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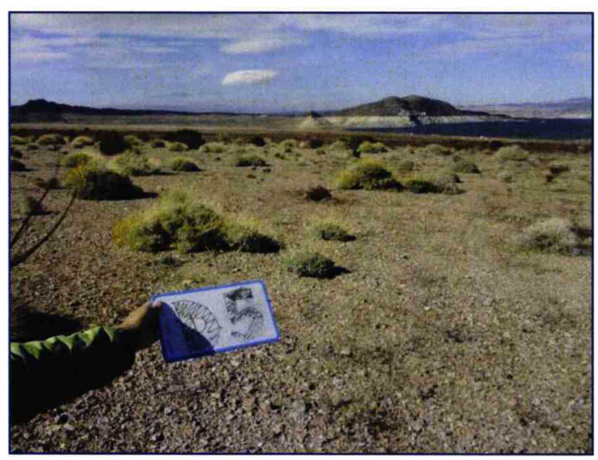
Investigation of Plant Colonization and Succession in the Lake Mead Shoreline Drawdown Zone

Principal Investigator: Cayenne Engel, Research Associate, Department of Environmental and Occupational Health, University of Nevada Las Vegas, Las Vegas, Nevada 89154-3064; cayenne.engel@unlv.edu

Federal Cooperator: Alice C. Newton, Vegetation Management Specialist, Lake Mead National Recreation Area, 601 Nevada Way, Boulder City, Nevada 89005



This project is funded by Lake Mead National Recreation Area and implemented through a cooperative agreement between the National Park Service and the University of Nevada Las Vegas.

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Executive Summary

"Investigation of Plant Colonization and Succession in the Lake Mead Shoreline Drawdown Zone" was a cooperative task agreement awarded to UNLV with the National Park Service (Lake Mead National Recreation Area) on September 15, 2010 with the term ending on May 1, 2013. The primary purpose of this task agreement was to work toward the accomplishment of four main project goals/products:

1. Examine patterns of natural plant species establishment within the drawdown zone of the Lake Mead shoreline
2. Describe the observed successional pathways, and evaluate post-disturbance recovery
3. Describe the exotic and native species distribution among the established species, with a focus on exotic species behavior through time since submersion.
4. Planting success in the drawdown zone: Assess how soil substrate, silt deposition, and lake level affect perennial species establishment.

These goals were met by completing thorough vegetation assessments in 150 plots positioned within three sites across Lake Mead National Recreation Area (LMNRA). We chose to place plots within three sites, each with different management concerns such as the impact of troublesome invasive species on visitor use and experience (Boulder Beach), the expansion of possible rare plant habitat as lake levels decline (Stewarts Point), and the establishment of native plant species for habitat along a riparian corridor heavily used by wildlife (Overton Beach).

From February 2011 – June 2011 we sampled the vegetation in the plots and collected soil samples for laboratory analysis. Results from the vegetation study were analyzed concurrently with soils data to examine patterns of successional development and recovery, and determine which soil and environmental factors that affect patterns in plant community composition across sites. Results from this study (project goals 1-3) are reported in a manuscript which was submitted to the journal *Lake Reservoir and Management* in May, 2012 (pages 9-40), and accepted with revisions December, 2012.

During the establishment and data collection in the vegetation plots, LMNRA nursery staff were propagating four native species that we requested based on omnipresence in the intact communities across all three study sites (*Ambrosia dumosa* (white bursage), *Encelia farinosa* (brittlebush), *Hymenoclea salsola* (cheesebush), and *Larrea tridentata* (creosote bush). Experimental plots were established to test the viability of planting vegetation islands as a method of active revegetation for use in areas of specific management concern. The design was intended to test whether there was a difference in survival rate across soils that have been unsubmerged for different amounts of time and may have different properties as time since submersion increases. In December 2011, plants were outplanted at 18 plots, each adjacent to one of the plots used in the vegetation survey so that we could infer data from similar soil composition. Results are presented in this document on pages 44-45.

Summary of project activity and results

- We established 150 plots distributed in transects across three sites where we assessed plant species identity and abundance (including annual and perennial, native and exotic species). Plots were stratified across five elevations representing sites that were last submerged in 2008, 2005, 2002, 1998, and undisturbed control sites. Sampling occurred at Boulder Beach, Stewarts Point, and Overton Beach, each representing different site histories and management needs.
- We recorded dead and live density and abundance of tamarisk (*Tamarix ramosissima*) in each of the 150 plots to monitor population changes through time and to correlate with soil characteristics and native vegetation establishment.
- Soil samples were collected from each plot and analyzed at the UNLV Environmental Soils Analysis Laboratory for texture and chemical composition. Abella lab members performed bulk density and electrical conductivity (a proxy for soil salinity) analyses.
- Plant species richness and cover of native perennial species generally increased with time since submersion, while the density of *Tamarix ramosissima* declined. The oldest sites were colonized largely by early successional native perennial species, such as *Stephanomeria pauciflora*, *Encelia farinosa*, and *Hymenoclea salsola.*
- There were few differences in soil composition between younger and older sites, indicating that overall, we did not observe major changes to soil structure or composition by submersion, nor was there strong evidence of lasting effects of siltation at these sites.
- Managers can likely anticipate: 1) continued development of an early successional native shrubland persistent for several decades, and 2) eventual colonization by species of the mature vegetation inhabiting never-submerged surfaces.
- We observed colonization of formerly submerged land by a rare plant species of special conservation designation (*Arctomecon californica*).
- A manuscript describing the results of the natural establishment along the shoreline was submitted to *Lake and Reservoir Management* in May, 2012.
- An outplanting experiment designed to test survival of native species across sites and time since submergence was initiated in December, 2011. We planted 18 plots each containing 22 individuals of each of the four native species including *Ambrosia dumosa* (white bursage), *Encelia farinosa* (brittlebush), *Hymenoclea salsola* (cheesebush), and *Larrea tridentata* (creosote bush).
- We saw no differences in survival rate across formerly submerged sites of different ages. Site differences were much more evident than time since submersion, with greater success at Overton Beach than Stewarts Point. This indicates that active restoration efforts could be successful across much of Lake Mead, which shares sandy, rocky soil types found at the Overton Beach site.

Investigation of Plant Colonization and Succession in the Lake Mead Shoreline Drawdown Zone

Project Background and Objectives

Southwestern deserts are vulnerable to disturbances including off-road vehicle activity, mining, and fire, among many others. In the Mojave specifically, the footprint left from major disturbances may last hundreds of years (Wells 1961, Vasek 1980, Belnap and Warren 2002). Disturbances distort habitats by altering soil structure and removing plant cover, which can negatively impact sensitive wildlife species, and can result in severe soil wind erosion resulting in hazardous air pollution (Grantz, et al. 1998, Esque, et al. 2003). However, the processes that drive plant establishment, especially the primary succession which occurs after severe disturbances, has long puzzled ecologists and environmental managers.

There are currently competing theories regarding what drives successional dynamics, or if they exist at all. Some believe that the age and stability of the community determines the degree to which it can recover (Webb et al. 1988), or succession may not occur at all because what would typically be "early successional" species are also present in desert climax communities (Vasek 1983). However, climate and other conditions (e.g., invasion of exotic species, anthropogenic N deposition) have changed since the communities developed, so another stable community may become established instead of the original community. Several concepts have been advanced in the literature about succession in deserts. Disturbance type has been theorized to influence succession, where the most severe disturbances, those that completely remove surface vegetation or heavily compact soils, retard succession and recovery (Webb et al. 1987). It is uncertain how these principles will apply to vegetation colonization of desert lakeshores.

The slow growth and establishment rates of plants in the Mojave Desert make it difficult for researchers to study changes in deserts on the typical short research funding cycles and poses logistical challenges for finding sites that have had sufficient time to actually record a succession (Cody 2000, Guo 2004). A variety of studies in American Southwest deserts have examined plant establishment after disturbances (e.g., Bolling et al. 2000, Prose et al. 2000, Alford et al. 2005). However, fewer have examined primary succession and none have assessed shoreline succession. This shoreline succession may differ from other types because soil properties have been altered by lake inundation and plant propagules have been removed.

Understanding natural vegetation reestablishment after disturbance is important for several reasons. First, understanding whether natural reestablishment can assist decision-making on whether attempting active revegetation is needed or worth the expense. Second, understanding natural recovery could help inform how to make active revegetation more successful by mimicking natural processes. Third, knowledge of recovery can allow estimates of how long original plant communities may take to reestablish, or even if they will fully recover since present climates may differ from the past evolutionary environments of the species.

Damming is an example of a disturbance that drastically alters the environment, and little is known about recovery once water subsides. In the Mojave, lake formation from damming is a relatively unusual, but locally catastrophic due to the magnitude of the disturbance, and it can affect hundreds of square miles at a single location. Exposed lakebeds are generally slow to establish plant communities due to limitations of seed dispersal in addition to inhospitable soils (Schaber 1994, Fort and Richards 1998). Until recently, water levels in Lake Mead were dropping consistently from full capacity in 1998 (averaging 1214 feet elevation) to a low in 2010 of 1091 feet. Low Colorado River runoff coupled with the need for a fixed amount to be released to meet downstream municipal and agricultural demands result in this decline (Figure 1). After the lake recedes the land is barren, soil structure is modified from pre-dam conditions because of siltation and salinization, and soil seed banks are depleted. There is little understanding to date about successional processes in Mojave Desert ecosystems, much less after a disturbance like anthropogenic lake formation from river damming. As water levels drop (and are predicted to continue to drop, Barnett and Pierce 2008) shorelines are exposed and land that has been submerged since the lake's previous low in 1965 (when water was being retained to fill Lake Powell) is now exposed year round.

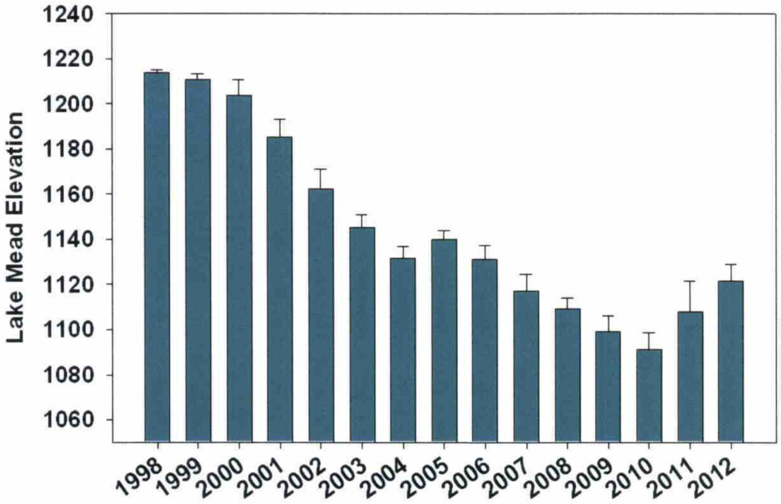

Figure 1. Mean annual elevation of Lake Mead (in feet) measured at the Hoover Dam (data compiled by bureau of reclamation). Error bars represent 1 S.D. from monthly data throughout the year.

UNLV and NPS collaborated to investigate patterns of primary succession along the newly exposed shoreline of Lake Mead. We monitored plant community composition across several different soil types along the shoreline corresponding with the time since exposure from the receding lake, and investigated correlations among soil texture and composition with plant establishment. Additionally, we planted native perennial species that would have been found at these sites before the flooding to test their re-establishment capability in the current environment where the lake has receded.

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Monitoring plant community establishment in the Lake Mead drawdown zone

The specific objectives of this project included: 1) understanding primary succession on the shoreline by determining which species establish on newly exposed ground; 2) determining the exotic to native species distribution among the established species; and 3) detecting how soil substrate, silt deposition, and lake levels affect plant species colonization and active restoration potential.

Plant community sampling

We collected plant community data (cover of all species), *Tamarix ramosissima* density and cover, and soil samples from 150 plots across three sites and five elevation bands representing time since submersion by Lake Mead (outlined in project proposal). We established 10 m x 10 m (100 m^2) plots where we collected species cover and *Tamarisk ramosissima* density along transects perpendicular to the water. Plots were placed along the transects at elevations representing sites that were last submerged in 2008 (1109 ft), 2005 (1140 ft), 2002 (1162 ft), and 1998 (1214 ft). The fifth site in each transect was placed approximately 100 m beyond the full capacity boundary (in line with the other four plots along the transect) to capture plant community and soil composition for sites that were never submerged (and therefore should be equivalent to the historical composition of sites that were flooded). See Table X for site locations.

From January - February, 2011, we recorded the density of live and dead *Tamarix ramosissima* individuals within each 100 m^2 plot. Data were entered and initial analyses conducted to look for patterns of cover and density across site, time since submersion, and soil characteristics. From March – June, 2011 we conducted plant community sampling for all annual and perennial plant species cover within each plot.

Soil analyses

500 cm^3 soil samples (from the NE and SW corners of each plot) were collected from the top five cm of the surface soil along with site descriptors (slope, aspect, soil surface composition, etc.). Soil samples were brought to the Abella lab at UNLV and processed for bulk density analyses, electrical conductivity, and soil texture and composition. Soil samples were submitted to the UNLV Environmental Soil Analysis Laboratory (http://geoscience.unlv.edu/ESAL/ESAL.html) at UNLV for analysis of soil texture (% sand, silt, and clay), total N, total C, $CaCO_3$, inorganic C, organic C, and total S. Abella lab members performed analyses of electrical conductivity (EC – often used as an equivalent measurement of soil salinity) using the saturated paste method performed on equipment in the lab of Dr. Dale Devitt. We utilized the results of these analyses to evaluate the lasting effects of submersion by Lake Mead, and to effectively choose outplanting sites that differ in texture and chemical composition.

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Plant succession and soil properties on newly exposed shoreline during drawdown of Lake Mead, Mojave Desert

E. Cayenne Engel*, Scott R. Abella, and Kenneth L. Chittick

Department of Environmental and Occupational Health, University of Nevada Las Vegas, Las Vegas, NV 89154

*Corresponding author: cayenne.engel@unlv.edu

Abbreviated title: Lake Mead shoreline plant succession

Abstract

Drawdown of Lake Mead from 1998 to 2011 reduced the lake's perimeter by over 400 km while exposing over 25,000 ha of formerly submerged land. To evaluate primary plant succession and soil properties in this new shoreline habitat, we sampled surfaces last submerged 3, 6, 9, or 13 years ago (including a never-submerged control) using 150, 0.01-ha plots at three sites varying in topography and soil parent material. Plant species richness/100 m^2 generally increased with surface age at two sites but not at the third. Consistent with previous research, abundance of the exotic *Tamarix ramossisima* declined with increasing surface age. Conversely, cover of native species was greatest overall on older surfaces across sites. Early successional native perennial species, such as *Stephanomeria pauciflora*, *Encelia farinosa*, and *Hymenoclea salsola*, had colonized the 13-year-old surface. Unexpectedly, multivariate soil properties did not differ between never submerged and formerly submerged surfaces. Based on the first 13 years of plant colonization and previous research on longer term desert vegetation succession, managers can likely anticipate: 1) continued development of an early successional native shrubland persistent

for several decades, and 2) eventual colonization by species of the mature vegetation (e.g., *Larrea tridentata*) inhabiting never-submerged surfaces. Moreover, we observed colonization of formerly submerged land by a rare plant species of special conservation designation (*Arctomecon californica*). While Lake Mead's drawdown might be viewed negatively from a perspective of maintaining full-pool water storage, it has re-exposed a vast area of new terrestrial habitat increasingly colonized by native species.

[Supplemental materials are available for this article. Go to the publisher's online edition of Lake and Reservoir Management *to view the supplemental file.]*

Key words: colonization, primary succession, species richness, *Tamarix ramossisima*, vegetation

The public benefits, as well as challenges to environmental quality, of the water of Lake Mead in the southwestern USA have been extensively discussed (Rosen 2012). However, functional benefits and challenges to maintaining environmental quality of the shoreline habitat of Lake Mead are not as well articulated. Changing water levels are a particularly important influence to shoreline habitat in lakes and reservoirs, such as Lake Mead, characterized by large and variable fluctuations in water level (Hill et al. 1998, Ali 2006, Auble et al. 2007). Water levels of Lake Mead have fluctuated since its creation by the Hoover Dam in 1935, ranging from the lake's full pool elevation of 372 m in 1941 and 1983 to a low of 330 m in 2010 (Holdren and Turner 2010). Over the last 13 years, lake levels have declined to among their lowest for an extended period of time during the 77-year history of the lake (Holdren and Turner 2010). Decreasing water levels reduce lake perimeter, while increasing the amount of shoreline area relative to the amount unsubmerged when a lake is at full pool. By 2011, Lake Mead's drawdown had reduced the

lake's perimeter by over 400 km, while exposing more than 25,000 ha of formerly submerged land – an area roughly equivalent to the size of the city of Sacramento, CA (Fig. 1).

This vast area of new terrestrial habitat, together with continued fluctuations in lake levels and inherent uncertainty to projections of future lake levels, afford an interesting management dilemma. On one hand, the newly exposed area offers significant potential for supporting a variety of terrestrial habitats, including those that contain rare plant (e.g., *Arctomecon californica* [Las Vegas bearpoppy]) and animal (e.g., *Phainopepla nitens* [Phainopepla]) species that have special conservation protection. Additional lakeshore recreation opportunities for humans might also be available in this new habitat. On the other hand, the new land might be colonized by invasive, exotic plants such as *Tamarix ramosissima* (saltcedar), instead of native species, or plant colonization might be slow altogether to leave soil bare (Walker et al. 2006). Moreover, any attempted management activities (e.g., exotic species treatment, revegetating with native species, creation of recreation sites) near the new shoreline might be counteracted if lake levels again rise (Tallent et al. 2011). This dilemma is especially interesting given that management jurisdiction of the new shoreline habitat is under the U.S. National Park Service (Lake Mead National Recreation Area), which has managing and conserving native species habitats as a key part of its mission. Lake Mead shoreline habitat is inherently an artificial habitat, yet it is a location where native species could be conserved or the area could impact upland habitat, such as if the shoreline creates source populations for spread of exotic species.

Understanding vegetation colonization patterns and soil properties underpins assessing environmental quality and potential management scenarios of shoreline habitat. Plant

colonization of formerly submerged shoreline area would be primary succession along the primary-secondary successional continuum in terrestrial habitats (Walker and del Moral 2003). Primary succession occurs on new land surfaces where no terrestrial vegetation existed at the time succession initiated. Secondary succession, in comparison, occurs on surfaces where some soil biota and possibly some vegetation survived the disturbance and is present when succession begins. Studies of primary plant community succession have occurred on debris flows (new soil surfaces created by formation of alluvial fans through flooding-induced mass soil movement) in the Mojave Desert, where Lake Mead is located (Abella 2010). These studies reported that long time periods were required for colonization of these surfaces by species typical of nearby mature communities. In their study of debris flows along the Grand Canyon, for example, Bowers et al. (1997) reported that the late-successional *Larrea tridentata* (creosote bush) was not present on any flows younger than 285 years. However, the studies suggest that within 10 years, early successional plants can colonize the surfaces and provide a total plant cover approaching half or more of the total plant cove of mature communities (Abella 2010). It is unclear how closely successional patterns on these surfaces might match those in the shoreline environment and if properties of the formerly submerged soil are related to succession. Submersion could have altered soils through processes such as sedimentation, erosion, incorporation or dissolution of elements, and production and decomposition of organic matter.

Dropping levels of Lake Mead might be viewed as disconcerting from a perspective of maintaining full-pool water storage, but it has resulted in vast areas of new shoreline habitat. This habitat and its potential values are poorly understood. The objective of this study was to determine plant community colonization and soil properties along a time-since-submersion,

surface age gradient over the last 13 years during the present Lake Mead drawdown. We hypothesized that: 1) species richness and native plant colonization increases with increasing surface age, 2) exotic species dominance declines on the oldest surfaces, and 3) soil properties differ along the surface age gradient, with higher fine fraction content, lower organic C and total N, and elevated salt-related properties on submerged compared to non-submerged surfaces. Results can augment theory regarding succession in arid lands while helping to understand quality of the new shoreline habitat to support potential shoreline management scenarios.

Methods

Site selection

We conducted this study at three sites (Boulder Beach, Overton, and Stewarts Point). Representing a range of topography, soil parent material, and management considerations (Fig. 2). Boulder Beach soils are described as gravelly outwash, mixed alluvium piedmont fans, and are part of the Carrizo-Riverbend association classified as Typic Torriorthents and Typic Haplocalcids (Lato 2006). Management considerations at this site include visitor use of nearby beaches for water recreation, fire management, fugitive dust control, and weed encroachment. Stewarts Point contains soils associated with gypsum parent material, interspersed with fan alluvium derived from igneous, metamorphic and sedimentary rock in the Cololag-badland association (Lato 2006). Never-submerged soils near Stewarts Point support rare plant species of management priority such as *Anulocaulis leiosolenus* (sticky ringstem) and *Arctomecon californica* (Las Vegas bearpaw poppy). Because of the open, running Muddy River adjacent to ther Overton sties, the the water table remains high in this area allowing for marshy habitats and siltier soils immediately adjacent to the river. Soils at Overton also are associated with gypsum

and are within the Drygyp-Bluegyp association classified as Typic Petrogypsids and Leptic Haplogypsids (Lato 2006). Management considerations here include trespass cattle, unauthorized off-road vehicle use, weeds, with the objective of creating habitat suitable for use by rare or threatened species, particularly along the riparian corridor.

Based on elevation grids derived from LiDAR (Light Detection And Ranging) data (captured August-September 2009, provided by National Park Service, Boulder City, Nevada), ten transects were established along each of the three sites with five 10 × 10 m plots placed along each transect at elevations representing average lake levels for the years 1998 (the most recent time when the lake was near full pool; 1214 m), 2002 (1162 m), 2005 (1140 m), and 2008 (1109 m). Additionally, transects were extended to include a control plot 50 m past the high water mark for each transect A total of 150 plots were sampled. Transects were developed by randomly generating points within the 1109 m elevation band, developing a transect perpendicular to the shoreline, and placing plots at the proper elevations along that transect. Because Lake Mead fills the former Colorado River Valley, elevations increase with distance from water. Requirements for sites include undisturbed by roads, off-road vehicle traffic, or hiking trails, with a slope gradient of less than 30%.

Data collection

Plots were established along transects during December 2010. Plant and soils data were collected from February- May 2011. Within each plot, we recorded percent cover for all live species present in plots. Additionally, we recorded the number (density) of live *Tamarix ramossisima* (hereafter "*Tamarix*") individuals within each plot.

Soil samples (480 cm^3) were collected from the top 5 cm of soil (excluding surface litter), with half the volume collected from the southwest and half from the northeast inside corner of each plot. An additional 480 cm^3 was collected (total from each of two plot corners) for estimating bulk density and coarse fragment content. Soils were air dried, sieved through a 2-mm sieve, and analyzed for texture (hydrometer method); $CaCO_3$ (manometer method); total C, N, and S (dry combustion, elemental CNS analyzer); organic C (difference between total and inorganic C), and electrical conductivity (saturated paste) following Burt (2004). Bulk density was estimated by sieving through a 2-mm sieve, oven drying the < 2-mm fraction at 105 C for 24 h, and making calculations both with and without volume of coarse fragments > 2 mm included in the total soil volume. Associated data such as elevation, slope, and aspect, were also recorded at each plot.

Data analysis

We calculated species richness and cover for each plot and grouped species into four groups for each metric: native annual, native perennial, exotic annual and exotic perennial, as defined by the USDA-PLANTS database (http://plants.usda.gov/). *Washingtonia filerifera* (California fan palm), while listed as native to Clark County on the USDA-PLANTS website, is defined as an exotic invasive plant when found around Lake Mead known to expand population sizes and alter sensitive spring habitat (NPS 2010).

We analyzed cover (total and relative), richness, and *Tamarix* density using a two-factor analysis of variance with time since submersion (surface age) and site as fixed effects and transect nested within site as a repeated measure in SAS software (SAS institute 2009). *Tamarix* density and

cover, and relative exotic annual, native annual, and native perennial cover were log transformed to meet assumptions of normality.

Soil characteristics were analyzed using the same analysis of variance model as for plant richness and cover. N, Organic C, total S, and electrical conductivity were log transformed to meet assumptions of normality. We ordinated soil variables using principal components analysis (PCA; cross-products matrix derived from correlation) in PC-Ord software (McCune and Mefford 1999) to examine variation among sites and surface ages. Multi-response permutation procedures, performed in PC-ORD, were utilized to examine differences in multivariate soils composition among sites and among surface ages within sites.

Results

Species richness and cover

On the 150 plots, we recorded a total of 118 species consisting of 11 exotic, 67 native annual, and 40 native perennial species. Total richness increased significantly with surface age at the Overton site, where the youngest plots had the fewest species and the oldest had significantly more but not yet equivalent to never-submerged surfaces (site × year interaction: $F_{8,95} = 7.53$, $P < 0.0001$; Fig. 3). There also was a trend toward increasing richness with surface age at Stewarts Point, but at Boulder Beach, species richness did not differ significantly among any surfaces.

Differences in richness within sites sites were driven largely by richness of native annual and native perennial species (Fig. 3). Native annual species richness did not differ between never-submerged and 13-year-old surfaces at Overton, but younger surfaces had lower richness,

showing re-establishment of native annual species after 13 years (site × year interaction: $F_{8,95}$ = 8.12, $P < 0.0001$). However, native annual richness was lower in all previously submerged sites than on the never-submerged surface at Stewarts Point, and did not differ among surface ages at Boulder Beach. Native perennial species richness increased overall with surface age at all sites, and was equivalent to richness in control plots in Boulder Beach (site × year interaction: $F_{8,95}$ = 6.47, $P < 0.0001$). The sole exception to this pattern was the Overton site where native perennial richness in the youngest plots did not differ from control sites. This was related to proximity of the Overton site to the Muddy River riparian corridor, where three-year-old surfaces transitioned from submerged lake to wetland habitat supporting more and different native perennial species (Appendix 1). While no rare species were detected within the boundaries of the study plots, at Stewarts Point we observed the establishment of *Arctomecon californica* immediately adjacent to one of the 13 year old plots (and in the vicinity of two other 13 year old plots), indicating that it is possible for rare species to recolonize the disturbed area.

Total plant cover did not vary with surface age within Boulder Beach or Stewarts Point. However, within the Overton site, cover was greater in the youngest plots (62 ± 11%; mean ± 1 S.E.) plots than on nine-year-old (26 ± 5%), 13-year-old (21 ± 7%), or never-submerged surfaces (26 ± 5%; site × year interaction: $F_{8,95} = 2.56$, $P = 0.01$). This related to influence of *Typha domingensis* (southern cattail), which averaged 26% ± 12% cover on the youngest surfaces, four of which were near the banks of the Muddy River. *Typha* was absent from all other plots. Relative cover of native perennial species increased with time since submersion in all sites except Stewarts Point, where the only statistical differences were between formerly submerged and control plots (site × year interaction: $F_{8,95} = 9.19$, $P < 0.0001$, Fig. 3).

Exotic species

Among 11 exotic species detected on plots, *Tamarix* was most abundant (Table 1). As hypothesized, *Tamarix* density and cover decreased with surface age (Fig. 4). Live *Tamarix* density decreased the most drastically from the youngest to the oldest sites (year: $F_{4,107} = 22.26$, $P < 0.001$), with a similar pattern in cover (year: $F_{4,95} = 11.60$, $P < 0.001$).

Soil properties

The first two components within the soil PCA accounted for 60% of the variance at Boulder Beach, 77% at Overton, and 57% at Stewarts Point. While there was little clear segregation among sites, soils at Boulder Beach and Overton were more similar to each other than at Stewarts point which had a larger breadth of composition and generally had greater total S, and more $CaCO_3$ and Inorganic C (MRPP: $A = 0.09$, $P < 0.0001$; Fig 5a).

There were generally few differences within sites among age groups of formerly submerged plots, with a lack of conspicuous differences between submerged plots and control plots (Fig. 5 b-c). The exception to this was that some young surfaces at Overton had a stronger correlation with EC, total S, organic C, total N, total C, and a greater percentage of clay and silt. Similarly, at Boulder Beach several of the submerged surfaces across a range of ages have strong associations with inorganic C, total C, organic C, $CaCO_3$, silt and clay. At each of these two sites, variation in soil composition within never-submerged surfaces was lower than variation within submerged surfaces, which had large variation in soils. However, there were no overall differences among ages at the three sites (MRPP: $P > 0.05$).

Electrical conductivity decreased on older surfaces at Boulder Beach, with an average of 3.85 ± 0.90 on the youngest surfaces and 1.29 ± 0.53 on 13-year-old surfaces (the oldest plots did not differ from control sites; site × year: $F_{8,95} = 3.27$, $P = 0.003$). Conductivity at Overton showed the same pattern, with a mean of 11.19 ± 3.72 for the youngest surfaces and 0.96 ± 0.18 for 13-year-old surfaces (which also did not differ from control sites). Conductivity did not differ with surface age at Stewarts point. Soil analyses at this site reflected gypsum parent material, with greater conductivity and 9 times greater total S concentrations than at other sites (site: $F_{2,27} = 36.67$, $P < 0.0001$).

Discussion

Hypotheses

Vegetation

Results for the hypothesis that total species richness increases with increasing surface age were site specific, where two of three sites (Overton and Stewarts Point) displayed this general pattern and the third (Boulder Beach) showed no pattern with surface age. Native species richness generally displayed the same pattern as total richness. Other successional studies in North American deserts have collectively reported little relationship between species richness and time since disturbance or surface age, because most studies have found that richness recovers to or exceeds that of undisturbed levels shortly after succession begins (Abella 2010). In a study of primary succession on debris flows around Grand Canyon, Arizona, for example, Bowers et al. (1997) found that 80% of sites younger than the oldest site (~ 3000 years) examined had greater species richness than the oldest site. The pattern was different in our study where the oldest

surfaces had either similar or significantly greater richness than younger surfaces. Considering only native perennial species richness, however, we did find a trend in our study similar to Bowers et al. (1997) where richness on our 13-year-old surfaces overall began to most closely resemble the never-submerged surfaces.

The hypothesis that native plant colonization is greatest on the oldest surfaces was supported, except that Overton had high relative cover of native plants on both the youngest and the oldest submerged surface. Aside from Overton, where the youngest site exhibited large native perennial relative cover due to an abundance of *T. domingnsis* adjacent to the riverbank (Appendix 1), apparently about 13 years is required for appreciable native perennial plant colonization to occur during this primary succession. On Grand Canyon and Death Valley debris flows, significant native perennial plant cover had accrued on five-year-old surfaces (Webb et al. 1987, Bowers et al. 1997).

Exotic plant dominance declined with increasing surface age, supporting our hypothesis. This pattern was largely driven by *Tamarix*, which sharply declined in density and cover from the youngest to the oldest surfaces. These results concurred with those of a previous study in the Boulder Basin of Lake Mead, where *Tamarix* dominated within 200 m of the water's edge but sharply declined at greater distances and was absent beyond 250 m (Walker et al. 2006). The presence of dense, dead *Tamarix* stems on the older, formerly submerged surfaces suggested that environmental conditions on these surfaces were no longer suitable for survival of adult plants or for recruitment. Presumably this decline was linked to depletion of subsurface water as the lake receded, making conditions too dry to support *Tamarix*. Other exotic species displayed little

pattern with surface age, apparently consistent with their abilities to occupy either moist or dry sites. For instance, this study's finding of *Bromus rubens* (red brome) inhabiting recently submerged surfaces near the shoreline as well as never submerged surfaces concurs with a landscape-scale distribution study of *Bromus rubens* within Lake Mead National Recreation Area, where the species occupied a variety of riparian and upland sites (Abella et al. 2012).

Soil

In contrast to our hypothesis, strong multivariate differences in soil properties among surfaces were not evident. Further, few univariate patterns were strong (Appendix 2). Electrical conductivity, correlated with salt concentration, was highest on the youngest surface at Boulder Beach and Overton but displayed no consistent pattern at Stewarts Point. The large conductivity and total S concentration on the never-submerged surface at Stewarts Point relative other sites likely relates to properties of the gypsum parent material (Sheldon Thompson and Smith 1997) We had anticipated that processes such as deposition of fine soil fractions during submersion might alter texture. Unexpectedly, soil texture did not differ among surfaces, suggesting that submersion did not alter soil texture or that the net effects of submersion or subsequent exposure resulted in no textural changes. While all tributaries to Lake Mead carry heavy sediment loads (Holdren and Turner 2010), we did not see last effects of silt deposition on younger soil surfaces. Variation among sites differing in parent materials suggests that the underlying soil type of a site might more strongly influence soil properties than did submersion.

Our results of no strong overall difference in soils among surfaces and individualistic variation of specific soil properties concurs with Walker et al.'s (2006) previous study in Lake Mead's

Boulder Basin and Tallent et al. (2011) downriver around Lake Mohave's shoreline. Walker et al. (2006) found that soil total N and organic matter did not differ between submerged and non-submerged surfaces, while salinity and gravimetric moisture did differ between submerged and non-submerged surfaces but not among surface ages within submerged sites. Walker et al. (2006) and Tallent et al. (2011) found that salinity was positively correlated with *Tamarix* abundance. It is difficult to separate potential effects of *Tamarix* trees and submersion on salinity and electrical conductivity because *Tamarix* appears to readily colonize suitable newly exposed surfaces (Tallent et al. 2011).

Given that overall soil was not appreciably different among surfaces and only some individual variables displayed patterns with submersion status, an important unresolved question is whether native plant colonization is in any way limited by properties of formerly submerged soil. Most soil properties of formerly submerged surfaces were similar to never-submerged surfaces and thus were unlikely to limit native plants relative to never-submerged areas. Moreover, with an electrical conductivity of 11 dS/m, only the youngest Overton surface exceeded 8 ds/m. According to Shafroth et al. (2008), electrical conductivity ≤ 4 dS/m is satisfactory for plant growth, 4-8 limits some species, and 8-16 supports salt-tolerant species. It is unclear if the salt-concentrating ability of *Tamarix* contributed to salinity (Busch and Smith 1995), whether the majority of lower conductivities limited plant establishment, and if desert plants especially on gypsum parent materials had greater abilities to tolerate salinity. Conducting experimental plantings or seedings of native species in future research along the shoreline might help directly resolve if soil limits native plant colonization relative to other limiting factors such as seed dispersal and protected microsites for establishment (James et al. 2005).

Plant succession principles and projections

Plant succession in arid lands is poorly understood compared to temperate regions, and general principles of arid land succession have only recently been synthesized (Abella 2010, Allen et al. 2011). Our results are consistent with some of these principles. First, the observed early colonization by both annual and perennial plants concurs with the general principle that both plant groups are represented in both early and late-successional desert communities. Second, many of the colonizing perennial species, such as *Hymenoclea salsola* (cheesebush), *Bebbia juncea* (sweetbush), and *Stephanomeria pauciflora* (wirelettuce), also inhabit washes in non-anthropogenically disturbed ecosystems. Washes are periodically disturbed natural environments through flooding, and species inhabiting them colonize a variety of other disturbed environments including the Lake Mead shoreline. Third, *Ambrosia dumosa* (burrobush) was both an early colonizer of the new shoreline and an inhabitant of the never-submerged community, consistent with the principle that deserts contain 'versatile' species found throughout a successional sequence. Fourth, exclusive late-successional species such as *Larrea tridentata* remained sparse after 13 years of surface exposure, providing indication consistent with the principle that establishment of late-successional communities requires long time periods on the order of decades to centuries. Several factors can delay recruitment of late-successional species in deserts, such as rare occurrence of climatic conditions suitable for recruitment, seed availability (many native perennials do not form persistent soil seed banks), and absence of 'nurse' plants which afford protection and provide 'safe sites' for seedling establishment (McAuliffe 1988).

If succession continues proceeding along trends of the first 13 years and is consistent with longer term patterns of other studies (Abella 2010), then a projection of a potential scenario of succession is possible. For example, an early successional native perennial plant community dominated by *Stephanomeria pauciflora*, *Hymenoclea salsola*, and *Ambrosia dumosa* inhabited a 38-year-old bulldozed area of never-submerged terrestrial habitat just northwest of our Boulder Beach site (Abella et al. 2007). This was consistent with the persistence of these early successional communities reported in other studies (Abella 2010), and the community contained four times the perennial plant density and similar species richness as undisturbed old *Larrea tridentata* communities. Assuming the shoreline is not re-submerged, it is likely that an early successional community will continue to develop and persist for decades before colonization by species of old surfaces given suitable climatic conditions (Webb et al. 1987, Bowers et al. 1997). As illustrated in Abella et al. (2007) and other studies (Abella 2010), these early successional communities can have total plant cover, density, and richness that exceeds those of old communities.

Management implications

Fluctuating lake levels complicate developing shoreline habitat management strategies. Management activities such as controlling exotic plants or actively establishing native species near the current land:lake interface can be counteracted when lake levels rise, which occurred in 2012 following this study. A possible active management strategy would be identifying a potential new upper lake level (Barnett and Pierce 2009) during a desired management period of time and prioritizing efforts at elevations above that projected lake level. Another strategy might be to target or create islands of land higher than surrounding areas that would still be above

water if the lake rises (Alice Newton, Lake Mead National Recreation Area, personal communication). This strategy might be most effective in areas of gentler topography and may provide 'refuges' for terrestrial organisms and seed sources to repeatedly colonize a fluctuating environment (Bainbridge 2007). A positive aspect of the fluctuating lake level is that inundation is not optimal for *Tamarix* regeneration while continued dropping of lake levels has resulted in vast areas of *Tamarix* die off (Walker et al. 2006, this study). Moreover, the *Tamarix* biocontrol agent *Diorhabda carinulata* (tamarisk leaf beetle) has been moving south north of the Lake Mead area (Hultine et al. 2010). Further research that explores whether *Tamarix* or any of its possible soil legacy effects interferes with native plant colonization would be useful (Shafroth et al. 2008). If revegetating priority sites with native species to accelerate succession is a management goal, previous research has shown that planting nursery-grown stock using proper practices (e.g., timing plantings properly) ≥ 50% survival in the Mojave Desert (Bainbridge 2007, Abella and Newton 2009).

The past 13 years of overall drawdown of Lake Mead has re-exposed a dynamic new terrestrial habitat. Over time, exotic plant cover has generally decreased while native perennial plant cover has increased in this habitat. Moreover, at least one rare plant species of special conservation status (*Arctomecon californica*) had colonized the new habitat near sampling plots. These observations suggest that while declining water levels might be viewed negatively from a perspective of maintaining full-pool water storage capacity, the decline has benefited native terrestrial habitat by exposing surfaces for native species colonization.

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Table 1. Mean cover (% ± 1 S. E.) of exotic species found along the Lake Mead shoreline sampled 3, 6, 9, and 13 years since submersion, and sites that have never been submerged (control). "< 0.1" indicates species that were present but had a mean cover less than 0.1%.

	Years since submersion				
	3	**6**	**9**	**13**	**Control**
Brassica tournefortii	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.2	1.7± 1.4	<0.1
Bromus rubens	2.3± 1.5	2.3 ± 1.0	0.9 ± 0.5	0.8 ± 0.8	1.0 ± 0.5
Bromus tectorum	0	0	0	0	<0.1
Erodium cicutarium	0.4 ± 0.10	<0.1	0	<0.1	<0.1
Malcolmia africana	<0.1	<0.1	0.1 ± 0.1	0	<0.1
Salsola tragus	<0.1	0.1 ± 0.1	0.2 ± 0.2	0.5 ± 0.3	0
Schismus arabica	2.8 ± 1.2	11.4 ± 3.6	3.2 ± 1.4	1.8 ± 1.0	4.3 ± 3.0
Sisimbrium spp.	0	<0.1	<0.1	0	0
Sisimbrium altissima	<0.1	<0.1	1.8 ± 1.5	<0.1	0
Tamarisk ramosissima	19.1 ± 4.4	7.0 ± 1.2	7.2 ± 1.5	5.3 ± 1.3	0.2 ± 0.2
Washingtonia filifera	0	0	0	<0.1	0

FIGURES:

Figure 1. Lake Mead elevation (top), length of shoreline (middle), and land area that was formerly submerged by lake mead ("exposed area"; bottom) from 1998 (the last time Lake Mead was at full capacity) to early 2012.

Figure 2. Locations of study sites along the shoreline of Lake Mead within Lake Mead National Recreation Area (LAKE). Pictures of formerly disturbed sites showing differences in topography among (a) Boulder Beach, 9 years since submersion; (b) Overton, 12 years since submersion, and (c) Stewarts Point shoreline 3 years since submersion are shown.

Figure 3. Left panel: richness (species per 100 m^2 plot) across each of three sampling sites and years since submersion including a never-submerged control. Bars sharing letters do not differ ($P < 0.05$). Error bars are 1 S.E. Right panel: relative cover for annual and perennial, native and exotic species by site and years since submersion.

Figure 4. Density (top) and cover (bottom) of live *Tamarix ramosissima* individuals recorded in sites that were last submerged by Lake Mead in 3, 6, 9, and 13 years before sampling, and never submerged control plots. Bars sharing letters do not differ ($P > 0.05$). Error bars are 1 S.E.

Figure 5. Principal components analysis ordinations of soil composition by a) study site, and time since submersion groups within b) Boulder Beach, c) Overton, and d) Stewarts Point. Vectors represent soil and environmental variables that are correlated with soil compositional patterns. The length of the vectors are proportional to the strength of the correlation, with an r^2 cutoff of 0.25 for inclusion in the figure.

Figure 1.

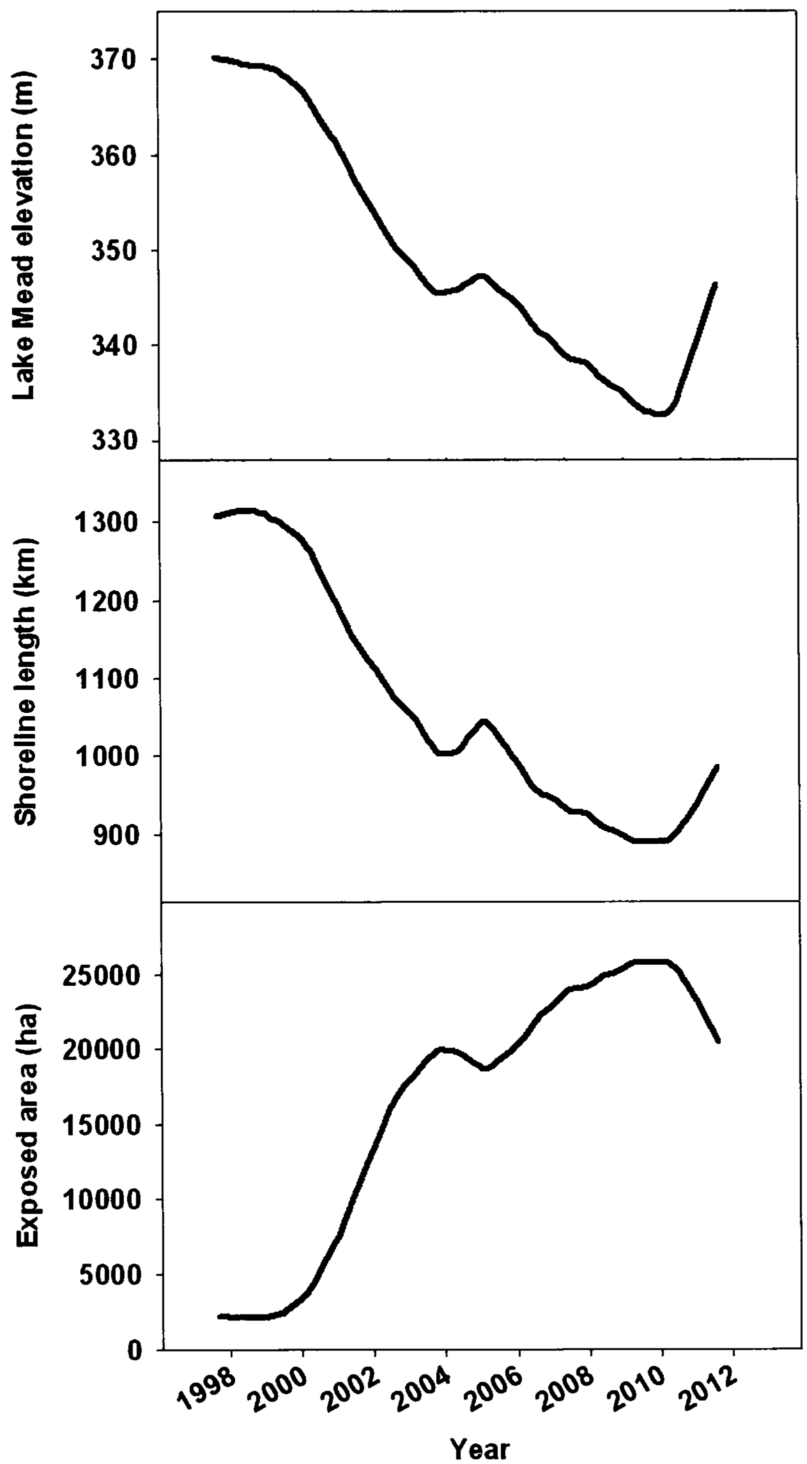

370
360
350
340
330
Lake Mead elevation (m)
1300
1200
1100
1000
900
Shoreline length (km)
25000
20000
15000
10000
5000
0
Exposed area (ha)
1998
2000
2002
2004
2006
2008
2010
2012
Year

Figure 2.

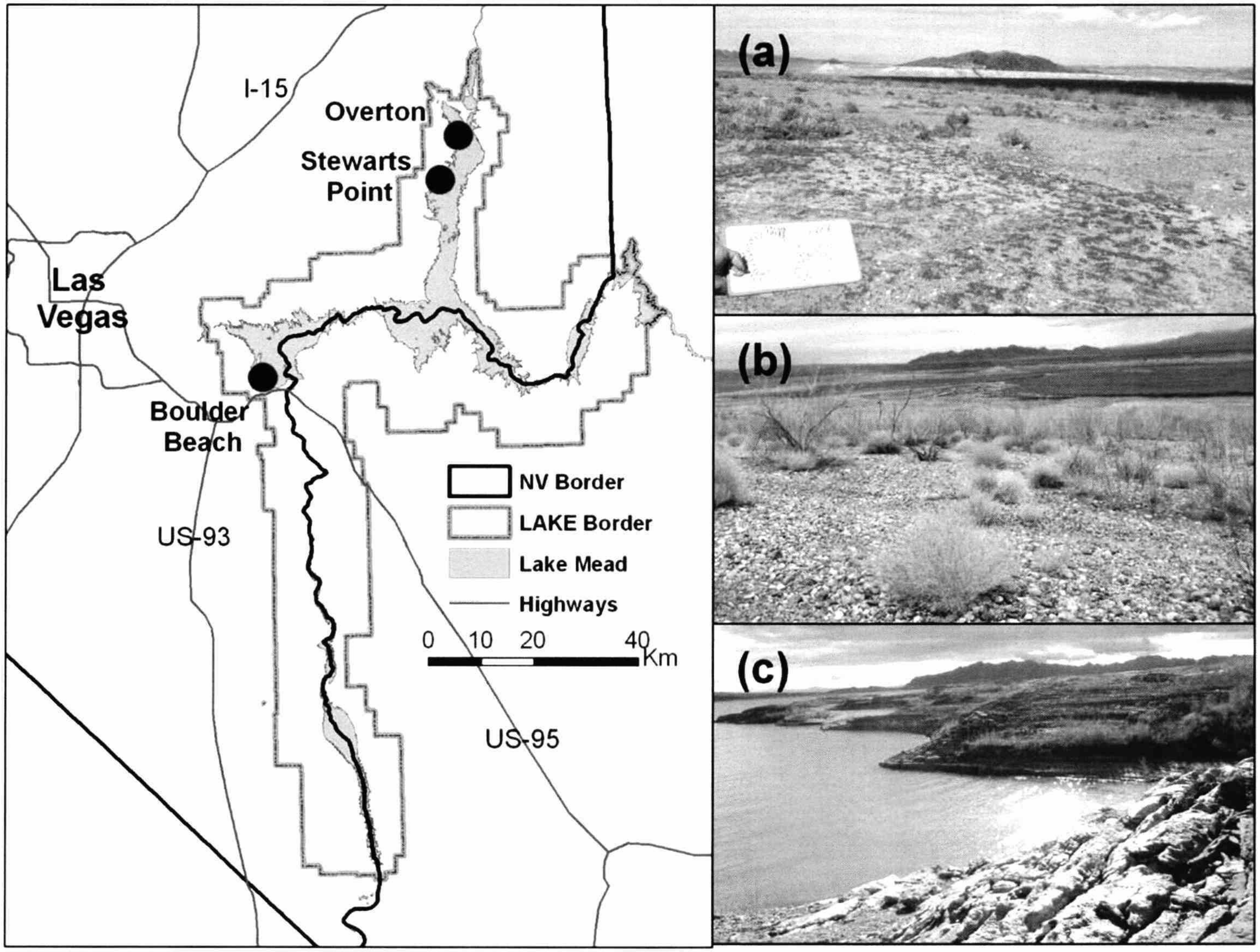
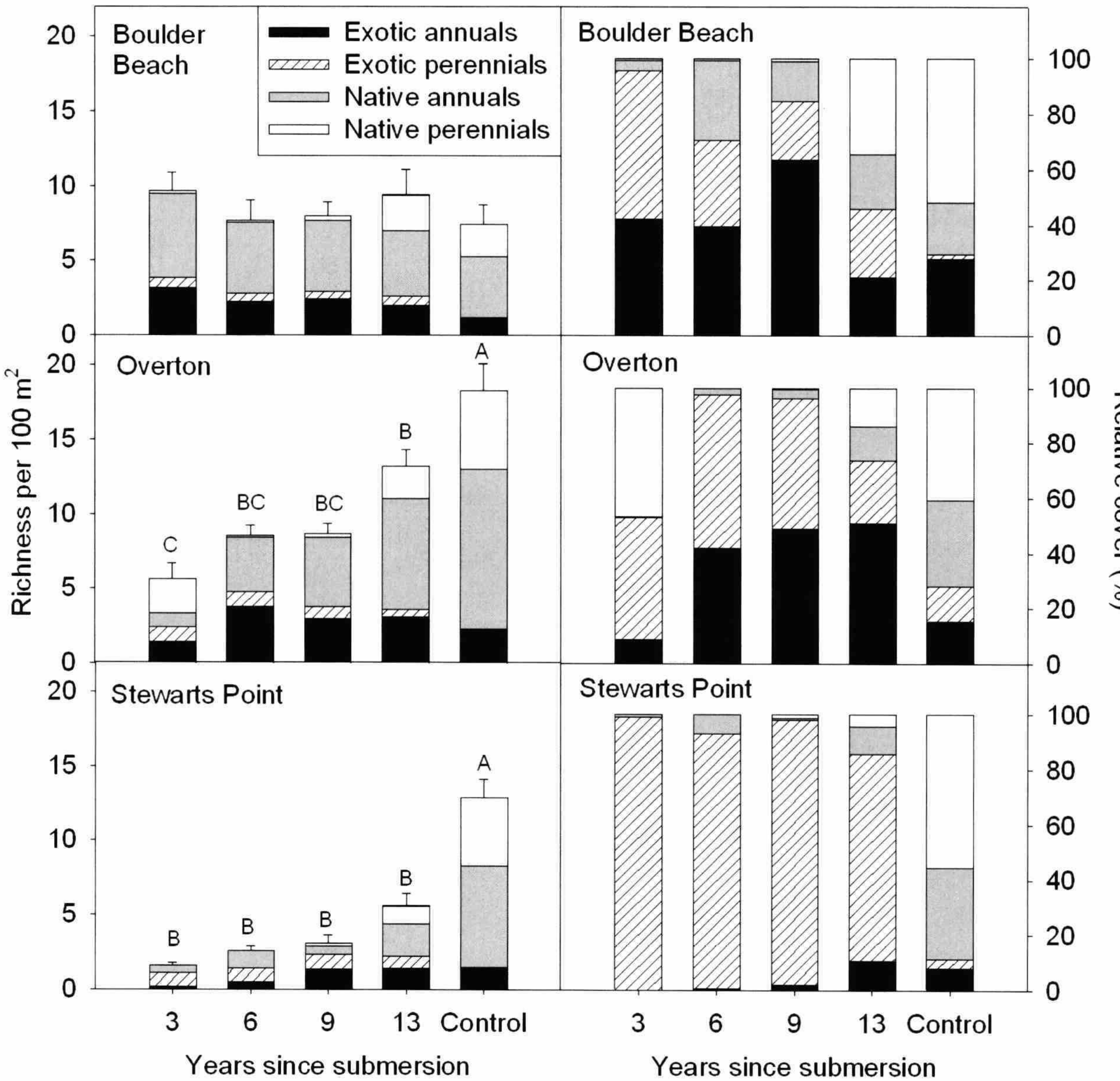
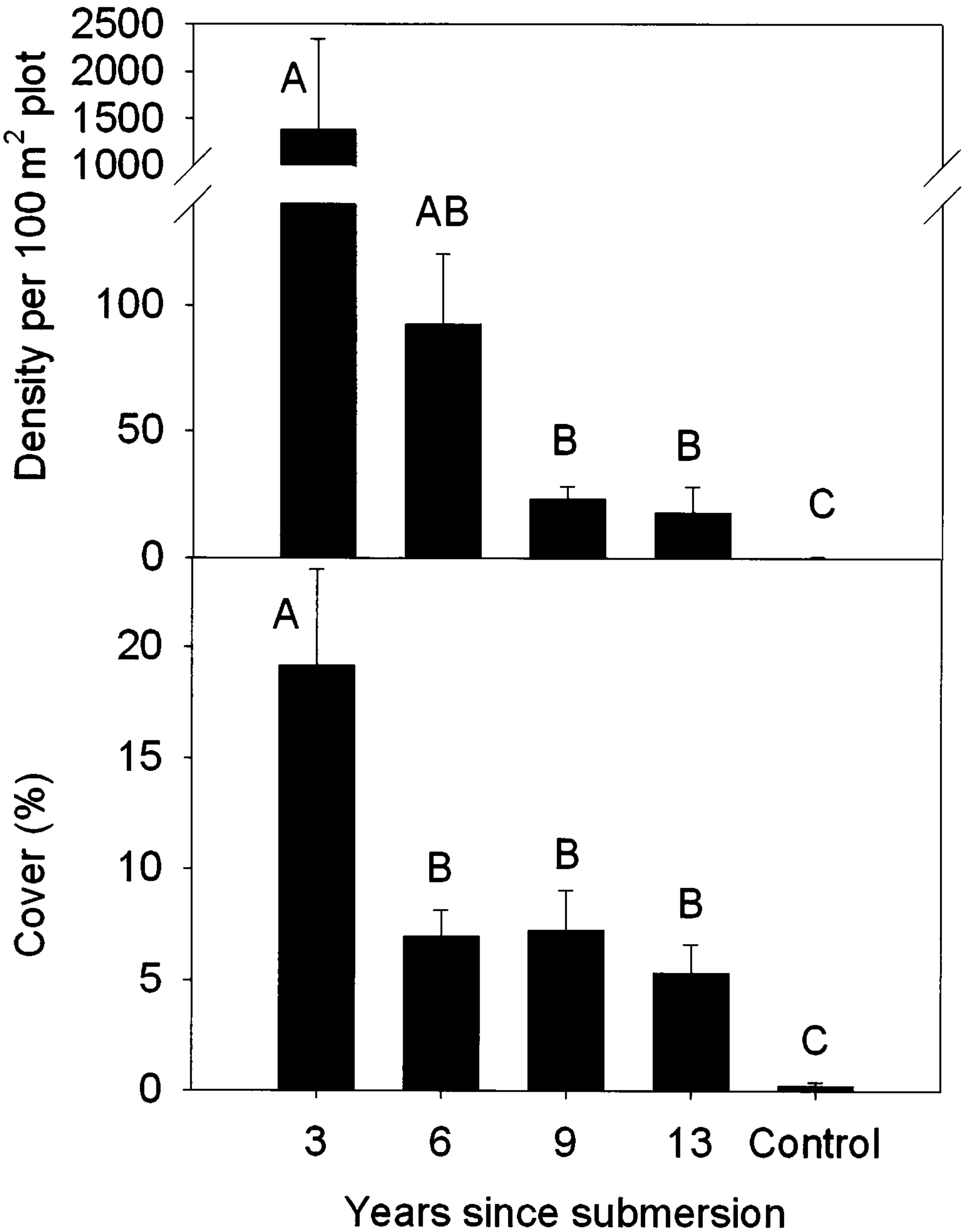

I-15
Overton
Stewarts Point
Las Vegas
Boulder Beach
US-93
US-95
NV Border
LAKE Border
Lake Mead
Highways
0 10 20 40 Km
(a)
(b)
(c)

Figure 3.



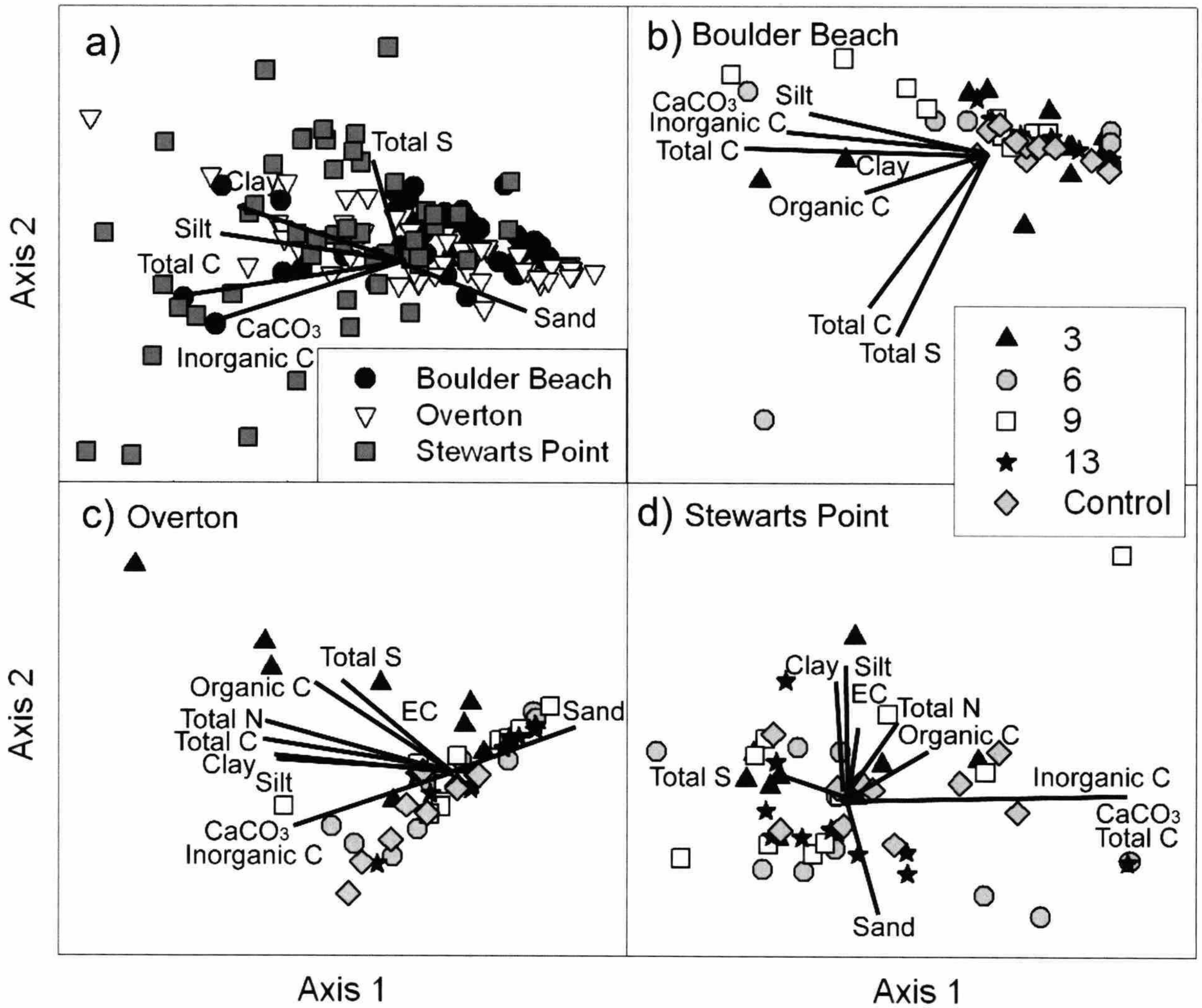
Boulder Beach
Exotic annuals
Exotic perennials
Native annuals
Native perennials
Overton
Stewarts Point
Richness per 100 m2
Relative cover (%)
C
BC
BC
B
A
B
B
B
B
A
3
6
9
13
Control
Years since submersion

Figure 4.



2500
2000
1500
1000
100
50
0
Density per 100 m2 plot
A
AB
B
B
C
20
15
10
5
0
Cover (%)
A
B
B
B
C
3
6
9
13
Control
Years since submersion

Figure 5.


a)
Total S
Clay
Silt
Total C
CaCO3
Inorganic C
Sand
Boulder Beach
Overton
Stewarts Point
b) Boulder Beach
CaCO3
Silt
Inorganic C
Total C
Clay
Organic C
Total C
Total S
3
6
9
13
Control
c) Overton
Total S
Organic C
EC
Sand
Total N
Total C
Clay
Silt
CaCO3
Inorganic C
d) Stewarts Point
Clay
Silt
EC
Total N
Organic C
Total S
Inorganic C
CaCO3
Total C
Sand
Axis 2
Axis 2
Axis 1
Axis 1

Appendix 1. Frequency (occurrence out of 10 plots) for all native vascular plant species recorded during the study listed by perennial or annual lifespan by site after 3, 6, 9, or 13 years since submersion or never submerged control sites (C).

		Boulder Beach					Overton					Stewarts Point				
		3	6	9	13	C	3	6	9	13	C	3	6	9	13	C
Perennial	*Acacia greggii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Ambrosia dumosa	0	0	0	2	6	0	0	0	4	9	0	0	0	1	5
	Astragalus preussii	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0
	Atriplex confertifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Atriplex hymenelytra	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Atriplex polycarpa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Baileya multiradiata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Bebbia juncea	0	0	0	1	2	0	0	0	4	0	0	0	0	0	0
	Carex sp.	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Cholla sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Cryptantha flava	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
	Cylindropuntia acanthocarpa	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
	Enceliopsis argophylla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Encelia farinosa	0	0	0	8	4	0	0	0	1	0	0	0	0	0	0
	Ephedra nevadensis	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
	Eriogonum fasciculatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Eriogonum inflatum	0	1	0	0	0	0	0	0	4	5	0	0	0	2	7
	Eucnide urens	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Guillenia lasiophylla	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
	Hymenoclea salsola	0	0	0	5	3	0	0	0	0	0	0	0	0	0	0
	Krameria erecta	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
	Krameria grayi	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
	Larrea tridentata	0	0	0	2	10	0	0	0	0	10	0	0	0	0	4
	Lepidium fremontii	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	Phoradendron californicum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	Oenothera sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	Opuntia sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Opuntia basilaris	0	0	0	0	2	0	0	0	0	7	0	0	0	0	0
	Opuntia echinocarpa	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
	Psorothamnus fremontii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
	Salix gooddingii	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0

	Salix sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Solidago confinis	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
	Sphaeralcea ambigua	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
	Stephanomeria pauciflora	0	0	2	8	0	0	1	2	6	3	0	0	0	3	6
	Tiquilia canescens	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
	Typha domingensis	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
Annual	*Amsinckia tessellata*	0	0	4	1	8	0	0	0	0	0	0	0	0	1	0
	Astragalus sp.	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
	Camissonia sp.	0	1	0	0	0	0	1	0	3	3	0	3	0	2	4
	Camissonia brevipes	0	0	0	0	0	0	3	2	3	1	0	0	0	0	0
	Chamaesyce albomarginata	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	Chaenactis carphoclinia	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0
	Chaenactis sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Chaenactis fremontii	6	3	4	6	2	0	2	4	7	7	0	0	0	0	2
	Chaenactis stevioides	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Chorizanthe brevicornu	1	1	2	3	2	0	0	1	7	8	0	0	0	0	0
	Chorizanthe rigida	0	0	0	0	2	0	0	0	1	8	0	0	0	0	6
	Cryptantha sp.	1	3	3	4	7	0	1	5	3	2	0	0	1	4	8
	Cryptantha angustifolia	8	6	5	3	2	0	0	3	6	4	0	0	0	0	0
	Cryptantha nevadensis	2	1	4	3	0	0	3	3	5	6	0	0	0	0	0
	Cryptantha pterocarya	8	5	5	0	4	0	3	7	5	2	0	0	0	0	3
	Descurainia pinnata	0	0	0	0	0	0	0	0	1	2	0	0	0	1	2
	Draba cuneata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	Eriastrum diffusum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Eriogonum deflexum	7	4	3	1	0	1	5	3	5	2	5	9	3	4	2
	Eriophyllum lanatum	1	0	1	2	4	0	0	0	0	3	0	0	0	0	0
	Eriogonum sp.	1	0	0	1	2	0	4	3	3	0	0	0	0	1	2
	Eriophyllum wallacei	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5
	Erodium texanum	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
	Gilia sp.	0	0	0	0	0	0	0	1	1	7	0	0	0	0	0
	Heliotropium curassavicum	1	0	0	1	0	3	1	0	0	0	0	0	0	0	0
	Langloisia setosissima	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0
	Lepidium lasiocarpm	0	0	1	0	0	0	0	0	1	6	0	0	0	0	0
	Malacothrix glabrata	8	5	4	2	0	0	0	0	1	0	0	0	0	0	0
	Mentzelia albicaulis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Mentzelia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Mohavea confertiflora	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
Mimulus bigelovii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nama demissum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7
Pectocarya sp.	0	0	0	5	3	0	1	0	0	0	0	0	0	0	0
Pectocarya platycarpa	5	3	7	5	7	0	5	6	5	6	0	0	0	1	2
Pectocarya recurvata	0	0	2	2	0	0	0	0	0	1	0	0	0	0	0
Pectocarya setosa	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Perityle emoryi	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Phacelia sp.	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0
Phacelia crenulata	0	1	0	3	3	0	3	6	7	8	0	0	0	0	0
Phacelia parishii	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Phacelia pedicellata	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Plantago ovata	0	0	0	0	2	0	0	0	2	10	0	0	0	1	6
Rafinesquia neomexicana	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0
Samolus parviflorus	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Stephanomeria exigua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Stylocline micropoides	0	0	0	0	0	0	0	0	2	7	0	0	0	0	0
Unknown Brassicaceae	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Unknown Poaceae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Verbena bracteata	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Vulpia octoflora	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1

Appendix 2. Soil properties (means ± SE) after 3, 6, 9, or 13 years since submersion, and never submerged control sites (C).

Site	Age	BD† (g/cm^3)	EC‡ (dS/m)	Total N (%)	Total C (%)	$CaCO_3$ (%)	Inorganic C (%)	Organic C (%)	Total S (%)	Clay (%)	Silt (%)	Sand (%)
Boulder	**3**	0.65±0.14	3.84±0.79	0.058±0.020	1.74±0.37	8.0±1.0	0.96±0.12	0.77±0.27	0.11±0.04	5±1	19±4	76±5
	6	0.61±0.10	3.14±0.67	0.189±0.151	1.64±0.44	9.2±2.5	1.11±0.30	0.52±0.20	0.12±0.08	3±1	16±3	81±3
	9	0.70±0.10	2.76±0.61	0.053±0.011	2.06±0.35	14.5±2.1	1.75±0.26	0.31±0.10	0.04±0.01	3±1	23±3	74±3
	13	0.69±0.08	1.29±0.52	0.023±0.003	0.80±0.10	5.7±0.6	0.68±0.07	0.11±0.03	0.03±0.01	4±1	17±2	79±3
	C	0.87±0.07	1.06±0.29	0.052±0.008	1.05±0.11	4.2±0.4	0.5±0.05	0.55±0.10	0.03±0.01	4±1	24±2	72±3
Overton	**3**	0.87±0.07	11.19±3.33	0.044±0.013	1.84±0.33	11.2±1.6	1.34±0.19	0.49±0.14	0.21±0.10	6±1	23±5	71±6
	6	0.93±0.16	2.18±0.60	0.016±0.004	1.45±0.25	11.2±2.0	1.34±0.24	0.10±0.03	0.01±0.01	4±1	17±4	79±5
	9	1.05±0.03	1.78±0.53	0.023±0.007	1.45±0.28	10.7±1.9	1.28±0.23	0.16±0.06	0.02±0.01	4±1	14±3	83±4
	13	0.86±0.08	0.95±0.17	0.013±0.003	1.25±0.20	9.7±1.5	1.16±0.19	0.08±0.03	0.01±0.01	3±1	12±3	85±4
	C	1.06±0.02	0.94±0.15	0.023±0.002	1.40±0.14	11.0±1.2	1.32±0.14	0.08±0.02	0.01±0.01	7±1	30±3	63±4
Stewart	**3**	0.89±0.09	4.78±1.32	0.021±0.002	1.94±0.29	15.3±2.2	1.84±0.27	0.09±0.02	0.58±0.22	11±2	28±3	61±4
	6	0.95±0.11	3.30±0.50	0.014±0.001	2.66±0.68	21.7±5.6	2.61±0.67	0.05±0.01	0.37±0.23	6±1	25±5	69±5
	9	0.89±0.13	6.22±2.12	0.034±0.009	2.19±0.39	17.1±2.8	2.05±0.34	0.13±0.08	0.40±0.13	7±1	33±3	60±4
	13	0.78±0.08	7.21±3.59	0.018±0.003	2.24±0.52	18.1±4.2	2.18±0.51	0.07±0.01	0.34±0.16	7±1	22±2	71±3
	C	0.96±0.05	3.43±0.52	0.023±0.001	2.67±0.40	21.5±3.2	2.59±0.39	0.09±0.04	0.16±0.08	7±1	32±2	61±3

† Bulk density

‡ Electrical conductivity

Outplanting success in the drawdown zone: How does soil substrate, silt deposition, and lake level affect perennial species establishment?

Outplanting methods

Individuals of four species of native perennial species (*Ambrosia dumosa*, *Encelia farinosa*, *Hymenoclea salsola*, and *Larrea tridentata)* were propagated by the Lake Mead NRA nursery staff and outplanted (along with Driwater) by UNLV staff in an experimental design addressing survival across different post-submersion environments. UNLV staff aided LAKE nursery staff to sow seeds for all species intended for outplanting in January, 2011. Seedlings were outplanted in December 2011. We chose species that were common in never-submerged plots across all sites, with the idea that those species would have been present pre-submersion and therefore they would be the most appropriate candidates for active restoration. The goal of the outplanting experiment is to evaluate whether the changed soil and environmental conditions post-submersion would be hospitable for establishment of these species if outplanted.

Lake levels rose approximately 40 feet between November 2010 (project inception) and November 2011, flooding the lowest elevation (2008) plots. Additionally, with this rise in water levels, the visitor use areas of Boulder Beach were augmented to create more useable beach area, resulting in bulldozing some of the second lowest elevation (2005) plots, and leaving others very close to active recreation sites. After evaluation of the soil analysis data, we found that soil texture and composition was similar between Boulder Beach and Overton Beach sites. Therefore, due to high visibility to park visitors at the Boulder Beach plots, much disturbance, and flooding of the lowest elevation plots we decided to restrict outplanting experiments to the Stewarts Point and Overton Beach sites.

For the outplanting, we chose three transects at the Stewarts Point and Overton Beach sites, and outplanted plants at elevations equivalent to lake levels in 2005, 2002, and 1998. The number of transects planted were guided by the availability of suitable plant material. We instituted a minimum size of plant material for planting, individuals needed to be at least 10 cm in height. Our goal was six replicates per plot, but we agreed that four would be sufficient for the *L. tridentata*, which was the species with the most limited availability of plants of sufficient size. Reducing the number of replicates of *L. tridentata* per plot allowed us to plant plots along three transects per site. In each plot, we outplanted six individuals each of *A. dumosa*, *E. farinosa*, *H. salsola*, and four individuals of *L. tridentdata*. The number of outplanted individuals were largely determined by the availability of plant material. Each outplanted individual was outfitted with driwater, and was monitored until late November, 2012 for survival.

We chose transects based on random assignment coupled with deliberately choosing transects whose plots in the monitoring portion of the study had low *Tamarix ramosissima* density. We believed this would better represent regions that would more realistically be candidates for restoration treatments due to an assumed higher survival probability from less active competition from saltcedar, and would better mimic active management practices. Sites were located adjacent to the community composition plots where soils should be equivalent to sampled and analyzed soils. Because we were planting along transects, not all plots along the transect would necessarily have sparse *T. ramosissima*. Rather, we selected transects as a whole with relatively

low *T. ramosissima* abundance that also fit prerequisites of low disturbance and easy to moderate accessibility (also mimicking active management practices).

Seedlings were planted Dec 20, 2011 – Jan 4, 2012. Plots were arranged in a 4 × 6 grid such that each seedling was 2 m away from the nearest neighbor. Plants were randomly assigned grid positions for each plot. Individuals were planted traditionally using trowels and given supplemental aboveground water application (500 mL per plant) sufficient to saturate the soil around the plant in a 6-inche diameter area. Each plant also had a driwater installed at the time of planting. Each plant was outfitted with a hardware cloth cage to prevent herbivory made of 0.25" hardware cloth mesh, 50 cm tall, and 40 cm diameter.

Plants received driwater when it was depleted (approximately every 8-10 weeks in winter, every 4-6 weeks in summer). We assessed survival rates and performed upkeep on cages where necessary approximately every two months (generally coinciding with driwater application) throughout the year after planting. The final data collection date was the last week of November, 2012. Plants were labeled "live" if any green leaves were visible, or – when no leaves were present – if stem tissue was pliable. Plants were classified as dead if the plant individual was missing, lacking leaves and fine stems were brittle.

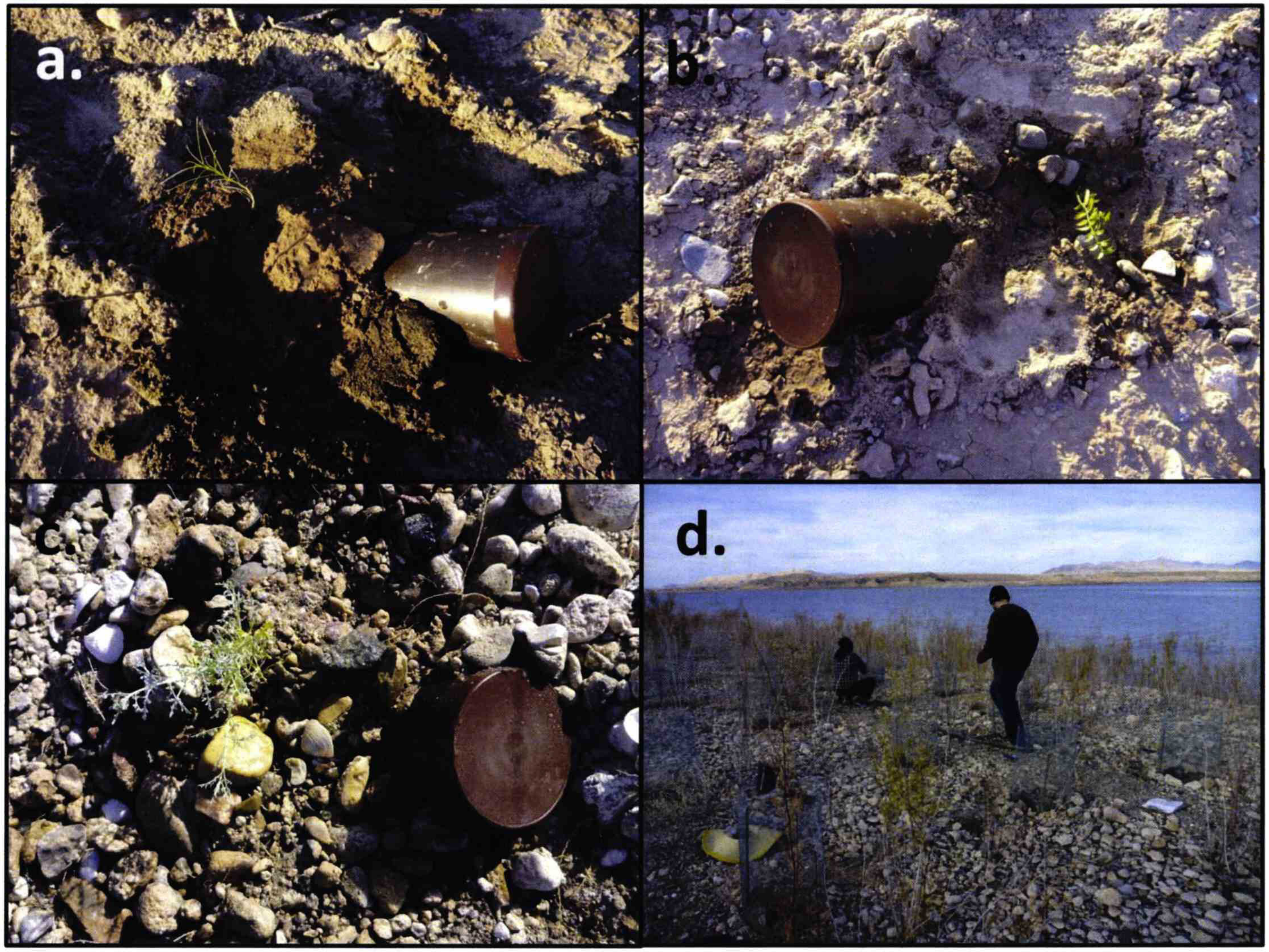


Figure 2.3. Outplanting along the Lake Mead shoreline, December 2011 – January 2012. *Hymenocla salsola* (a), *Larrea tridentata* (b), *Ambrosia dumosa* (c) individuals pictures on the day of outplanting, and (d) an example of a nearly finished plot with plants and protective cages installed at the 2005 lake elevation along the Overton Beach shoreline.

Data analysis
We performed a full factorial (three-way) ANOVA in SAS (SAS institute 2009) to examine the role of plant species identity, time since submersion, and site variation on survival rates of the four species planted. We also performed a principal components analysis (correlation matrix) in PC-ORD.

Results
As of one year after planting, 120 (30%) out of the 396 individuals planted were alive. Survival rates were similar among *A. dumosa*, *E. farinosa*, and *L. tridentata*, all ranging from 37-40% survival. *H. salsola* performed poorly across the planting, with survival just under 10%. Time since submersion had no overall or interactive effect on outplanting survival ($P > 0.05$). Rather, planting site (Overton Beach or Stewarts Point) dictated survival rates ($P < 0.0001$, Fig. 2.1), and rates also differed among species where *H. salsola* had lower survival rates than all other species ($P = 0.001$). Planting occurred within a two week time frame and all plants were randomly assigned plots from a common source so that variation in size and age were equivalent among sites. Thus, differences in soil properties (discussed in the manuscript above) are likely the driver for the differences in survival rates among the two sites (Fig. 2.2).

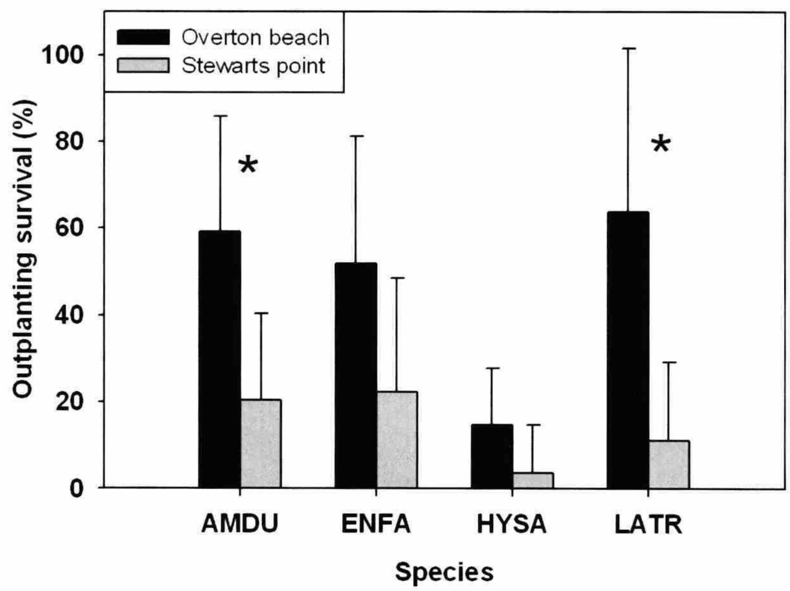
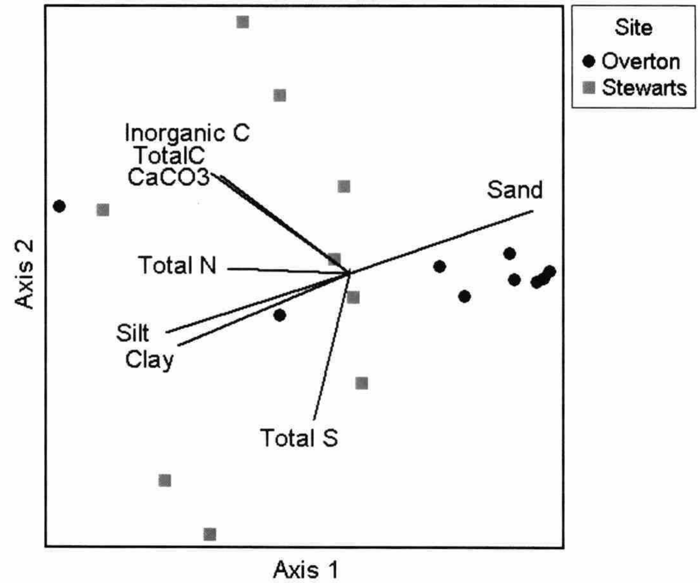


Figure 2.1. Survival rates (mean ± 1 S.D.) among each of four species planted. Species codes are as follows: AMDU = *Ambrosia dumosa*, ENFA = *Encelia farinosa*, HYSA = *Hymenoclea salsola*, and LATR = *Larrea tridentata*. Astrices (*) represent differences between sites, within a species ($P < 0.05$).

Figure 2.2. Principal components analysis (PCA) ordination of soil composition in plots immediately adjacent to planted sites. Soil composition differs across sites, but not across years within a site.



Management recommendations

Our data indicate that site rather than time since submersion determined differences in survival rate within a species. Even in species that did not significantly differ across sites (*E. farinosa* and *H. salsola*) trends indicated that survival rates were greater in the Overton Beach plots than at Stewarts Point. The Huevi association soils like those at Overton Beach are more prevalent throughout LMNRA. Huevi soils are very deep, well drained soils that formed in mixed gravelly alluvium, and is the most dominant soil group along the shoreline of Lake Mead. The huevi soils appear to be better general planting habitat than the gypsum-rich soils found at Stewarts point. The soils at Stewarts point overall were more loamy and silty, which should be better for water retention, but also had greater electrical conductivity values, indicating greater salinity – likely consisting of various mineral salts in addition to deposition from tamarisk. The Stewarts Point sites were the only site where time since submersion – and correlated tamarisk abundance – did not predict soil salinity because of the naturally occurring compounds. These soils are better for establishing specialist watch species like *Arctomecon californica* that we see occurring naturally (and re-establishing below the lake fill line), but is a much harsher environment to even the most common species that also do occur there naturally).

Overall survival rates were lower than desired or expected. We believe this is a result of non-ideal planting substrates (even the "better" conditions at Overton Beach are still harsh compared to many substrates) and in part due to the timeframe necessary which led to planting smaller than ideal individuals in this study. While we planted the seeds at the nursery in January, there were several instances of rodent herbivory, insect outbreaks, or other group die-offs of the seedlings in the nursery, resulting in multiple plantings throughout the growout period, ultimately resulting in small individuals for outplanting. We delayed the plantings two months (from October – December) to allow more time for plants to grow under ideal conditions, but that was still not enough for ideal conditions. The goal was to let the plants establish *in situ* over the winter months so they are best acclimated before the summer heat stress. Most of the *L. tridentata*, *H. salsola,* and *A. dumosa* individuals were between 10-15 cm tall at the time of planting (Fig 2.3),

and had not had time to harden outdoors, which is quite immature for an outplanting in a harsh, natural environment.

We conclude that revegetation of former tamarisk dominated shorelines will occur naturally since tamarisk self thins quite quickly once its water source is eliminated, but native perennial species will recolonize on the very slow timescale that is a feature of the extreme Mojave ecosystem. Our soils data indicate that while salinity is quite high in areas where tamarisk is still dense – closest to the water source – after just 6 years the salinity levels are not significantly greater than undisturbed sites. Additionally, after effects of siltation appear to fade relatively quickly as the soil dries out and blows away from the surface, leaving gravelly, sandy soil surfaces (at least, in sites that had that original composition) that are actually relatively amenable to outplanting. Provided the plant material is robust, it should take relatively little care and upkeep (protecting from herbivores and driwater) to successfully establish native plant islands throughout much of the exposed sandy soil surfaces along the Shoreline. However, harsher, siltier soils with heavy gypsum content are challenging habitats for establishing plants even for the most common plant species.

Appendix 1. Plot locations in UTM coordinates for all plots sampled (NAD 83, Zone 11). Point represents the southwest corner of the 10 m × 10 m plot.

Plot Name	Site	Year last submerged	Replicate	Easting	Northing
BouldD1	Boulder Beach	1998	1	697460	3991266
BouldE1	Boulder Beach	1998	1	697399	3991220
BouldD2	Boulder Beach	1998	2	697617	3991114
BouldD3	Boulder Beach	1998	3	697655	3991053
BouldD4	Boulder Beach	1998	4	697671	3991005
BouldD5	Boulder Beach	1998	5	698468	3990353
BouldD6	Boulder Beach	1998	6	698822	3990136
BouldD7	Boulder Beach	1998	7	698859	3990105
BouldD8	Boulder Beach	1998	8	698965	3990032
BouldD9	Boulder Beach	1998	9	699153	3989932
BouldD10	Boulder Beach	1998	10	699800	3989464
BouldC1	Boulder Beach	2002	1	700151	3989635
BouldC2	Boulder Beach	2002	2	699360	3990190
BouldC3	Boulder Beach	2002	3	699165	3990313
BouldC4	Boulder Beach	2002	4	699084	3990378
BouldC5	Boulder Beach	2002	5	699020	3990417
BouldC6	Boulder Beach	2002	6	698657	3990638
BouldC7	Boulder Beach	2002	7	697935	3991207
BouldC8	Boulder Beach	2002	8	697917	3991240
BouldC9	Boulder Beach	2002	9	697891	3991298
BouldC10	Boulder Beach	2002	10	697777	3991445
BouldB1	Boulder Beach	2005	1	697933	3991533
BouldB2	Boulder Beach	2005	2	698007	3991377
BouldB3	Boulder Beach	2005	3	698036	3991331
BouldB4	Boulder Beach	2005	4	698065	3991305
BouldB5	Boulder Beach	2005	5	698747	3990769
BouldB6	Boulder Beach	2005	6	699111	3990541
BouldB7	Boulder Beach	2005	7	699174	3990504
BouldB8	Boulder Beach	2005	8	699248	3990436
BouldB9	Boulder Beach	2005	9	699453	3990309
BouldB10	Boulder Beach	2005	10	700261	3989715
BouldA1	Boulder Beach	2008	1	700307	3989751
BouldA2	Boulder Beach	2008	2	699570	3990434
BouldA3	Boulder Beach	2008	3	699384	3990579
BouldA4	Boulder Beach	2008	4	699305	3990639
BouldA5	Boulder Beach	2008	5	699237	3990720
BouldA6	Boulder Beach	2008	6	698891	3990972
BouldA7	Boulder Beach	2008	7	698254	3991451

BouldA8	Boulder Beach	2008	8	698239	3991470
BouldA9	Boulder Beach	2008	9	698211	3991511
BouldA10	Boulder Beach	2008	10	698119	3991636
BouldE2	Boulder Beach	Control	2	697495	3991046
BouldE3	Boulder Beach	Control	3	697560	3991029
BouldE4	Boulder Beach	Control	4	697571	3990948
BouldE5	Boulder Beach	Control	5	698410	3990291
BouldE6	Boulder Beach	Control	6	698774	3990074
BouldE7	Boulder Beach	Control	7	698818	3990044
BouldE8	Boulder Beach	Control	8	698920	3989961
BouldE9	Boulder Beach	Control	9	699019	3989790
BouldE10	Boulder Beach	Control	10	699636	3989370
OvertD1	Overton Beach	1998	1	736289	4037059
OvertE1	Overton Beach	1998	1	736220	4037009
OvertD2	Overton Beach	1998	2	736340	4036978
OvertD3	Overton Beach	1998	3	737024	4036438
OvertD4	Overton Beach	1998	4	737057	4036407
OvertD5	Overton Beach	1998	5	737101	4036362
OvertD6	Overton Beach	1998	6	737205	4036158
OvertD7	Overton Beach	1998	7	737217	4036006
OvertD8	Overton Beach	1998	8	737040	4035736
OvertD9	Overton Beach	1998	9	736427	4036949
OvertD10	Overton Beach	1998	10	737066	4035900
OvertC1	Overton Beach	2002	1	737303	4035698
OvertC2	Overton Beach	2002	2	737368	4036166
OvertC3	Overton Beach	2002	3	737163	4036536
OvertC4	Overton Beach	2002	4	737199	4036511
OvertC5	Overton Beach	2002	5	737244	4036452
OvertC6	Overton Beach	2002	6	736620	4037299
OvertC7	Overton Beach	2002	7	736658	4037261
OvertC8	Overton Beach	2002	8	737255	4035867
OvertC9	Overton Beach	2002	9	737332	4035976
OvertC10	Overton Beach	2002	10	736714	4037164
OvertB1	Overton Beach	2005	1	736674	4037340
OvertB2	Overton Beach	2005	2	736725	4037322
OvertB3	Overton Beach	2005	3	737304	4036636
OvertB4	Overton Beach	2005	4	737341	4036613
OvertB5	Overton Beach	2005	5	737402	4036549
OvertB6	Overton Beach	2005	6	737487	4036173
OvertB7	Overton Beach	2005	7	737393	4035967
OvertB8	Overton Beach	2005	8	737345	4035691
OvertB9	Overton Beach	2005	9	736789	4037253
OvertB10	Overton Beach	2005	10	737341	4035855

OvertA1	Overton Beach	2008	1	737441	4035671
OvertA2	Overton Beach	2008	2	737462	4035942
OvertA3	Overton Beach	2008	3	737533	4036170
OvertA4	Overton Beach	2008	4	737473	4036589
OvertA5	Overton Beach	2008	5	737432	4036681
OvertA6	Overton Beach	2008	6	737407	4036711
OvertA7	Overton Beach	2008	7	736778	4037441
OvertA8	Overton Beach	2008	8	736814	4037402
OvertA9	Overton Beach	2008	9	736862	4037334
OvertA10	Overton Beach	2008	10	737458	4035840
OvertE2	Overton Beach	Control	2	736277	4036935
OvertE3	Overton Beach	Control	3	736285	4036898
OvertE4	Overton Beach	Control	4	736959	4036385
OvertE5	Overton Beach	Control	5	736999	4036345
OvertE6	Overton Beach	Control	6	737051	4036308
OvertE7	Overton Beach	Control	7	737115	4036153
OvertE8	Overton Beach	Control	8	737133	4036045
OvertE9	Overton Beach	Control	9	736975	4035917
OvertE10	Overton Beach	Control	10	736949	4035757
StewD1	Stewarts Point	1998	1	732461	4027895
StewE1	Stewarts Point	1998	1	732288	4028072
StewD2	Stewarts Point	1998	2	732485	4027982
StewD3	Stewarts Point	1998	3	732550	4028031
StewD4	Stewarts Point	1998	4	732580	4028079
StewD5	Stewarts Point	1998	5	732547	4028205
StewD6	Stewarts Point	1998	6	732596	4028392
StewD7	Stewarts Point	1998	7	732637	4028408
StewD8	Stewarts Point	1998	8	732533	4028326
StewD9	Stewarts Point	1998	9	732655	4028498
StewD10	Stewarts Point	1998	10	732882	4028648
StewC1	Stewarts Point	2002	1	732721	4027368
StewC2	Stewarts Point	2002	2	732762	4027457
StewC3	Stewarts Point	2002	3	732863	4027554
StewC4	Stewarts Point	2002	4	732908	4027583
StewC5	Stewarts Point	2002	5	732959	4027629
StewC6	Stewarts Point	2002	6	733108	4027701
StewC7	Stewarts Point	2002	7	733333	4027875
StewC8	Stewarts Point	2002	8	733200	4027680
StewC9	Stewarts Point	2002	9	733280	4027709
StewC10	Stewarts Point	2002	10	733206	4027871
StewB1	Stewarts Point	2005	1	733403	4027755
StewB2	Stewarts Point	2005	2	733298	4027444
StewB3	Stewarts Point	2005	3	733213	4027360

StewB4	Stewarts Point	2005	4	733079	4027332
StewB5	Stewarts Point	2005	5	732975	4027355
StewB6	Stewarts Point	2005	6	732909	4027383
StewB7	Stewarts Point	2005	7	732750	4027304
StewB8	Stewarts Point	2005	8	733289	4027590
StewB9	Stewarts Point	2005	9	733403	4027573
StewB10	Stewarts Point	2005	10	733413	4027645
StewA1	Stewarts Point	2008	1	732847	4027201
StewA2	Stewarts Point	2008	2	732959	4027134
StewA3	Stewarts Point	2008	3	733060	4027236
StewA4	Stewarts Point	2008	4	733141	4027277
StewA5	Stewarts Point	2008	5	733260	4027270
StewA6	Stewarts Point	2008	6	733395	4027420
StewA7	Stewarts Point	2008	7	733481	4027619
StewA8	Stewarts Point	2008	8	733374	4027508
StewA9	Stewarts Point	2008	9	733456	4027514
StewA10	Stewarts Point	2008	10	733458	4027592
StewE2	Stewarts Point	Control	2	732368	4028131
StewE3	Stewarts Point	Control	3	732451	4028119
StewE4	Stewarts Point	Control	4	732453	4028171
StewE5	Stewarts Point	Control	5	732427	4028258
StewE6	Stewarts Point	Control	6	732380	4028379
StewE7	Stewarts Point	Control	7	732425	4028482
StewE8	Stewarts Point	Control	8	732486	4028541
StewE9	Stewarts Point	Control	9	732531	4028597
StewE10	Stewarts Point	Control	10	732848	4028736

Appendix 2. Site locations for the outplanting experiment. Points represent southwest corner of each of the 10 m × 6 m outplanting plots.

Plot Name	Site	Year Last Submerged	Replicate	easting	northing
Ob5plant	Overton	2005	1	4036560	737387
Ob6plant	Overton	2005	2	4036191	737480
Ob7plant	Overton	2005	3	4035952	737399
Oc2plant	Overton	2002	1	4036166	737378
Oc5plant	Overton	2002	2	4036461	737255
Oc9plant	Overton	2002	3	4035993	737333
Od5plant	Overton	1998	1	4036360	737121
Od6plant	Overton	1998	2	4036140	737216
Od7plant	Overton	1998	3	4036002	737222
Sb2plant	Stewarts Point	2005	1	4027442	733290
Sb3plant	Stewarts Point	2005	2	4027370	733194
Sb4plant	Stewarts Point	2005	3	4027339	733066
Sc3plant	Stewarts Point	2002	1	4027565	732870
sc5plant	Stewarts Point	2002	2	4027637	732975
Sc6plant	Stewarts Point	2002	3	4027695	733094
Sd3plant	Stewarts Point	1998	1	4028027	732574
Sd5plant	Stewarts Point	1998	2	4028228	732564
Sd8plant	Stewarts Point	1998	3	4028326	732554

Appendix 3. Example datasheet for plant cover and plot descriptors.

LAKE SHORELINE SUCCESSION **DATE:** ______
PERENNIAL/ANNUAL SPECIES COVER

*Values represent raw cover estimates

PLOT:	**PLOT:**	**PLOT:**	**PLOT:**
PHOTO:	**PHOTO:**	**PHOTO:**	**PHOTO:**
SLOPE:	**SLOPE:**	**SLOPE:**	**SLOPE:**
ASPECT:	**ASPECT:**	**ASPECT:**	**ASPECT:**

Species		Species		Species		Species	
TAMRAM (live)		TAMRAM (live)		TAMRAM (live)		TAMRAM (live)	
TAMRAM (dead)		TAMRAM (dead)		TAMRAM (dead)		TAMRAM (dead)	

Notes: Bare ground: Fine rock: Coarse rock: Litter:	Notes: Bare ground: Fine rock: Coarse rock: Litter:	Notes: Bare ground: Fine rock: Coarse rock: Litter:	Notes: Bare ground: Fine rock: Coarse rock: Litter:

Appendix 4. Datasheet for recording *Tamarisk ramosissima* density.

LAKE SHORELINE SUCCESSION **Data recorder:** ____________________

TAMARIX COUNTS **Date:** ____________________

SITE (one site per sheet): ____________________

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

Plot:		Plot:		Plot:		Plot:	
Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR	Dead TR	Live TR

NOTES: ____________________

Manuscripts submitted to professional journals:
Plant succession and soil properties on newly exposed shoreline during drawdown of Lake Mead, Mojave Desert. E. Cayenne Engel, Scott R. Abella, and Kenneth L. Chittick. Submitted to *Lake and Reservoir Management*. Submitted May, 2012, accepted with revisions December 2012.

Additional products provided in separate files:

Professional talk:
Chittick, K., E. C. Engel, and S. R. Abella. Plant succession and native plant species establishment along the newly exposed shoreline of Lake Mead. *Lake Mead Symposium*, March 5-6, 2012, Las Vegas, NV.

Poster presentation:
Chittick, K., E. C. Engel, and S. R. Abella. Plant succession and dynamics of soil properties along the Lake Mead Shoreline. *Lake Mead Symposium*, March 5-6, 2012, Las Vegas, NV.

Submitted by:

Cayenne Engel, Principal Investigator	12/31/2012
	Date