The Revegetation of Disturbed Areas Associated with Roads at Lake Mead National Recreation Area, Nevada

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Executive Summary

In a collaborative effort between US Geological Survey scientists and National Park Service resource specialists, two studies were established in spring and summer 2001 at Lake Mead National Recreation Area (LMNRA) to quantify the success of revegetation efforts following disturbance of surface soils and vascular plants. One study focused on the removal, storage and application of stored surface soil during road improvements along Lake Shore Road. A second study evaluated whether decompacting, mulching and reseeding surface soils helps revegetate decommissioned roads in the Newberry Mountains. These studies were established because reclamation techniques have had variable success on vegetation establishment at LMNRA, and restoration efforts have not been quantified or systematically assessed (Alice Newton, pers. comm.).

During the winter and spring 2001/02, one year after studies were established, LMNRA received only 10% of average winter precipitation. The resulting absence of germination for annual and perennial plants constrains our conclusions from both studies in this first year. While this report primarily describes the study design established for long-term evaluation of restoration efforts at LMNRA, preliminary results in this unusually dry year are also reported.

In the study of shallow surface soil (0-5 cm) reclamation along Lake Shore Road, soil that was collected, stored in large piles and applied along the new road shoulder lost 85% of germinable seeds compared to adjacent undisturbed areas. Such a large reduction is of concern, especially where the native seed bank is already at a fairly low level (685 seeds/m^2). Studies in the Mojave Desert have found seed banks ranging from 427 to 7682 seeds/m^2 (Guo *et al.* 1999, Nelson and Chew 1977). Most of the loss of germinable seed in this study occurred during soil pile construction (79%), likely due to mixing of soil fractions during collection with heavy machinery. Because germinable seed densities were diluted by the amount of sub-surface soil collected, we could not assess whether temperature, moisture and compaction conditions within the soil pile affected the germinability of seed stored on site for 2 months. Soil pile conditions differed from those normally experienced by seeds in the Mojave desert (higher soil moisture and lower average temperatures than undisturbed controls), but it remains to be seen whether these differing conditions play a significant role in seed bank dynamics within stored soil piles. We recognize that we measured only the seed bank response to surface soil reclamation, and other responses, such as mycorrhizal spore abundance, may have been affected differently by the soil reclamation process.

Phases 2 through 5 of the Lake Shore Road Realignment Project were revisited to determine revegetation success of reapplied surface soil over a period of seven years (1995-2001). Four and a half years after stored surface soil was reapplied, perennial species richness resembled that of nearby undisturbed areas (3 species). The exact species present, however, differed between treatments, with more variation among sites in the undisturbed areas. Sites with reapplied surface soil had lower perennial plant cover, even seven years after application (0.16% cover versus 5.9% in undisturbed areas). Perennial plant density was similar to undisturbed controls by this time (~0.05 plants/m^2), but most plants in the reapplied soil area were creosote bushes that had been planted by LMNRA (LeNoue 2002) instead of naturally established individuals. We were unable to compare the establishment of native and invasive annual plant species due to the poor precipitation year, which did not trigger any plant germination.

Although low precipitation also precluded measurements of annual or perennial plants in the Newberry Mountains, we measured seed capture and ant nests as initial indicators of recovery one growing season after decompaction, mulching and seeding treatments were applied to decommissioned roads. The species richness of seeds found on roads treated with Geojute© was comparable to that of undisturbed desert. This result was unaffected by the method of decompaction (hand-raking versus mechanical ripping) or by the addition of vertical mulch. Regardless of decompaction method (raking, ripping or none), areas without jute captured far fewer seed species, decreasing the potential for seedlings to establish. Hand seeding did not change these patterns, as we predicted, because we observed ants carrying away some seed after it was broadcast. We will determine whether these patterns of seed capture translate into similar patterns of vegetation establishment once the Newberry Mountains receive sufficient rainfall. Ant nest density was initially high in areas where just Geojute© was applied; addition of vertical mulch with jute did not influence ant nest density. The ants likely take advantage of newly available space. Continued monitoring of these studies, especially in years where rainfall is sufficient to stimulate plant germination, will shed light on the passive versus active restoration of these disturbed areas within the LMNRA.

Abstract

Shallow surface soil reclamation is thought to increase the re-establishment of native vegetation following surface disturbance by preserving and eventually replacing the indigenous seed bank. Decompaction and mulching of disturbed surface soils are methods used on decommissioned roads to speed recovery by enhancing seedling germination and establishment. These efforts have had variable success in re-establishing vegetation at LMNRA, but to date these observations have not been quantified. In our first study, we measured the change in abundance of germinable seed when surface soil was mechanically collected, stored for two months, and redistributed upon completion of a scenic loop within the park. The greatest loss of seed occurred during the process of soil collection (79% of total). Losses of germinable seed also occurred during the two-month storage of soil and following soil replacement, but these losses were negligible (each < 5% of total loss). At similar surface soil replacement sites, we found no perennial plant cover from 0.5 to 5 years after application and low cover after 7 years (5% of control cover). The reduction in abundance of germinable seed during surface soil reclamation was primarily due to dilution of the seed bank when deeper soil fractions containing no seed were mixed with the shallow surface soil during collection and likely not due to mechanical injury. Because the density of seeds within the soil pile was low, the effects of high soil moisture and less variable soil temperature on seed germinability could not be adequately addressed. In a second study, we measured seed species richness along with ant nest density and species richness on decommissioned road plots in the Newberry Mountains with three different levels of mulching treatment and two levels of decompaction. Mulching with commercially available GeoJute© in combination with decompaction increased seed species richness to the level of undisturbed areas, although no other treatment had any additional effect on seed diversity. Ants did not respond to any restoration method, but they were found in greater density and richness on the decommissioned roads than in undisturbed desert.

Introduction

The National Park Service (NPS) has identified a need to understand the impacts associated with roads at the Lake Mead National Recreation Area (LMNRA). Currently, road improvement efforts at LMNRA include removing and storing shallow surface soil (0-5 cm) before road improvements are made. This surface soil is replaced after improvements are made with the intent that the salvaged seed bank and soil microbes will enhance revegetation following disturbance. However, surface soil removal and replacement has had variable effects on vegetation reestablishment in LMNRA to date, and these results have not been entirely quantified (Alice Newton, pers. comm.). In addition to road improvement activities, unpaved roads that were previously established within the Newberry Mountains are being removed from public use. These roads have left a lasting imprint on the landscape that will persist unless restoration efforts are implemented and quantitatively assessed in a resource management plan.

The establishment of roads can have enduring effects on the soil and vegetation communities in the Mojave Desert. Estimated recovery rates of desert lands that have been disturbed by motorized vehicular use range from decades to centuries (Lovich and Bainbridge 1999). An assessment of the methods for revegetating disturbed areas is paramount for minimizing future disturbances and for directing restoration efforts. The upper portion of desert soils contains the majority of the seed bank and a large percentage of the organisms associated with nutrient cycling (Foth and Turk 1972). In addition to seed loss and damage, mechanical compaction of soil can reduce seedling establishment and impede root penetration and growth (Bainbridge and Virginia 1990). Revegetation of disturbed soils in arid regions can have highly variable success due to the amount and frequency of rainfall at the time plants are seeded or transplanted (Grantz *et al.* 1998). Surface soil removal, storage and replacement have become standard practice in reclamation, particularly in the mining industry, for promoting soil genesis (Allen 1995). Application of mulch on top of the disturbed soil surface may enhance seedling establishment by reducing evaporation and stabilizing soils against wind and water erosion (Fraser and Wolfe 1982, Brammer 1982). Mulch may also act in the manner of a shrub, capturing windblown litter and seed. In some arid regions, however, mulching has had limited success (Winkel *et al.* 1995).

Five separate phases of road construction were completed by NPS along Lake Shore Road in 1995 (Phase 1 and 2), 1998 (Phase 3), 2000 (Phase 4) and 2002 (Phase 5). During road construction at LMNRA, surface soil was collected mechanically in early spring, placed nearby in large soil piles during the spring and summer months, and then applied using a backhoe once roadside construction was completed. Soil collection depth, although prescribed as 2-8 inches, ranged up to 6 feet when large rocks were encountered (LeNoue 2002). The process of removing surface soil, storing soil in piles and replacing it after several months may cause seed mortality of some vascular plant species (e.g., through mechanical injury, deep burial) and enhance germination of others (e.g., through seed scarification, break in physiological dormancy). We established studies to determine the effect of shallow surface soil manipulation on plant seed bank (Part I), examine short-term vegetation recovery following surface soil salvage and subsequent replacement (Part II) and assess the success of various restoration techniques for decommissioned roads (Part III). Parts I and II were conducted along Lake Shore Road along the eastern shore of Lake Mead; Part III occurred in the Newberry Mountains south of Lake Mead.

Study area

Lake Shore Road is located in the Boulder Beach District of LMNRA, northeast of Boulder City, Nevada. From 1993 to 2002, the NPS contracted to have the 14-mile road completely re-constructed, partially over existing roadbed, partially through undisturbed desert. During each of five phases, shallow surface soil was stockpiled and then replaced upon completion of construction. The stockpile study concentrated on the fifth phase of the project, located from near 33 Hole to the fish hatchery. This phase of construction consisted almost entirely of new road alignment through undisturbed desert. The affected area of LMNRA consists of benches separated by 5-10 m deep washes where a 0.5 m thick caliche layer is readily visible several meters below the soil surface of the benches. The bench tops are older surfaces with desert pavement and sparse perennial plant cover of creosote bush (*Larrea tridentata*), white bur-sage (*Ambrosia dumosa*) and beavertail cactus (*Opuntia basilaris*).

The Newberry Mountains are located in the southernmost portion of LMNRA, south of Lake Mead and northwest of Laughlin, Nevada. Four secondary unpaved roads branching off Christmas Tree Pass Road were selected for this study based on adequate length for all treatments, minimal slope and lack of public access after closure. All four roads were hard-packed soil with no improvements and slated for closure before this study began. Roads were closed to vehicular traffic by LMNRA using large wooden posts and signs. The study area is located in the foothills of the Newberry Mountains with a coarse, granitic soil. Compared to the Lake Shore Road area, the relatively young soil has little horizon development. Perennial vegetation is more plentiful and diverse than in the Lake Shore Road area. Creosote bush and white bur-sage are abundant, along with Mojave yucca (*Yucca schidigera*), juniper (*Juniperus osteosperma*), cat-claw acacia (*Acacia greggii*), cheesebush (*Hymenoclea salsola*) and several other composite shrubs.

Methods

Part 1—Determine the fate of seed bank in the surface soil removal/storage/replacement process.

During summer and fall 2001, we determined whether losses of germinable seed occurred during the collection, storage or replacement phases of shallow surface soil reclamation. Ideally, the top 2”-8” (5.1-20.3 cm) of soil was mechanically scraped and placed in three tall soil piles during the construction of a 2.8 mile scenic loop on Lake Shore Road in LMNRA. In reality, soil collection depths reached 6 feet when large rocks or caliche were encountered (LeNoue 2002), and regularly averaged 10”-12” (LeNoue, pers. comm.). We instrumented one soil pile to relate soil pile temperature, moisture and bulk density to seed germinability during storage. Soil cores were collected from the soil pile on July 5 and 6 just after completion and at twelve randomly selected undisturbed (control) areas just outside the tortoise fencing. Soil cores were collected at 20, 50 and 70-cm depths within the soil pile on four dates during storage (July 20, August 3, August 17 and August 24) and once in adjacent control areas (August 17). Finally, soil cores were collected after surface soil was replaced and from twelve adjacent undisturbed areas (October 25). All soil cores were collected using two to four 4-cm deep sampling tins (each tin volume = 113.1 cm^3), placed in labeled plastic bags and stored at 25°C.

The temperature, moisture and compaction of stockpiled soil were monitored at the three depths (20, 50 and 70 cm) at the same time samples were collected for seed bank analysis. Thirty-six StowAway temperature data loggers (Onset Computer Corp., Pocasset, MA) were placed at the three depths (twelve per depth) during the first soil sample collection. Two replicate data loggers per depth were removed during each subsequent sampling and soil cores taken from these locations. After the first round of data loggers was removed, two data loggers were placed in an adjacent undisturbed area just under the surface to monitor control areas. Soil cores were analyzed for bulk density (Rundel and Jarrell 1989) and gravimetric soil water content (Gardner 1986) before seed viability tests were conducted. Drying soil samples slowly at 40°C to analyze soil water content should not negatively impact seeds because the average temperature of undisturbed soils just under the surface was 41°C, varying from 22°C to 68°C (see results).

For seed bank analysis, samples were transported to the greenhouse (LMNRA), where each was homogenized and ½ cup placed in a 6” diameter plastic bulb pot. The soil samples were covered with a thin Vermiculite layer to reduce water loss during germination. All pots were randomized on a bench in the greenhouse and subjected to a series of treatments to germinate all possible seed (T. Esque, USGS, pers. comm.): water for 2 weeks, dry for one month, water for 2 weeks, dry for one month, water with NH_4NO_3 for 2 weeks, dry for one month, water with gibberellic acid for 2 weeks. During the wet periods, all seedlings were counted, identified to species and removed from the pots. The total number of seedlings for each species was then combined across all wetting cycles. Natural germination in the field was not expected during sample collection because the stockpiles were constructed in July, and germination usually depends on winter or early spring rainfall in the Mojave Desert (Beatley 1974). However, to be sure, we searched carefully for seedlings on the stockpile and in the control areas at the same time that soil cores were collected.

Part II—Determine short-term recovery of vegetation after stored surface soil application.

In addition to seed bank dynamics during surface soil storage, we measured perennial plant establishment along roadside areas where surface soil was reapplied over a 7-year period. Cover and density of perennial seedlings were measured at each of the different construction phases along Lake Shore Road, except Phase 1 because the treatments applied during this phase were different than those applied during the other phases (e.g., shallow surface soil was not applied to most parts of the roadside). In March 2002, nine permanent belt-transects (20 m x 2 m) were established in each treatment area and nine in adjacent control areas using a portable GPS unit and concealed reinforcement bar with numbered tags. These transects were grouped into three replicates per time treatment (i.e. years since soil replacement). Perennial plant cover and density were recorded by species. Cover was measured using the line-intercept method on 20-m long transects, and density was determined on adjoining belt-transects (Elzinga *et al.* 1998). We searched carefully for annual plants during perennial plant measurements, but none were found.

Part III—Determine the success of decompaction, mulching and seeding in revegetating decommissioned roads.

In spring 2001, four replicate secondary roads along the Christmas Tree Pass Road in the Newberry Mountains were selected and named for the purpose of this study– Spirit Mountain Road, Willow Springs Road, Catacombs Road and Discovery Arch Road. Each road served as a block, with two replicates nested within each block. Within each replicate, the levels of soil decompaction and mulching were randomly assigned to equally sized plots. The soil decompaction factor has two levels that were tested: decompaction using hand tools and decompaction and smoothing with a tractor. Three levels of mulching treatment were tested: ground cover with GeoJute©, a commercially available woven coconut fiber mat used to slow surface erosion, GeoJute© with vertical mulch (dead persistent plant material placed under the GeoJute©), and no mulch. One treatment control plot with no decompaction and no mulching was also assigned within each replicate for a total of seven experimental units per replicate (2 levels of decompaction x 3 levels of surface treatment + 1 untreated road plot). Undisturbed controls were randomly located near the roadbed.

A mixture of native seed collected from the area was hand-broadcast in May 2001, adding another factor. The native seed mixture contained 76% goldenbush (*Ericameria* spp.), 15% cheesebush (*Hymenoclea salsola*) and 9% golden-eye (*Viguiera deltoidea*) by volume and was spread such that half of each treatment plot received the same density of seed. The fourth road, Discovery Arch, did not receive a seeding treatment because it was decommissioned after the season when seed could be readily collected (e.g. November 10, 2001 versus March 21-23, 2001 for the other roads).

Because no perennial or annual plants germinated during winter and spring 2001-2002, plants were not quantified on the different treatments. We instead quantified seed laying on the surface using 1-m^2 quadrats, five in each mulching x decompaction x seeding treatment. On Discovery Arch Road, which had no seeding, we placed ten quadrats per mulching x decompaction treatment plot. In all cases, quadrats were evenly spaced down the middle of the former roadbed to avoid edge effects. For each quadrat, we recorded the species of seed present. Ten randomly selected undisturbed control quadrats per road were also assessed. These data were used to compare the species richness of seed on each treatment type.

In addition to seeds, we mapped all ant nests on each treatment plot. On an overcast day (July 19), when ant activity was high, 50-m tapes were laid along two perpendicular edges of each treatment plot. Each plot was thoroughly searched twice and any ant nests found mapped along with the species of ant. Two randomly-located undisturbed control plots per road were searched and mapped in the same manner. Undisturbed control plots were the average size of treatment plots for that road. The ant maps will be used to determine the future survivorship of colonies, but this year, we used them to calculate nest densities.

Statistical analyses. All statistical analyses were conducted using SAS statistical software (v. 8.0, SAS, Inc., Cary, NC). To determine whether surface soil reclamation influenced total germinable seed (Part I), we compared the surface soil treatment with controls at each phase of surface soil reclamation (collection, storage and application) in a two-factor ANOVA. We also used a two-factor ANOVA (year x soil treatment) to assess short-term perennial plant recovery (total density, cover and species richness) several years after surface soil replacement (Part II). To evaluate the initial plant and ant responses to road restoration methods, species richness of seed, ant nest density and ant species richness were tested using a factorial ANOVA with site as a blocking factor. Violations of the assumption of equal variance were examined in residual plots and using Levene's test. Violations of normality were examined in normality plots and tested according to D'Agostino (1971). When necessary, $\log_{10}$-transformations were performed to meet the assumption of equal variance (Box and Cox 1964). Significance was determined at the $\alpha = 0.05$ level.

Results

Part I—Seed bank fate in soil pile. By the time stored surface soil was applied along the shoulder of Lake Shore Road, 85% of the germinable seed was lost compared with the undisturbed control ($P < 0.001$). The undisturbed control (mean ± SE) had an average germinable seed density of 685 ± 87 seeds/m^2, while the average density of respread surface soil was 104 ± 24 seeds/m^2 (Figure 1). The greatest loss of germinable seed occurred during the process of soil collection, where densities dropped 79% compared to the control. Losses of germinable seed also occurred during the two-month storage of surface soil (5%) and following soil replacement (3%), but these additional losses were not significant ($P > 0.05$). The majority of seed species in both respread soil and control soil were the annuals plantain (*Plantago patagonica*, 39%), Mediterranean grass (*Schismus barbatus*, 23%), foxtail chess (*Bromus madritensis* ssp. *rubens*, 1%) and combseed (*Pectocarya* spp., 1%); the remaining seedlings were not identified to species.

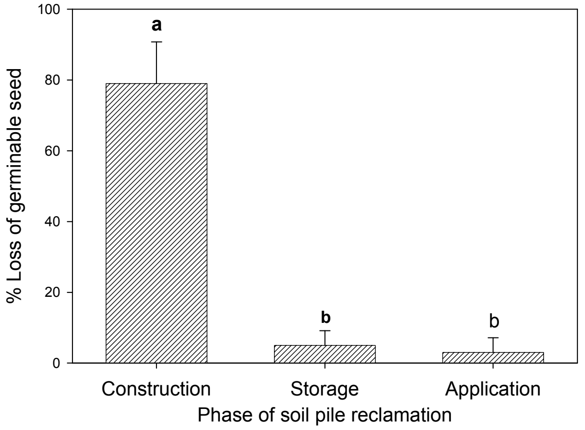

Figure 1. Mean germinable seed bank loss (± 1 SE) during surface soil salvage at LMNRA. Phases with significantly different losses are denoted by different letters.

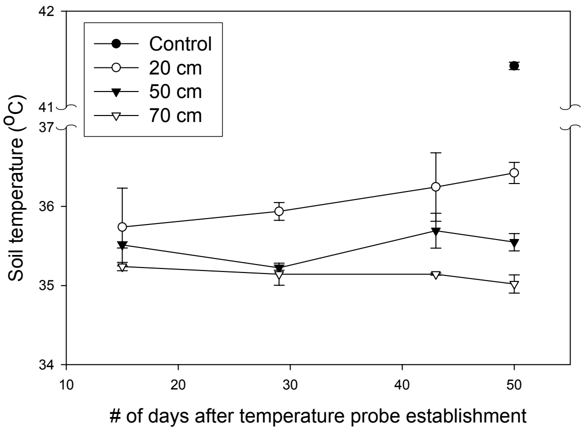

Figure 2. Mean temperature (± 1 SE) of soil stored in a salvage pile at LMNRA. Data loggers were removed from 20 July (day 15) to 25 October 2001.

The low number of germinable seeds in all samples including controls prevented us from statistically relating soil pile conditions to the loss of seed during storage. Despite this limitation, we did find that the soil pile created conditions different from those normally experienced by seeds in LMNRA. Within the stockpile, the average temperature from July 7 to October 25 was 35.7 ± 0.15°C, lower than the average undisturbed surface temperature of 41.4 ± 0.04°C (Figure 2). Soil water content was higher in the stockpile than in undisturbed areas and higher at 50 and 70 cm depths than at 20 cm (Figure 3). Soil bulk density was greater at 20 cm than at 50 cm across all dates. Bulk density at 70 cm, however, was initially high and decreased through time (Figure 4).

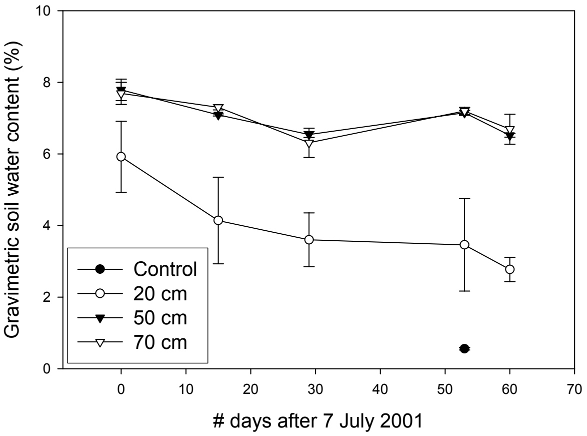

Figure 3. Mean water content (± 1 SE) of soil stored in a salvage pile at LMNRA. Soil cores were collected from 7 July (day 0) to 25 October 2001.

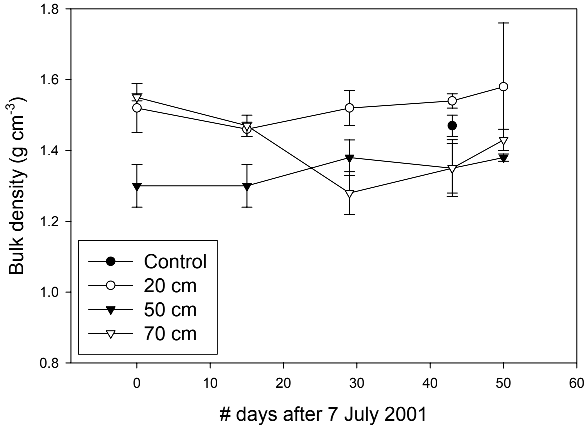

Figure 4. Mean bulk density (± 1 SE) of soil stored in a salvage pile at LMNRA. Soil cores were collected from 7 July (day 0) to 25 October 2001.

Part II—Short-term vegetation recovery after surface soil manipulation. Total perennial plant cover was significantly lower at stored surface soil application areas than undisturbed controls, regardless of years since surface soil replacement ($P < 0.001$, Figure 5). Undisturbed areas averaged 4.8% perennial cover, while application locations averaged < 1%. When compared to the undisturbed control, perennial plant density was also significantly lower at all sites where stored soil was applied, regardless of age ($P < 0.001$, Figure 6). A significant year by treatment interaction for density was found ($P = 0.002$) due to low values on the undisturbed control for the oldest stored soil application site (Phase 2, 7 years). Creosote shrubs planted by LMNRA staff also increased plant density and cover on the reapplied surface soil at this site.

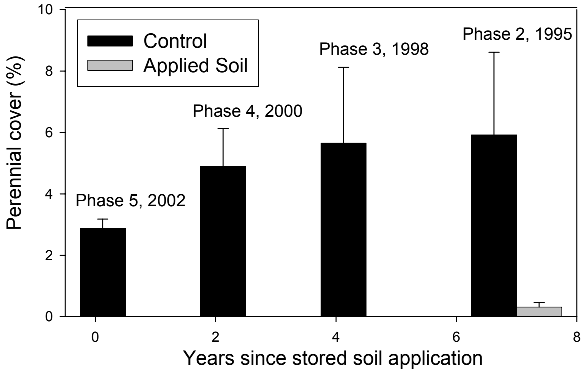

Figure 5. Mean perennial plant cover (± 1 SE) on line transects at sites representing years since stored surface soil application at LMNRA. Controls represent undisturbed sites adjacent to those where stored soil was applied. Cover for Phases 3, 4 and 5 was zero.

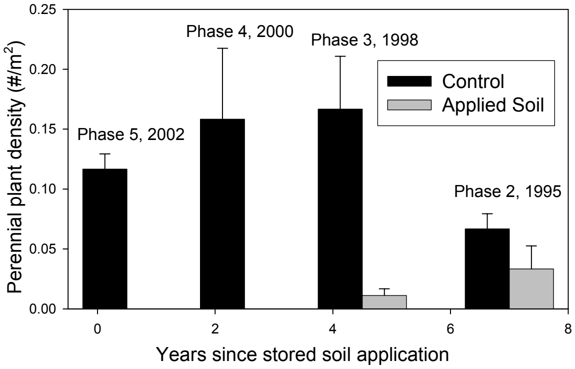

Figure 6. Mean perennial plant density (± 1 SE) on belt transects at sites representing different years since stored surface soil application at LMNRA. Controls represent undisturbed sites adjacent to those where stored soil was applied. Density for Phases 4 and 5 was zero.

Perennial species diversity along Lake Shore Road was low, with a total of eight species encountered on all transects measured. Species richness had reached the 3-species average 4.5 years after surface soil was reapplied, but a different species composition was found in the respread areas than in the undisturbed controls. Species found in undisturbed areas were creosote bush (66.9%), white bur-sage (15.1%), beavertail cactus (9.4%), sunray (*Enceliopsis argophylla*, 3.7%), spurge (*Euphorbia* spp., 3.5%), cheesebush (0.9%) and desert alyssum (*Lepidium fremontii*, 0.5%). Stored soil application areas contained creosote bush (37.5%, mostly planted individuals), desert holly (*Atriplex hymenelytra*, 34.4%), white bur-sage (15.6%) and sunray (12.5%).

Part III—Success of decompaction and mulching in revegetation. We counted the number of seed species that rested on the soil surface for each treatment. Because the small size of many native seeds, particularly annual species, makes them difficult to count accurately, we likely missed some species entirely. However, we used this ocular estimate of seed species to examine treatment differences assuming that we could identify the seed species equally for all treatments. Utilizing a block design to analyze results was justified because we found a significant difference between sites ($P < 0.001$). Species richness was not significantly different for the sites where seed was applied ($P = 0.49$), so seeded and unseeded treatments were combined for the remaining analyses. The Discovery Arch site was also included to analyze decompaction and mulching effects.

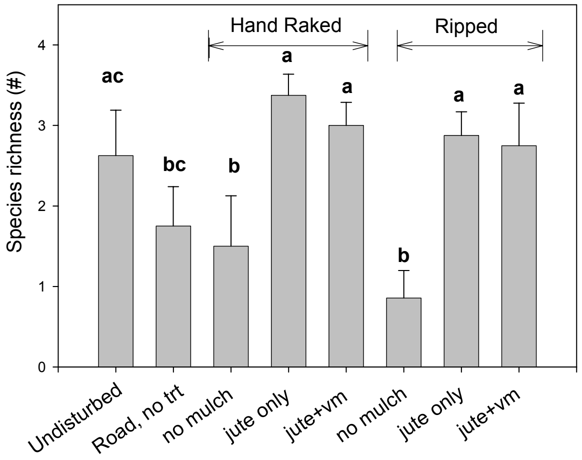

Figure 7. Mean species richness of plant seeds (± 1 SE) found on decompaction and mulching treatments applied to decommissioned roads at LMNRA in 2001. Significantly different treatments are denoted by different letters.

When the seeded and unseeded portions of each plot were combined and the Discovery Arch data added, an interesting pattern emerged (Figure 7). The combination of decompaction with mulch increased seed species richness by more then one species. Interestingly, the different types of decompaction, either hand raking or ripping, had an equal increase in species richness. Although plots treated with Geojute© had significantly higher seed species richness than untreated plots, the addition of vertical mulch caused no additional increase in species richness. Undisturbed areas had species richness values comparable to those of the Geojute© and decompaction treated plots, suggesting that Geojute© captures and holds seed species more like native litter and shrubs than does bare ground. The species richness of unmulched ripped or raked plots was not significantly different than that of untreated roadbed, indicating that decompaction alone does not increase seed capture.

Year 2001 had significantly more ant nests than 2002; but because the dynamics of ant nest density differed between 2001 and 2002 (P = 0.007), years were analyzed separately (Figure 8). In 2001, the ripped and raked treatments had similar ant nest densities compared to undisturbed sites when only jute was added (treatment effect, P = 0.016). When only jute was added in either decompaction treatment, ant nest densities were as high as the undisturbed areas. By 2002, ant nest densities on decompacted-jute treatments and the undisturbed control had declined considerably, resulting in equal densities on most treatments. Densities on the untreated roadbed were higher than the undisturbed control and the raked with jute and vertical mulch treatment, but all other treatments were equal. Because this result was often a difference of only a few nests, increased visibility on the bare road surface may play a large role. In 2001, only two species of ants were observed – harvester ants (*Pogonomyrmex rugosa*) and *Forelius pruinosus*. By 2002, five ant species inhabited our treatment plots, but because we did not request permission to remove specimens for identification, only *Pogonomyrmex rugosa* was positively identified.

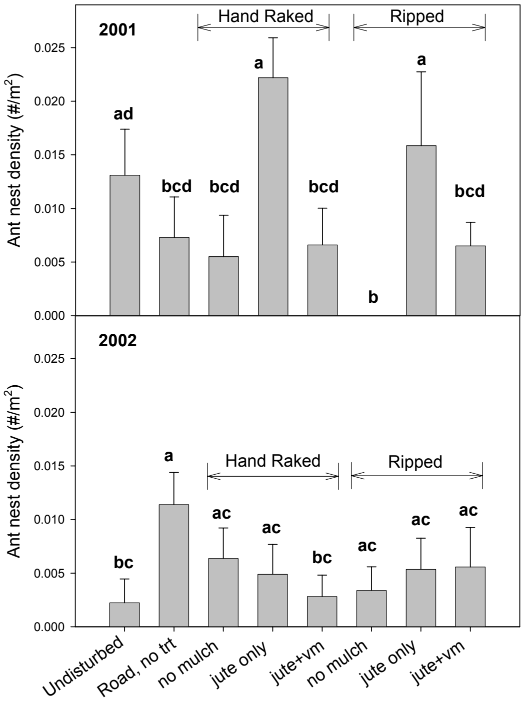

Figure 8. Mean density of ant nests (± 1 SE) found on decompaction and mulching treatments applied to decommissioned roads at LMNRA in 2001. Data was analyzed seperately for 2001 and 2002. Significantly different treatments are denoted by different letters.

Discussion

Low precipitation during winter and spring 2001/02 hindered our efforts to determine the vegetative responses to shallow surface soil reclamation and road restoration the first year of our studies. The Lake Shore Drive area received 13% of average precipitation, while the Newberry Mountains received only 6% of average. As weather patterns permit, plant responses will be measured in the future because they are important indicators of recovery. Recovery is expected to be slow in this desert ecosystem and will depend largely on precipitation patterns; thus, the research presented here was designed to test reclamation hypotheses while monitoring vegetation recovery for many years.

Despite climatic limitations, we conclude that soil collection during road construction severely decreased the available seed bank because deeper, seedless fractions of the soil profile became mixed with the top few centimeters, causing dilution. Averaged across four North American deserts (Mojave, Great Basin, Chihuahuan and Sonoran), Guo *et al.* (1998) found that 74% of the seed bank resides in the top 2 cm of soil. Given the tremendous loss we measured in the seed bank, it would be beneficial to determine if methods of surface soil collection besides using bulldozers would reduce mixing of soil fractions by concentrating collection efforts in these top few centimeters of soil. Conversely, seed collection prior to construction activities and subsequent broadcasting may be a more feasible and cost-effective solution to maintaining seed banks in disturbed areas.

The density of germinable seed we found in undisturbed soil samples at LMNRA (685 seeds/m^2) falls at the lower end of values found by other studies in the Mojave Desert. Guo *et al.* (1999) measured seed bank densities as low as 427 seeds/m^2 while Nelson and Chew (1977) found densities of up to 7682 seeds/m^2. Both of these studies, however, failed to discriminate between germinable and dead or inviable seeds, likely inflating the seed bank densities they measured. Stored and respread soil at LMNRA had seed bank densities well below those found in either study. Mojave Desert seed banks are known to display wide seasonal variation in addition to this spatial variation. Nelson and Chew (1977) found that seed bank densities increased from February through June, as winter annuals shed seed, and subsequently decreased until October, when ants and rodents became largely inactive. Collection of shallow surface soils in early summer, as in this study, should therefore maximize seed bank collection.

Annual plant species dominated the germinable seed bank. It is possible that perennial species were not well represented in the seed bank because 1) seed bank assay treatments did not stimulate germination of perennials if seed dormancy mechanisms were more difficult to break than those of annual species, 2) the soil sampling method did not adequately sample perennial species which may be more variably distributed across the landscape, especially for species that are cached by granivores, or 3) perennial seed occurs at naturally lower levels than annual species. We know from other studies that the seed bank assay method we used does germinate perennial species represented in the flora of the area (e.g., white bur-sage). Guo *et al.* (1998) found that perennial seeds were most often located in litter and on the soil surface under shrubs. The low abundance of perennial plants at Lake Shore Drive likely made perennial seed distribution more variable, and therefore less likely to be sampled, than seed of annual species in the area. We expect that perennial plant seed, even though poorly represented in our samples, would experience the same magnitude decrease in density (all other factors held constant) because they occupy the same shallow soil layers as annual seeds and would be as indiscriminately collected using heavy machinery.

Conditions within the soil pile were cooler and moister than those normally experienced by seeds at our site, but the relationship between these conditions and germinable seed loss could not be adequately determined in this study. The effect of these conditions on stored seeds needs to be explored in detail. Impacts on the native mycorrhizal community should also be considered because a reduction could impair establishment of many plant species in stored soil application areas. Cool, moist conditions increase the chances of elevated fungal activity and false germination of seeds, both of which could prove detrimental to the seed bank (Baskin and Baskin 1998). Because many mycorrhizal spores are susceptible to infection, increased fungal activity would also negatively impact the mycorrhizal community (Morton 2002). A study conducted by Stahl *et al.* (2002) found fewer mycorrhizal spores in stockpiled soil than in control areas, even seven years after application. This loss corresponded with reduced herbaceous plant cover.

The slow recovery of perennial plant cover (and perennial density if we exclude planted shrubs) at LMNRA seven years after stored surface soil application is consistent with results for desert plant communities. If low perennial abundance reflects the loss of seeds we found in the seed bank, consideration should be given to reseeding disturbed areas with mixtures representing the extant vegetation, although this effort would probably only be feasible in small areas where seed is plentiful. It remains to be seen whether mixing of soil fractions impacts seedling germination and establishment by means other than dilution. Soil structure was heavily disturbed during construction, which has the potential to negatively impact seedlings both bio-chemically and physically.

On decommissioned roads the addition of GeoJute© over decompacted roadbed increased the capture of seed species to the level of undisturbed areas, at least for common, large-seeded species. The addition of vertical mulch did not improve the capture of seed species, and raked and ripped areas responded in the same way. Broadcasting seed on plots did not increase seed species richness in part due to the movement of seeds by ants (S. Scoles, pers. obs.). Ant nest densities were initially greater in areas with jute applied, but by the following year densities in the jute treatments declined. Whether or not patterns of seed species richness and the activities of ants associated with road restoration treatments translate into patterns in germination and growth of plants remains to be seen once the study areas receive sufficient precipitation for plant germination.

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