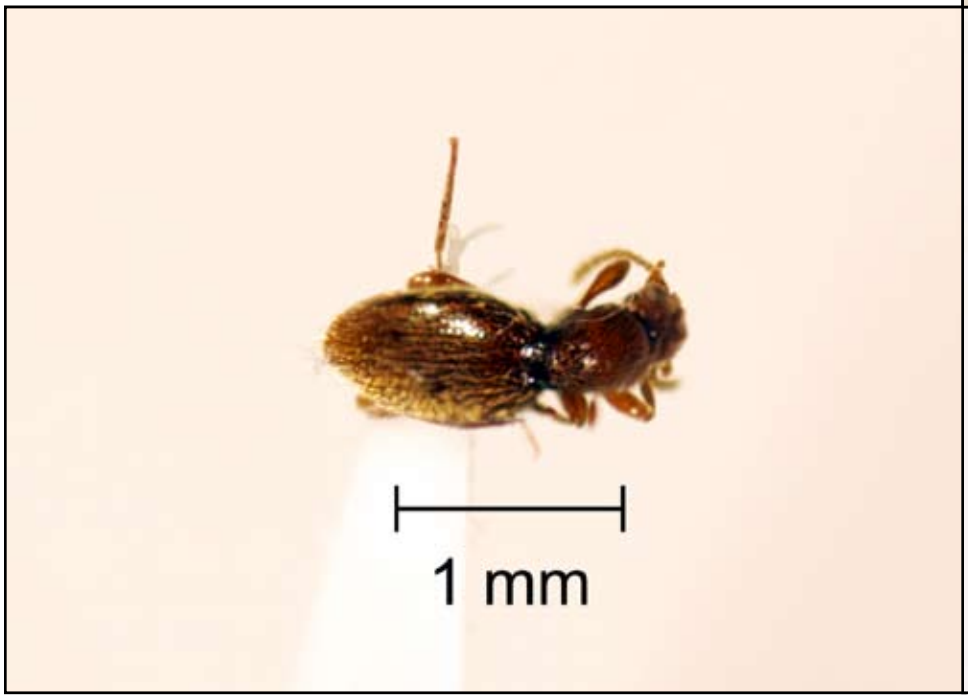
Rove Beetles (Staphylinidae)

Papusus (?n. sp.)

Order: Coleoptera
Suborder: Polyphaga
Family: Staphylinidae (Rove beetles)
Subfamily: Scydmaeninae
Tribe: Clidicini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.40%
Sampled in April and August







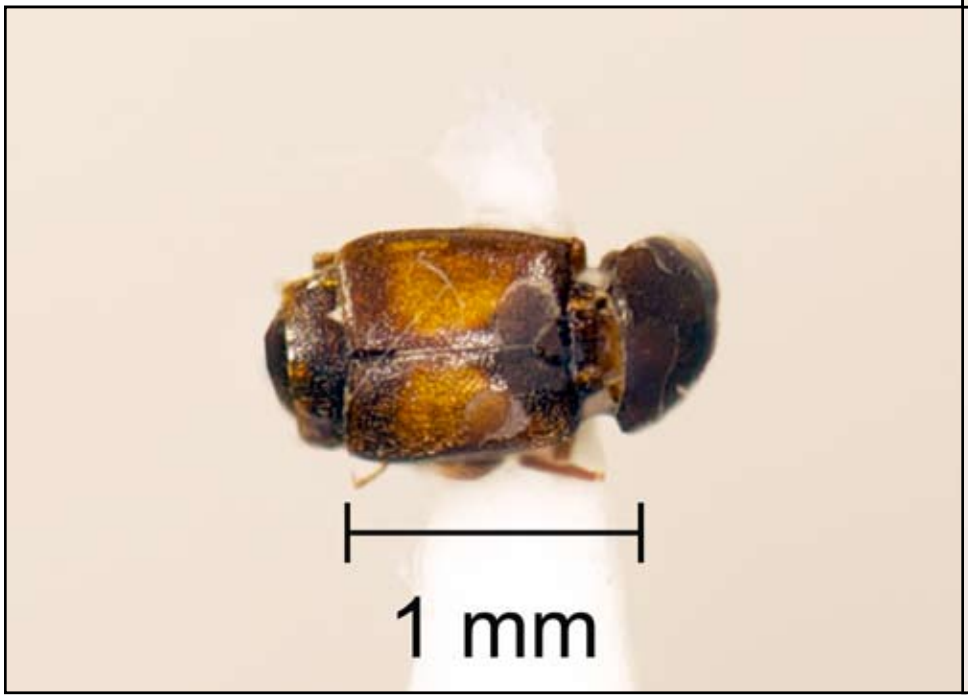
Sap-feeding Beetles (Nitidulidae)

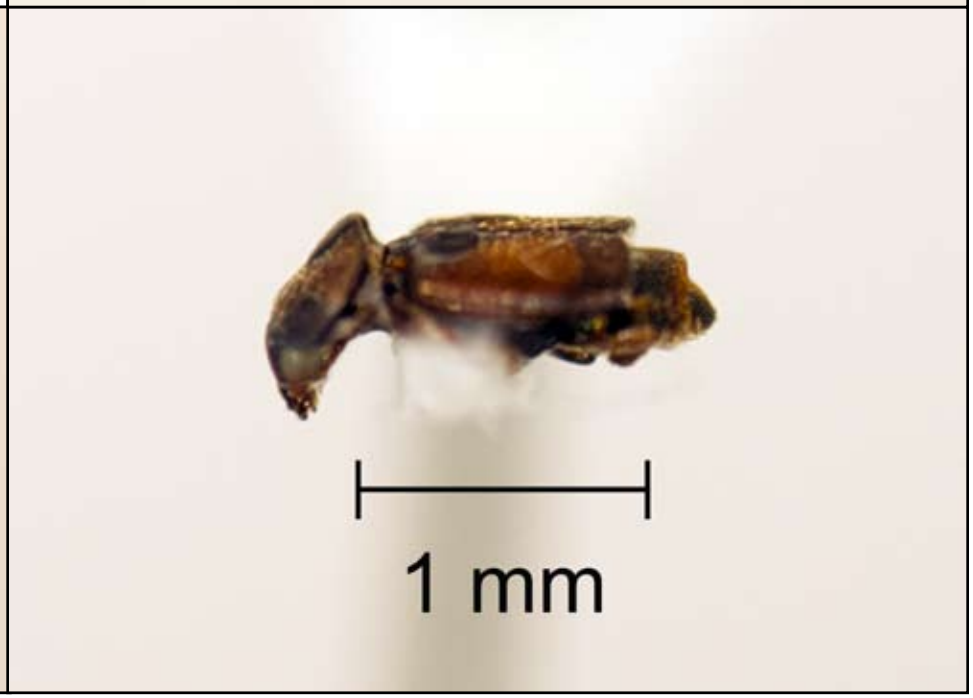
Carpophilus nr. *ligneus*

Order: Coleoptera
Suborder: Polyphaga
Family: Nitidulidae (Sap-feeding beetles)
Subfamily: Carpophilinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 0.08%
Sampled in August







Scarab Beetles (Scarabaeidae)

Diplotaxis n. sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Scarabaeidae (Scarab beetles)
Subfamily: Melolonthinae (May beetles and june bugs)
Tribe: Diplotaxini

Sampled in gypsum habitats
Relative abundance: 0.27%
Sampled in April and August









Gymnopyge sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Scarabaeidae (Scarab beetles)
Subfamily: Melolonthinae (May beetles and june bugs)
Tribe: Dichelonychini

Sampled in gypsum and desert pavement habitats
Relative abundance: 5.20%
Sampled in April







Phyllophaga n. sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Scarabaeidae (Scarab beetles)
Subfamily: Melolonthinae (May beetles and june bugs)
Tribe: Melolonthini

Sampled in gypsum and desert pavement habitats
Relative abundance: 2.65%
Sampled in April





Snout and Bark Beetles (Curculionidae)

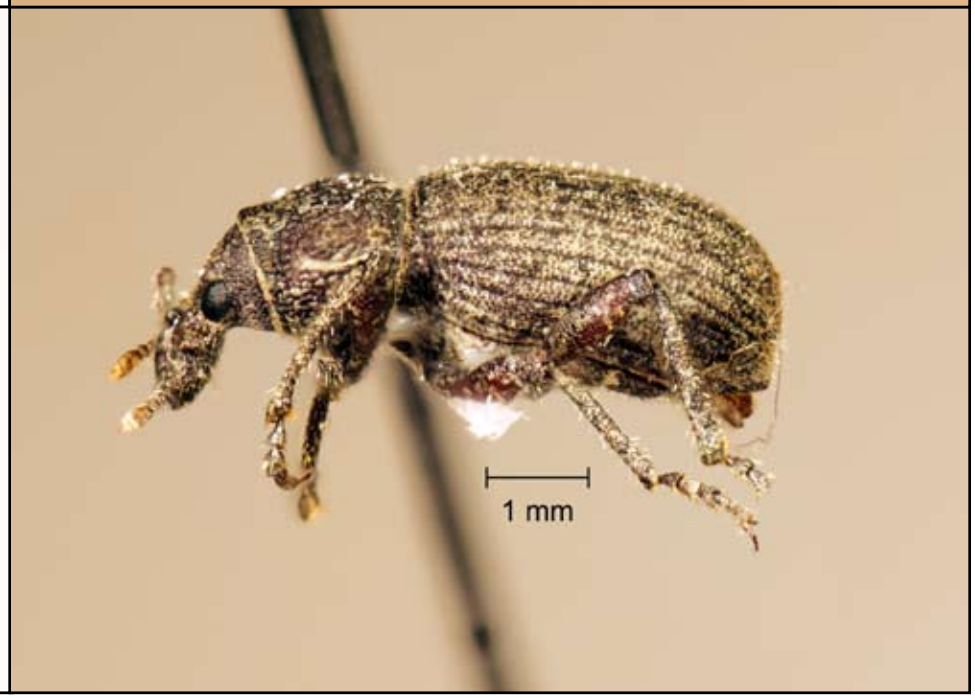
Entimine sp. 5

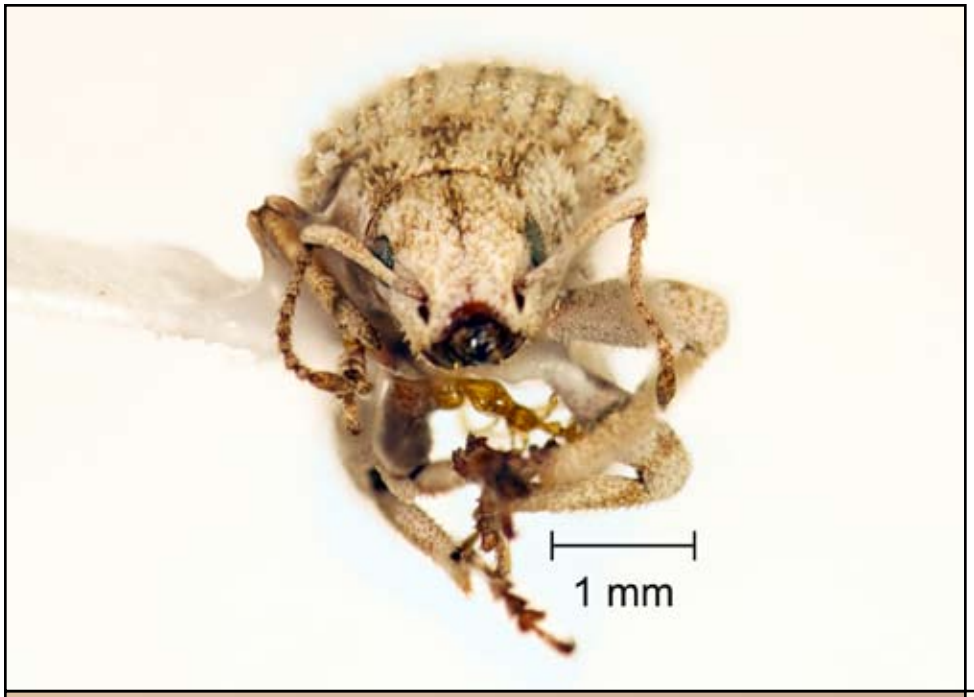
Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed weevils)
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.19%
Sampled in April and November





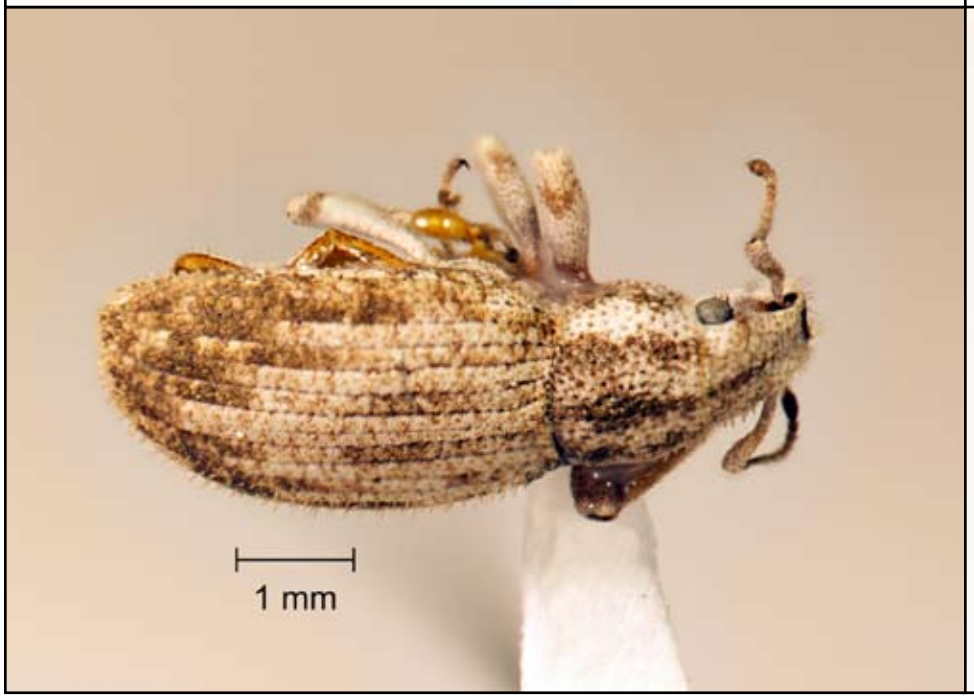




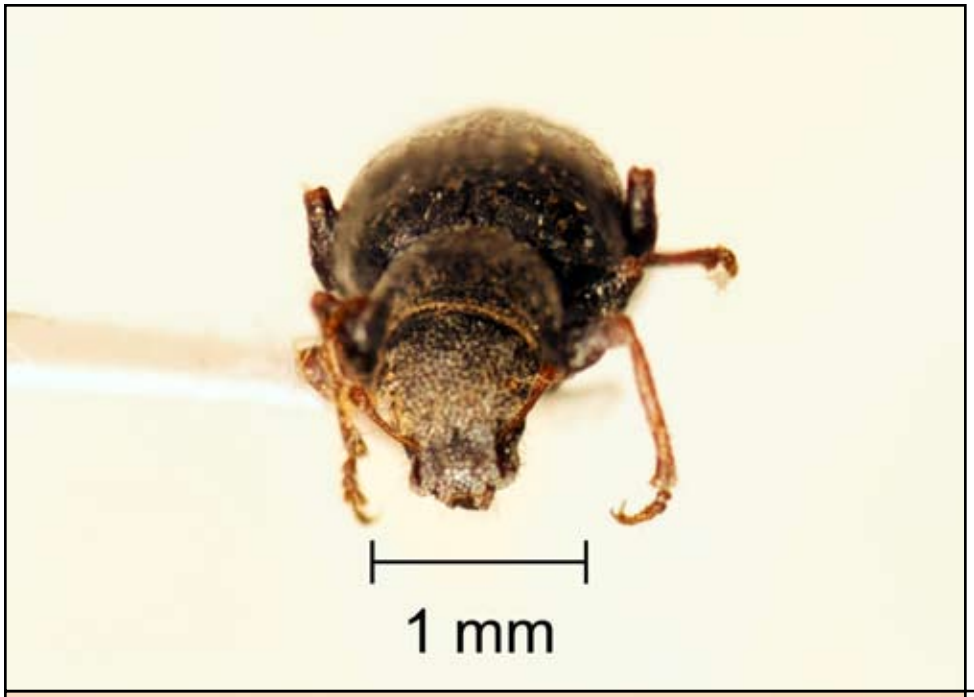
Eucyllus nr. *vagans*

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed weevils)
Tribe: Peritelini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.54%
Sampled in April, August, and November







Mesagroicus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Naupactini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.91%
Sampled in April





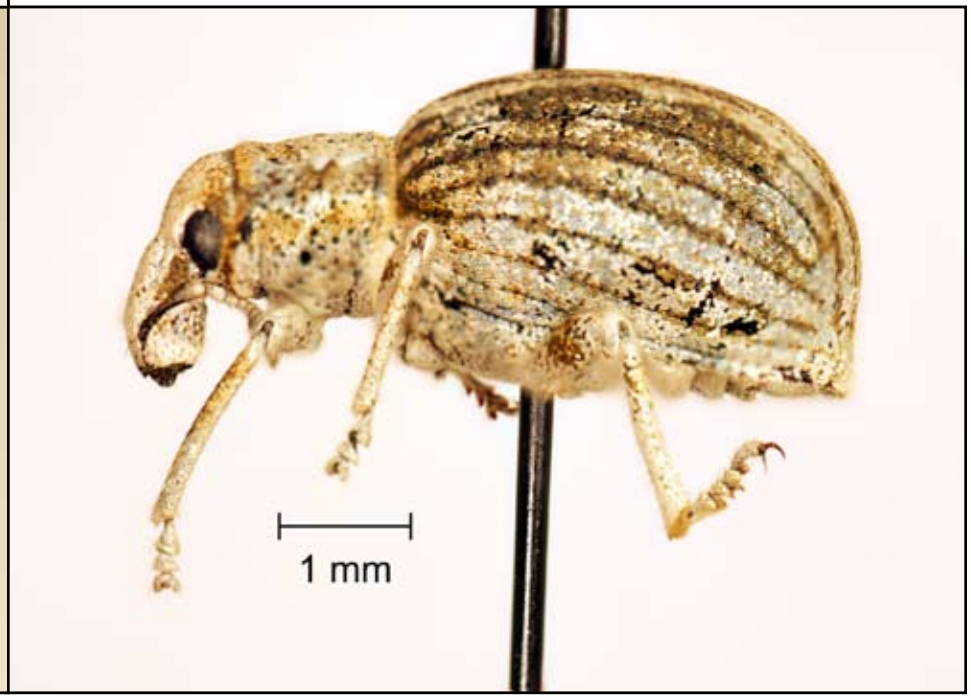


Ophryastes sp. 1

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Ophryastini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.85%
Sampled in April



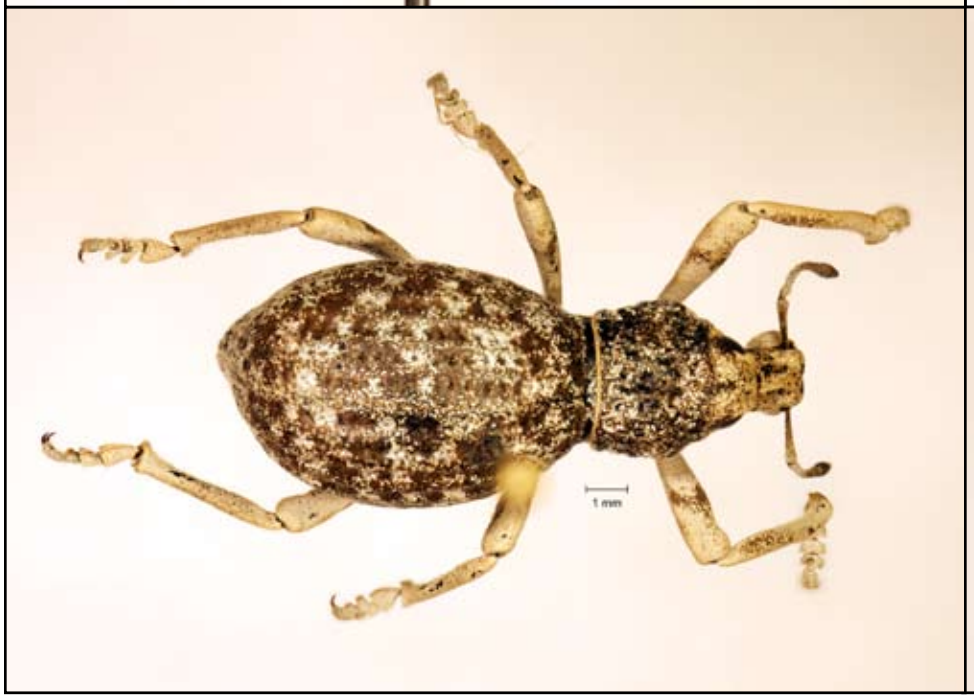




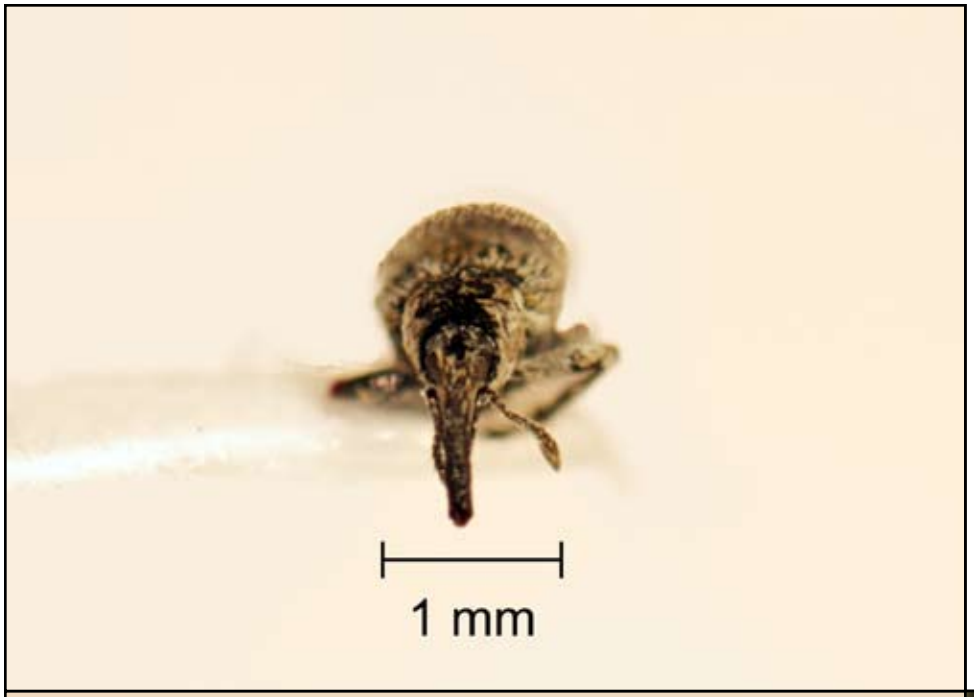
Ophryastes sp. 2

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Ophryastini

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.11%
Sampled in August



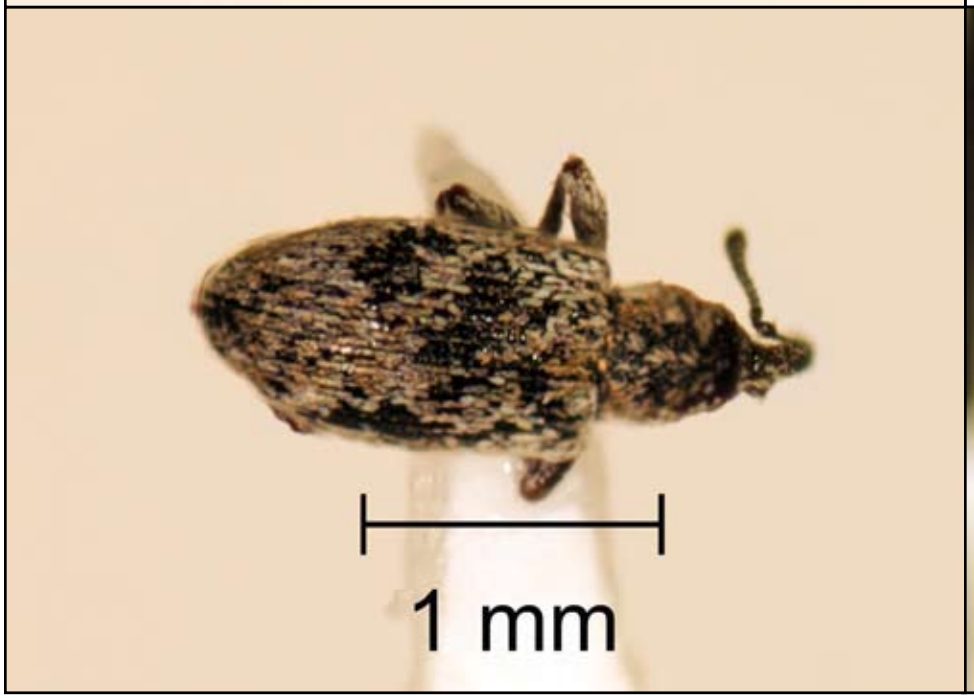




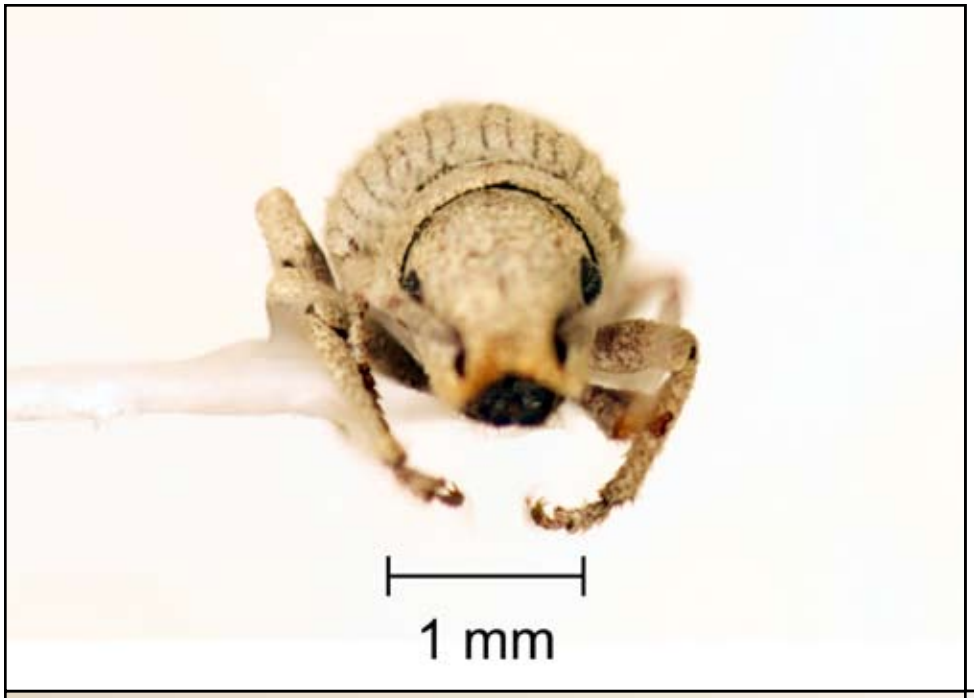
Smicronyx sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Curculioninae
Tribe: Smicronychini

Sampled in gypsum and desert pavement habitats
Relative abundance: 18.93%
Sampled in April



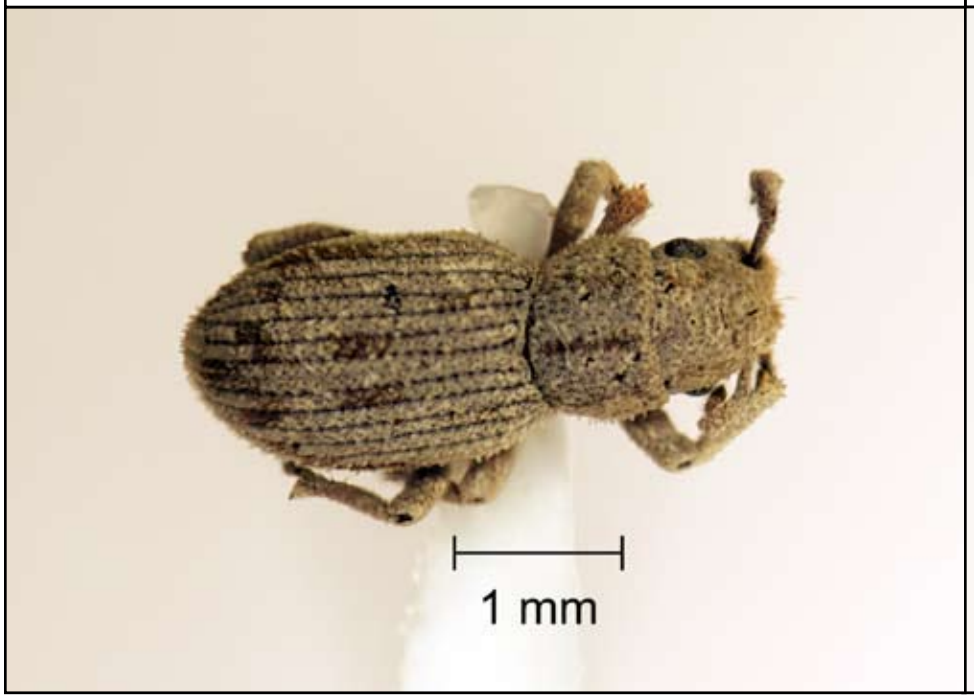




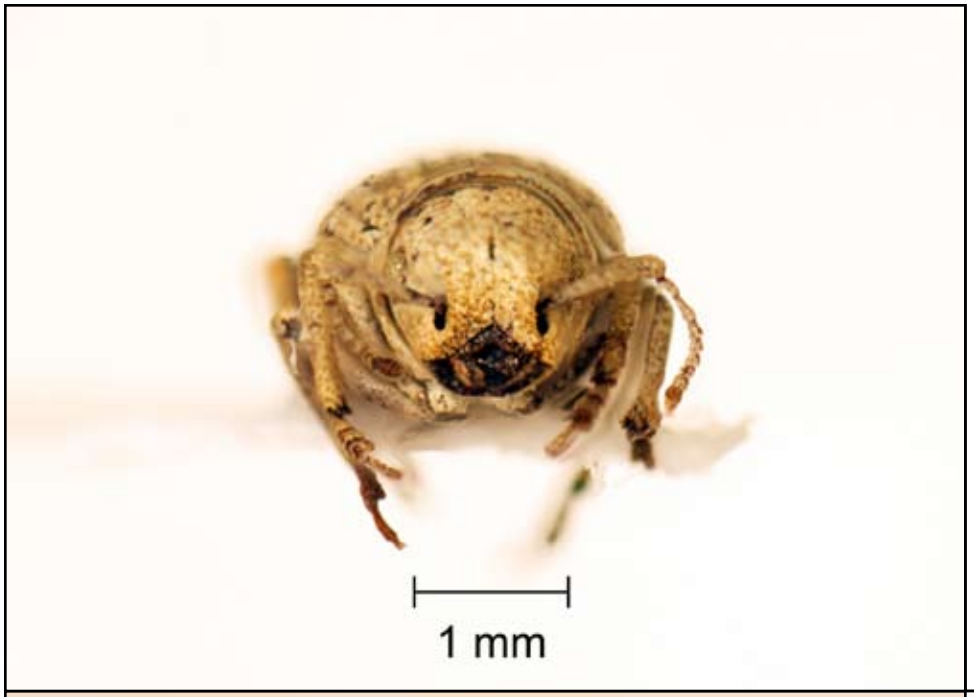
Thinoxenus sp. 2

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Peritelini

Sampled in gypsum habitats
Relative abundance: 0.16%
Sampled in August and November



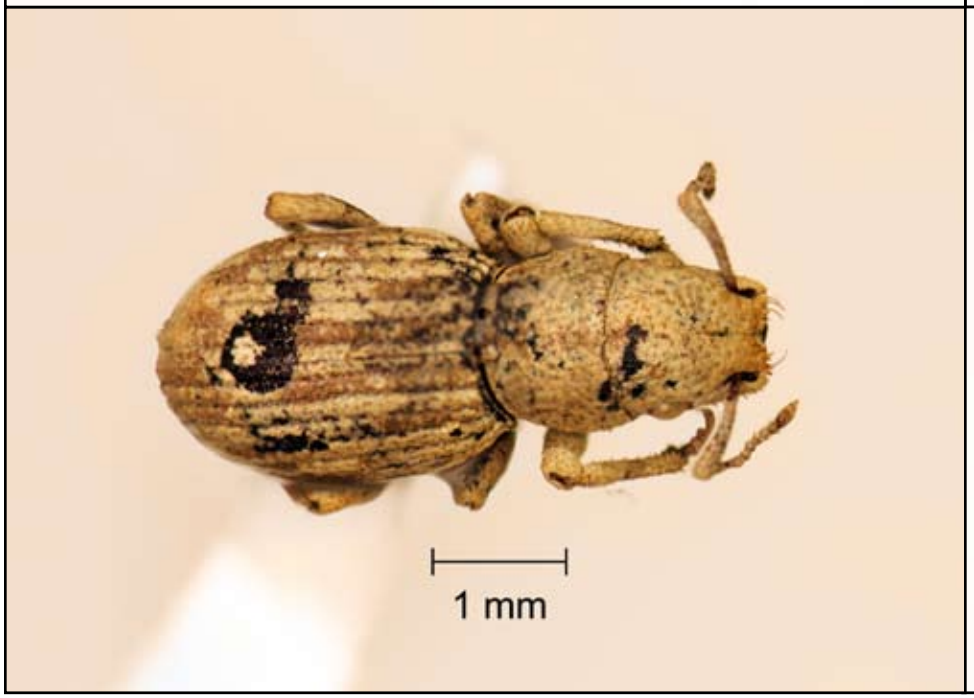




Thinoxenus sp. 3

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Peritelini

Sampled in gypsum habitats
Relative abundance: 0.16%
Sampled in April and November





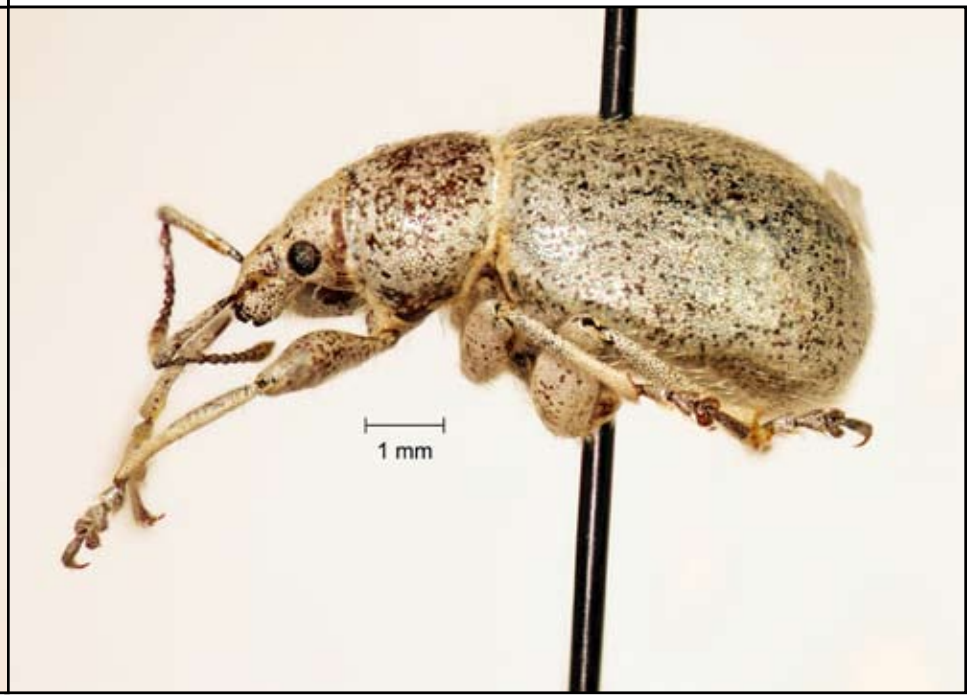


Trigonoscuta sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Curculionidae (Snout and bark beetles)
Subfamily: Entiminae (Broad-nosed Weevils)
Tribe: Geonemini

Sampled in gypsum habitats
Relative abundance: 0.05%
Sampled in April



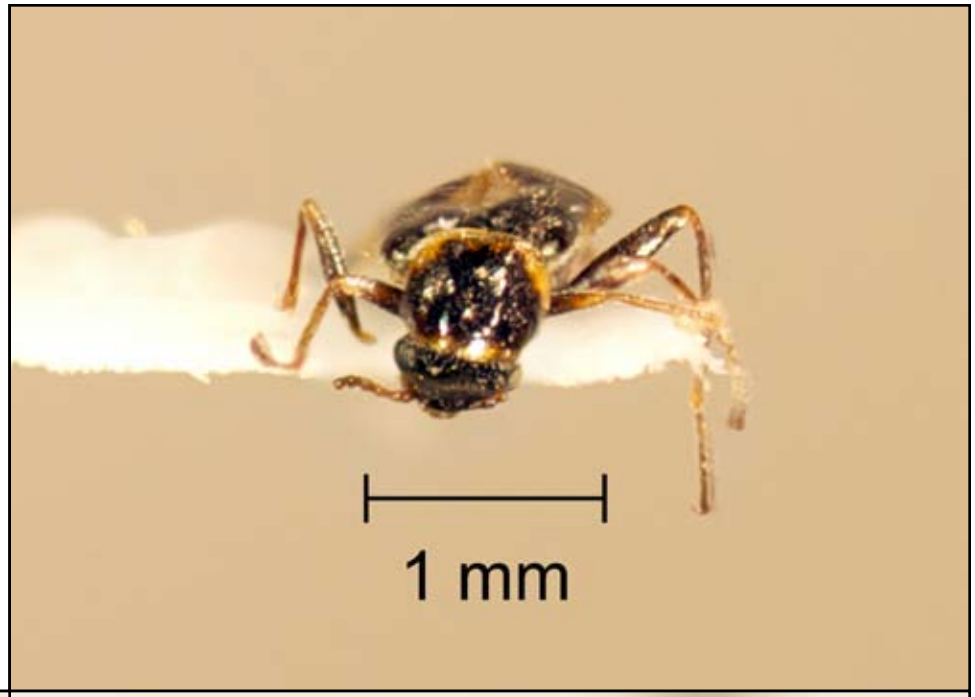


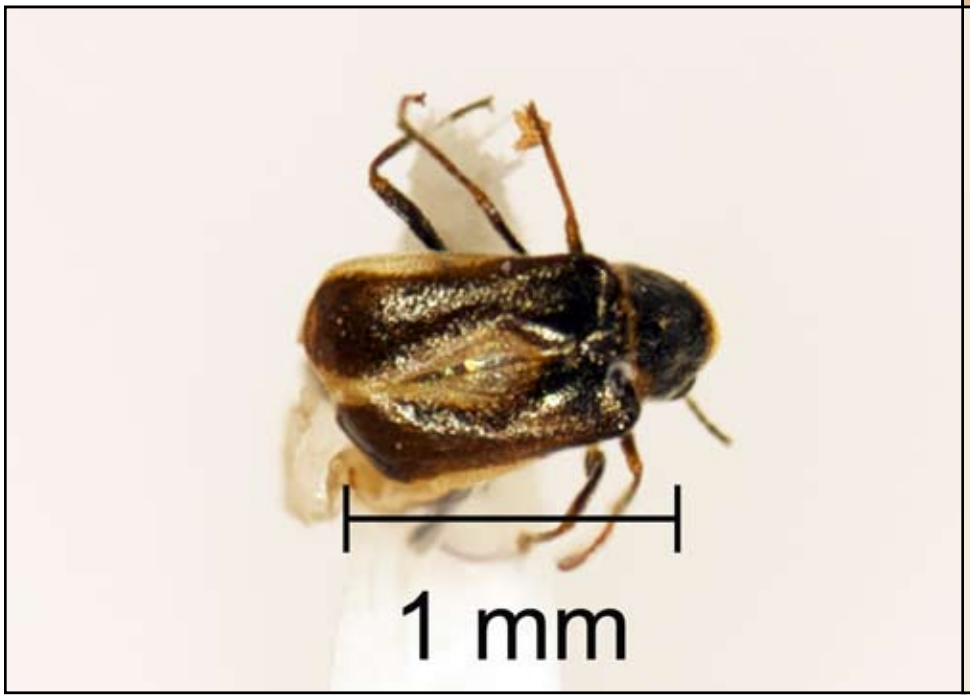
Soft-winged Flower Beetles (Melyridae)

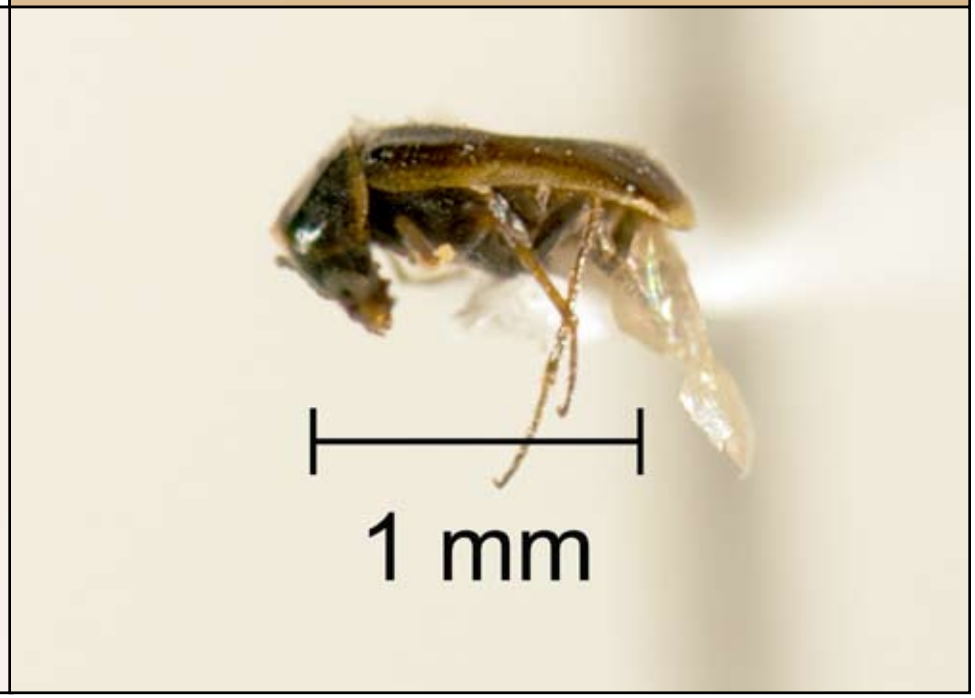
Attalus sp. 1

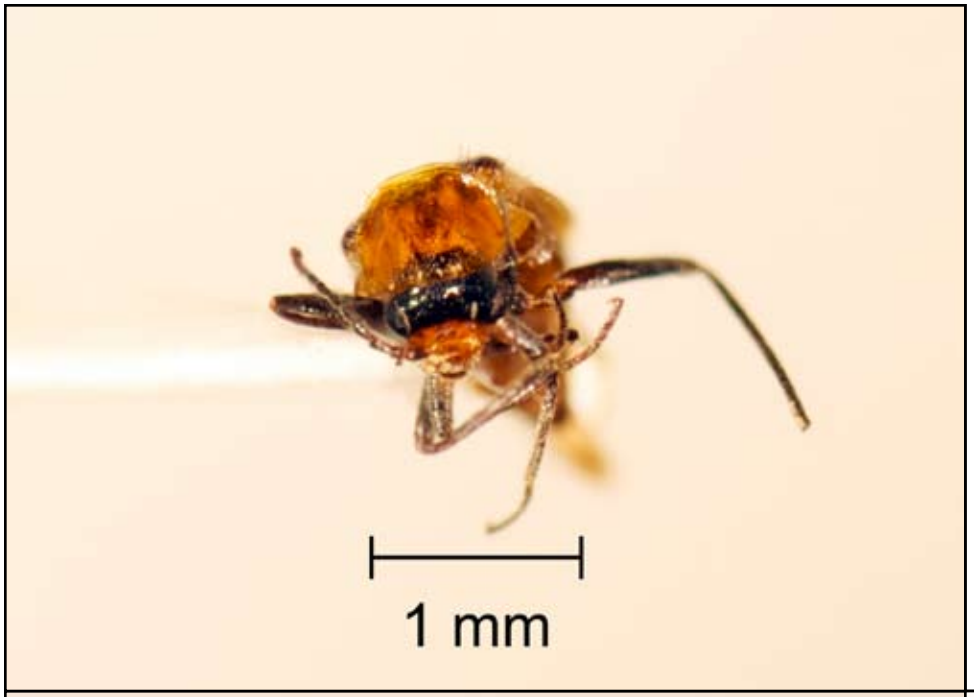
Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: Malachiinae
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.10%
Sampled in April





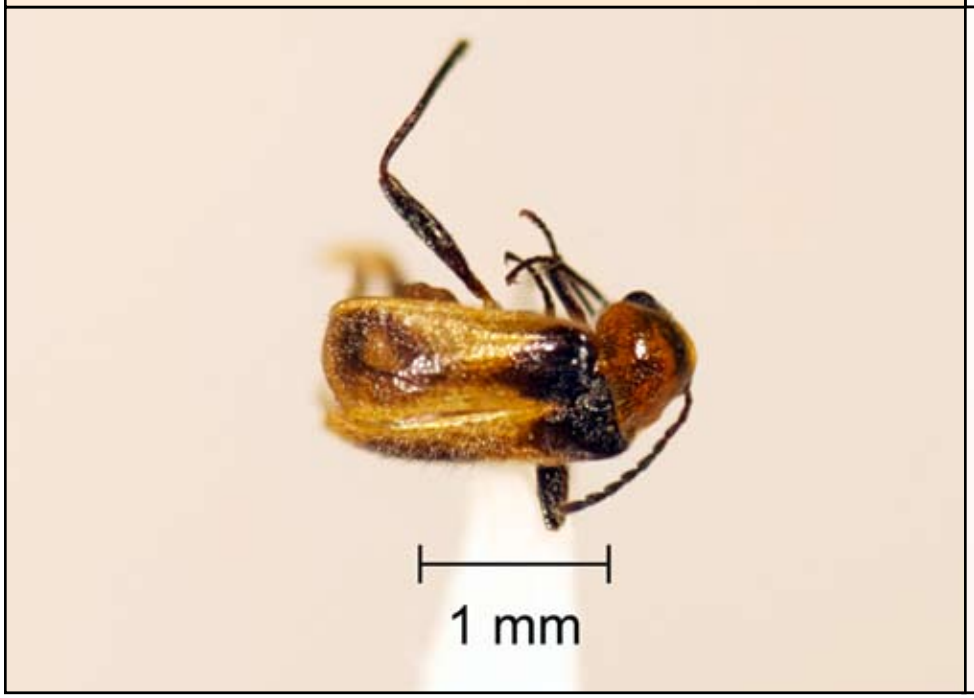


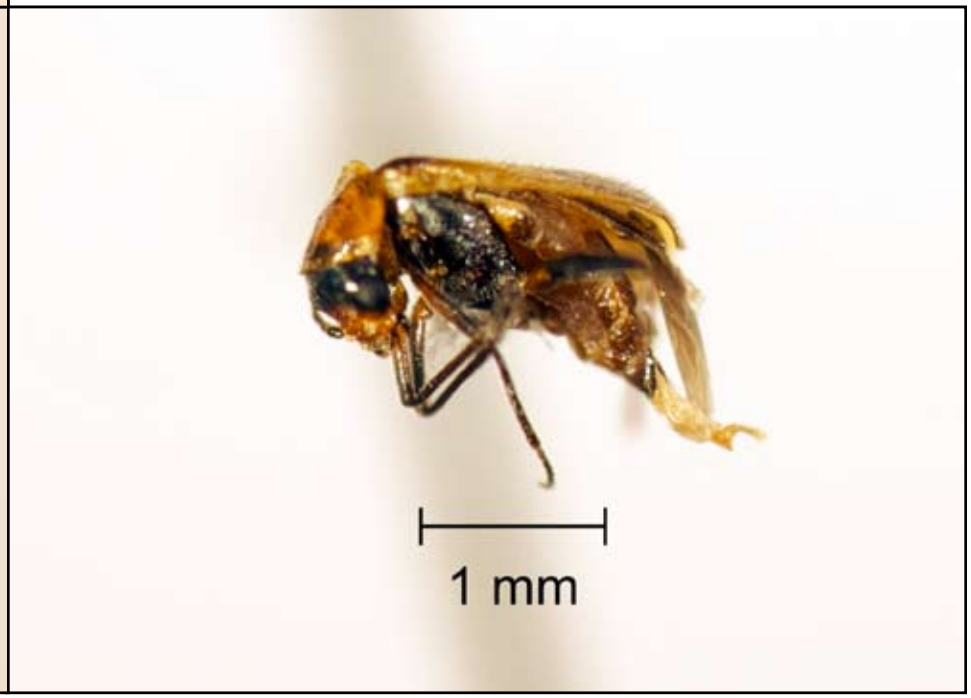


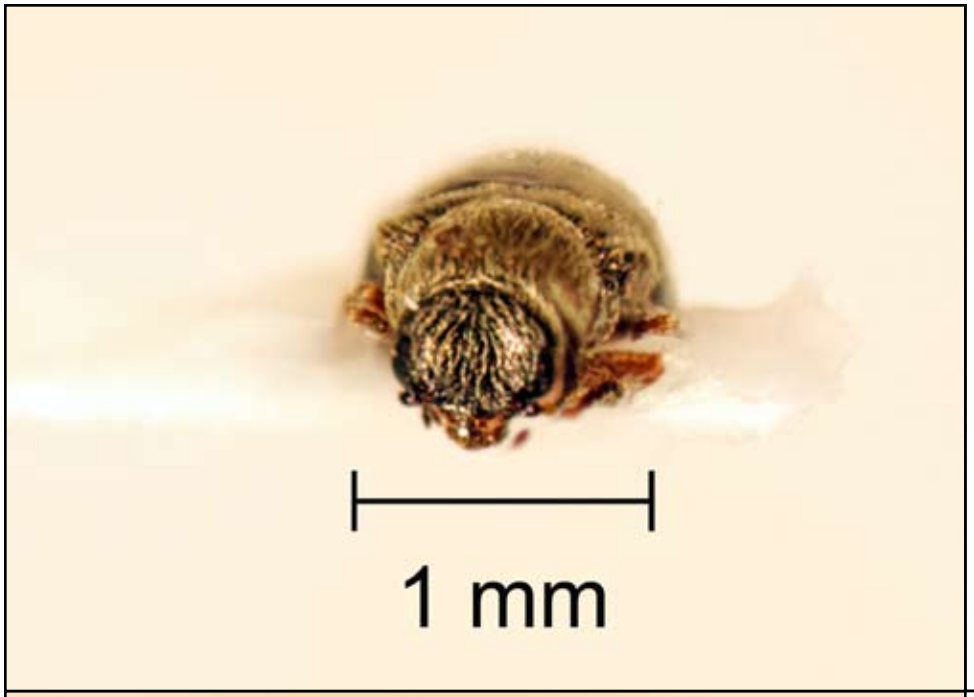
Attalus sp. 2

Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: Malachiinae
Tribe: n/a

Sampled in desert pavement habitats
Relative abundance: 0.05%
Sampled in April





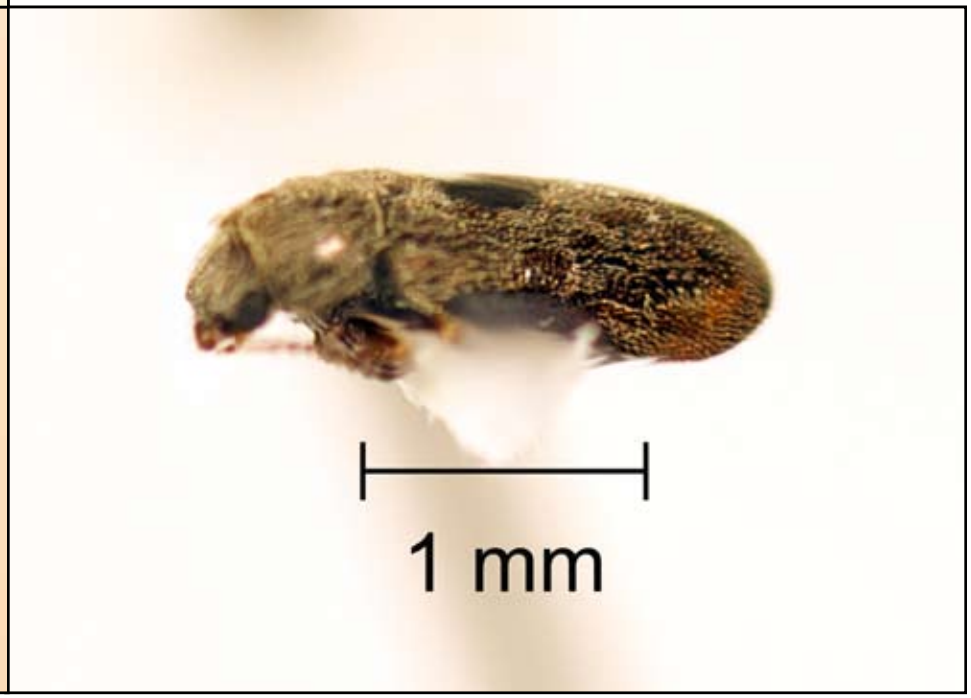


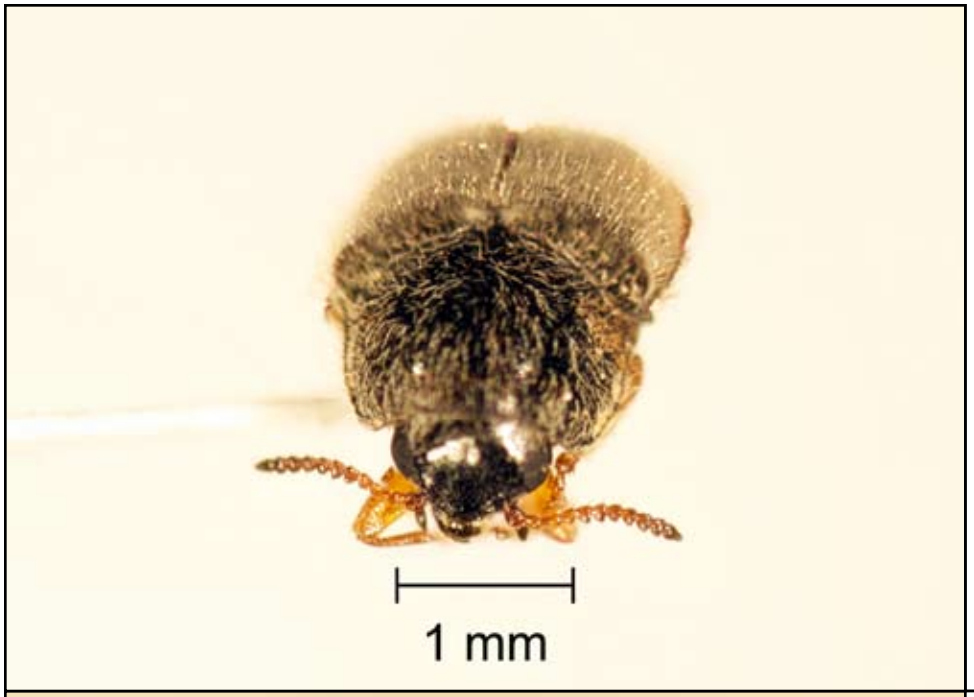
Dasytastes sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: n/a
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 0.99%
Sampled in April



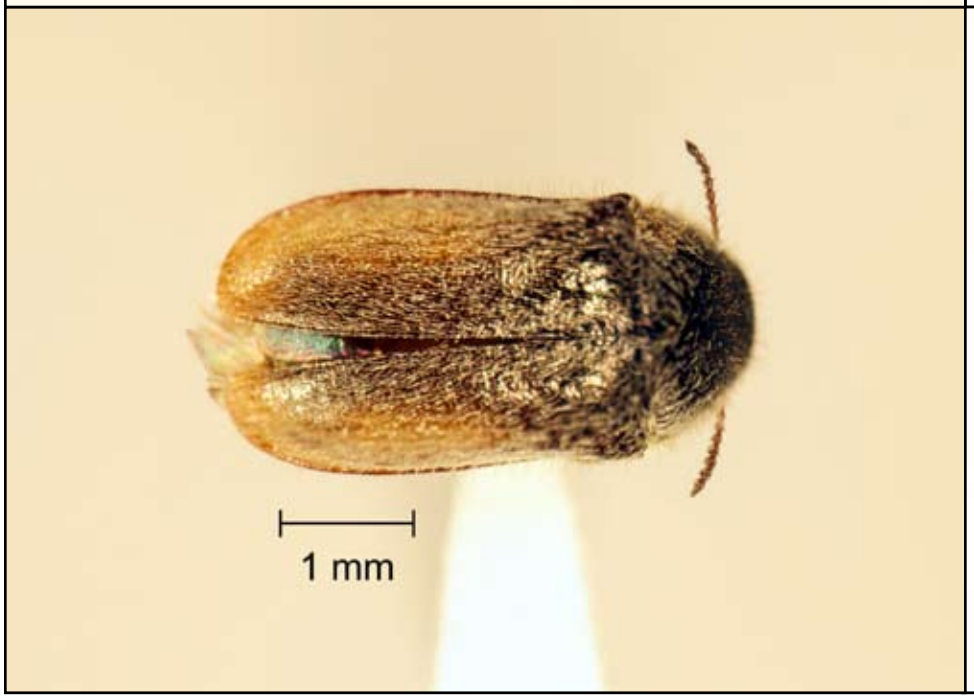




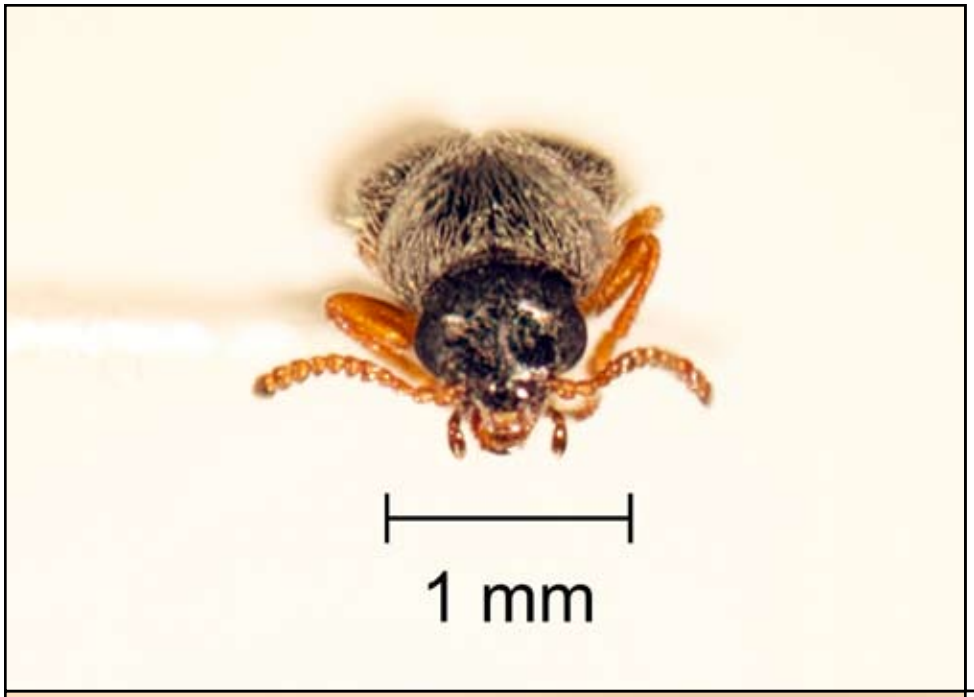
Eudasytes sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: n/a
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 9.87%
Sampled in April







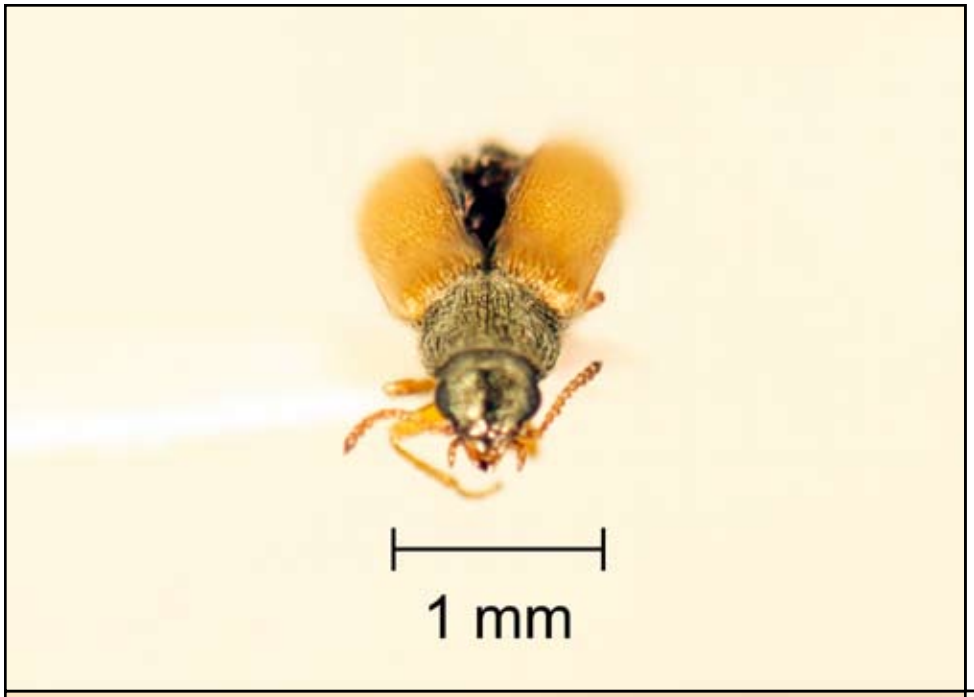
Eutrichopleurus sp.

Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: n/a
Tribe: n/a

Sampled in gypsum and desert pavement habitats
Relative abundance: 11.82%
Sampled in April



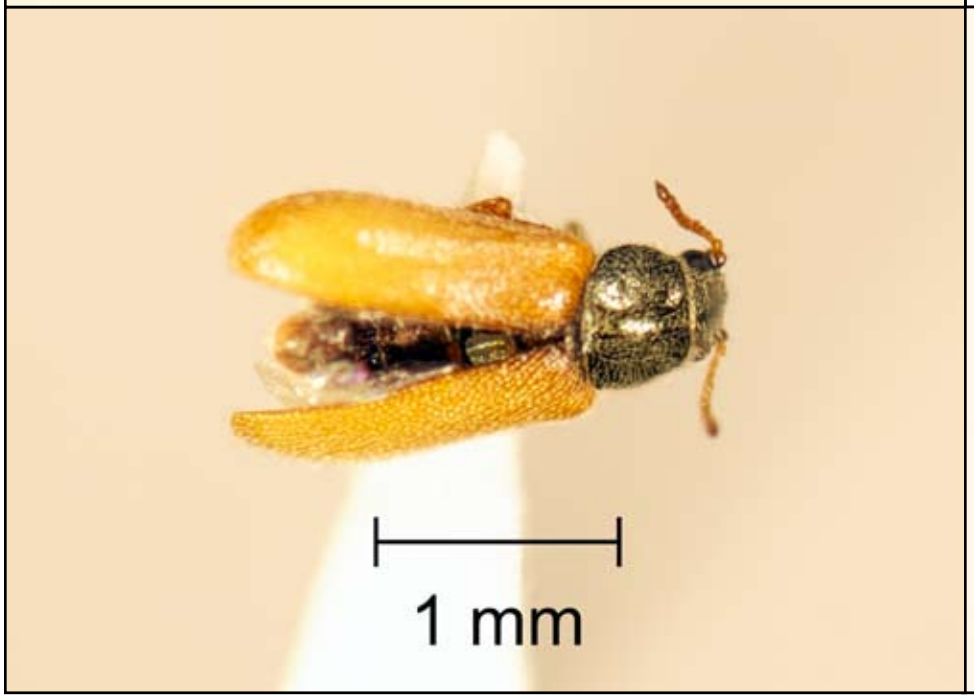


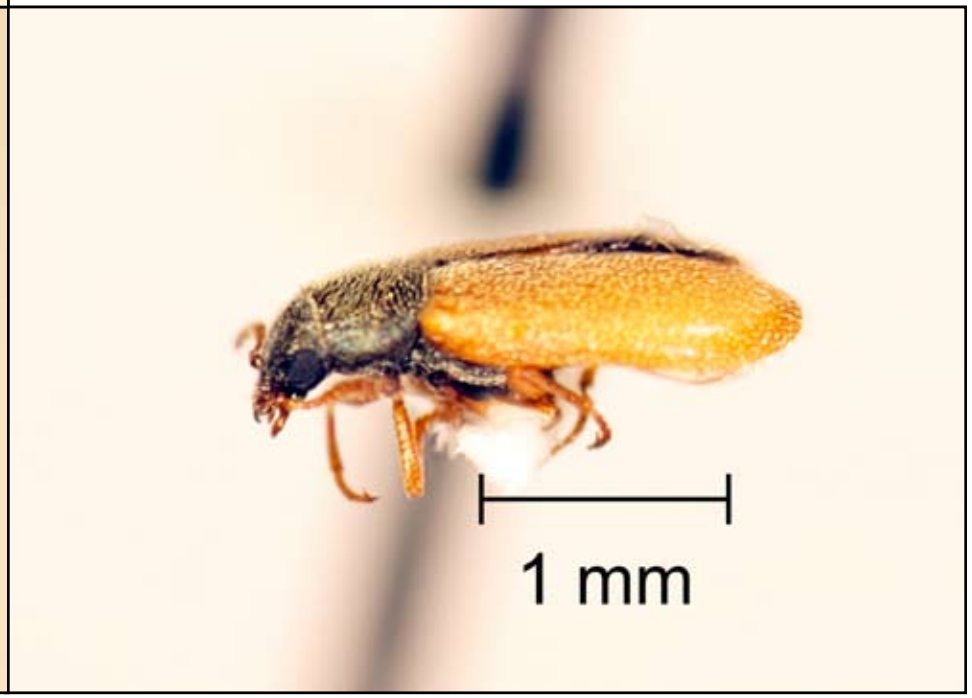


Trichochrous nr. *umbratus*

Order: Coleoptera
Suborder: Polyphaga
Family: Melyridae (Soft-winged flower beetles)
Subfamily: Dasytinae
Tribe: Listrini

Sampled in gypsum and desert pavement habitats
Relative abundance: 1.31%
Sampled in April





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