Restoration of The Ant Hill

Anza-Borrego Desert State Park

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Table of contents

Part 1. Executive summary

A historic step was taken in 1990 with the beginning of a research and implementation project to revegetate and restore a section of Anza-Borrego Desert State Park known as the Ant Hill. This cooperative project between the Biology Department, San Diego State University; State Park personnel, the Center for Arid System Restoration at Joshua Tree National Monument, and volunteers from a variety of groups and classes treated areas damaged by off-road vehicles (ORVs). The damaged area was fenced off in 1990 and work including transplanting, direct seeding, and soil treatment continued for three years.

Extreme temperatures, intense sun, and the limited soil moisture and low fertility make natural recovery of these areas very slow after disturbance. Conditions suitable for plant establishment occur only infrequently. It may take hundreds of years for recovery to take place without active intervention.

The specific objectives of this project were to conduct research that would:

- *characterize the effects of past abuse and explore methods to undo damage from ORVs*

and

- *improve the rate of recovery of the natural community by reducing the adverse affects of ORV operation on soil and ecosystem properties*

and

- *establish selected plant species (particularly dominant perennial shrub species) by transplanting and/or direct seeding.*

Site History

The primary impacts on the site were caused by heavy off-road vehicle use (ORVs) in the late 1970's and early 1980's. Photographs from 1979 clearly reveal damage patterns that led to the current gully and slope erosion problems. Fencing in 1990 has limited access to the site and more than any other factor this protection has contributed to the recovery of the site. The extensive use and abuse of the area made finding undisturbed areas for reference sites very difficult.

Vegetation and damage mapping (historical and present) was done from aerial photographs and ground observation. The extended drought 1986-1991 made damage mapping difficult as even the creosote bush was very stressed and many shrubs died. The area was base mapped from USGS topographic maps and aerial photographs. Special problem areas (roads, gullies, erosion, etc.) were identified and mapped.

Damage at the Ant Hill

Date	1979	1991
Roads legal until 1987	0.9 miles	0.5 in use for access
Major roads	5 miles	5
Gullies		0.7 miles
Trails, roads, and hill climbs	15 acres	30+ acres

Off-road vehicles adversely affect infiltration, soil strength, and increase erosion. Compaction of a desert soil reduces the root growth of desert plants and makes it much harder for seedlings to survive. Disturbance also reduces water infiltration into the soil and this makes revegetation much more difficult. Even moderate traffic can reduce infiltration to one fourth of the natural rate. Capturing and saving the rain that falls can be essential for plant establishment and restoration and efforts to eliminate the many adverse effects of ORVs on moisture collection and storage are critical.

Soil fertility is generally much higher under plant canopies and disturbance destroys these islands of fertility. Several feet of soil have been lost from extensive areas of the Ant Hill as a result of ORV-induced erosion and this has removed much of the more fertile top soil from large areas of the site. Mycorrhizal fungi, which increase phosphorus uptake, are less able to survive and grow in compacted dry soils.

All vegetation was stripped from the highly disturbed areas of the Ant Hill. Less disturbed areas have experienced large changes in plant communities. The removal of vegetation by vehicles eliminates sheltered areas and makes plant establishment much more difficult.

Grazing pressure (herbivory) has not generally been regarded as a serious problem for desert revegetation because mammal, reptile, and insect populations are generally low. However, recent studies have demonstrated that grazing is one of the key factors limiting plant survival and establishment and this was also a common problem in revegetation at the Ant Hill. Grazing pressure was reduced after the drought but mammal and lizard populations recovered quickly and the invasion of the caterpillars in 1991 limited recovery of vegetation.

The need for intervention

Desert areas damaged by human activities may take centuries to recover without active intervention. Revegetation and restoration work can help mitigate many of the adverse effects of human activities and speed recovery, but the severe conditions and unpredictable rainfall still make recovery of these sites very difficult. Plant recovery usually requires site improvement, direct seeding and transplanting perennial shrubs. Compacted soil can be improved by ripping and loosening with implements. Direct seeding is less expensive than many other alternatives, worth trying, but often unsuccessful in the low desert. Several trials produced few seedlings. Many research tests with transplanting dominant shrubs and trees have provided new insight into the best planting strategies and methods. Survival of transplants has been very good for some treatments.

Summary

A full appreciation of the ecological setting and adaptation of desert plants can make establishment less costly and more successful, but it is still expensive. The cost of restoring roadside areas in Joshua Tree National Monument is fairly well established (about $40,000 acre). Replicating the same level of effort at a remote site like the Ant Hill would be much more expensive. The methods used here are less costly but the recovery will not be as rapid as the 7 year visual recovery goal at Joshua Tree. This research has emphasized lower cost, less-intensive restoration, but the costs (excluding research which was a primary part of this contract) would still be on the order of ten thousand dollars per acre. Even these high cost projects provide no guarantee of success if the weather patterns are unfavorable.

<u>The key lesson of this research has been the critical importance of minimizing disturbance and destruction in the desert</u>. Fences, signs, and enforcement to prevent further damage may often be a better investment than intensive restoration. The wheel tracks of a full-size off-road vehicle operating in an undisturbed area can damage an acre of land with every four miles traveled. In a single weekend a full-size four wheel drive vehicle can cause tens of thousands of dollars of damage. A major restoration project for the Ant Hill region could cost more than $2 million dollars. Funding for this project permitted only a limited restoration effort even with hundreds of days of volunteer labor.

Undoing the damage done to the soil system by disturbance is a critical step toward recovery and restoration. In general, strategies that recreate or mimic natural conditions are most likely to speed recovery of the entire ecosystem. Direct seeding and transplanting a range of container sizes onto the site can be very effective. Many transplants set seed in the first season, a first step to a successful restoration project.

The research conducted in this project should help Anza-Borrego Desert State Park and other desert parks of the American Southwest restore damaged areas. It can also benefit the hundreds of millions of people who live in the World's deteriorating arid zones. These ecosystems have been degraded by overgrazing, poor farming, and removal of trees and shrubs for fuelwood. The lessons learned at Anza-Borrego Desert State Park will help these people restore the productivity of their lands and improve their lives.

Acknowledgments

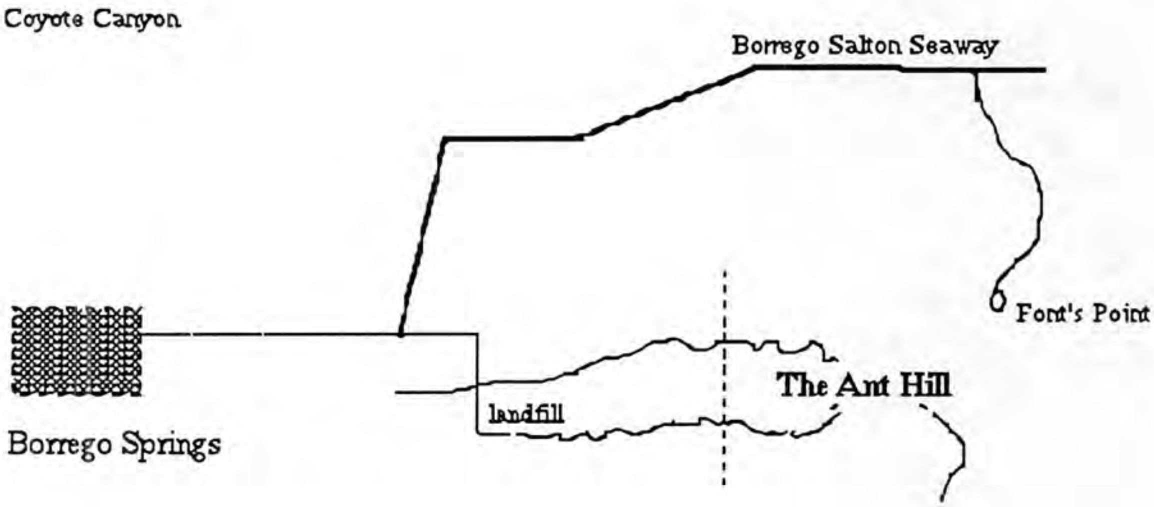
This project has involved many institutions and hundreds of people. Special thanks to all involved in working on this difficult site. Ross Virginia deserves special credit for his support, advice, and enthusiasm for this research. Students and staff at SDSU have provided much assistance, with special credit to NaDene Sorensen, Matt Fidelibus, Steve Netto, Robert MacAller, Robin McBride, Debbie Waldecker, Marcie Darby, Nicki Rorive, Terry Tilford, Edie and Mike Allen, and Nancy Flexman deserve special thanks. Jim Dice, Bill Tippets, Ronie Clark, Debbie Hillyard, Mark Jorgensen, and Paul Manski of Anza-Borrego Desert State Park provided essential support and guidance. Bob Moon, Mark Holden, and Carol Miller and the rest of the staff at the Center for Arid System Restoration at Joshua Tree National Monument grew excellent plants and cooperated in many research projects. Laurie Lippitt from California Department of Forestry's L.A. Moran Reforestation Center provided seed analysis and advice on plant production. Tom Landis, US Forest Service, also was very helpful This work could not have been undertaken without the support of the State Park Stewardship Funds.

Volunteers from the Sierra Club (special thanks to the North county group), the California Native Plant Society, the Crisis Kids, Audubon field school, Restoration Ecology Class (SDSU), the University of Baja California, Ensenada, and many volunteers from Borrego Springs provided essential field work and assistance.

Borrego Valley Growers, S&S Seeds, International Reforestation Suppliers, TUBEX, Pacific Western Container, Steuwe and Sons, Gardener's Supply, Rider's Automotive, Chefs for You (white buckets, gallons of ice tea, and more) , and ABD Irrigation also contributed much to this project.

Part 2. Site description

The Ant Hill is located west of Font's Point and east of the end of Palm Canyon Drive. This area several miles east of Borrego Springs includes a small group of hills and includes more than 300 acres, map 2-1.



Map 2-1. Location

The Borrego Badlands were deposited in shallow seas approximately 500 million years ago. The Ant Hill also includes more recent lake and river deposits with lenses of gravel and stones. The area has been desert for about 8,000 years and erosion during this period has carved the canyons and features such as Font's Point (Jee, 1989).

This area was possibly within the range of both the Kumeyaay (Shipek, 1989) and Cahuilla Indians (Bean & Saubel, 1972) who utilized the many resources of the area. Mesquite pods from the playas and washes were an essential food (Felger, 1977, Bainbridge et al., 1990). Plants and trees including palm, mesquite and oak trees were selected, planted and transplanted (Bean & Saubel, 1972; Bainbridge, 1985b; Bainbridge et al., 1990; Shipek, 1990). Fire was commonly used to control pests and facilitate food harvests (Shipek, 1990; Bean & Saubel, 1972).

Many of the plant species found at the Ant Hill were utilized, including the garlicky bulb of the desert lily (*Hesperocallis undulata*); leaves, buds, or fruits of cholla (*Opuntia sp.*), evening primrose (*Oenethera sp*); and seeds of ocotillo (*Fouquieria splendens*), Indian ricegrass (*Orzyopsis hymenoides*), sunflower (*Helianthus sp.*), and four-wing saltbush (*Atriplex canescens*) (Ebeling, 1989).

Hunting pressure on common herbivores was high, and bones of the black-tailed jackrabbit (*Lepus californica*) are very common in coprolites from a similar area in the Coachella Valley (Wilke, 1978). Hunting was probably common in the Ant Hill area in the spring and early summer until the pods of the mesquite were harvested. Kangaroo rats and other rodents were also hunted. The sphinx moth (*Hyles lineata*), which experienced a population explosion in 1991, was a favored delicacy and large quantities were collected and eaten (Wright, 1884; Bean & Saubel, 1972). Farming may have been practiced in washes and wet spots in the Borrego Valley (Lawton & Bean, 1968). This may have increased hunting pressure in the summer.

Ranchers and farmers entered the area after most of the native people were disappeared, primarily felled by disease. Cattle grazing in the late 1800's and early 1900's (Reed, 1963) may have played an important role in plant community changes in the Borrego Valley and at the Ant Hill. Large herds of cattle passed through the area and overwintered. Herds with as many as ten riders and more than a thousand head of cattle were found in the area. These herds may have affected many of the native grasses and forbs as recent studies in more humid areas of the Southwest have demonstratedLight winter grazing in the much wetter Canyonlands National Park led to marked changes in plant composition (Kleiner and Harper, 1977). Galleta grass (*Hilaria jamesii*) was 47% more abundant in the ungrazed section. Grasses, including Indian ricegrass (*Oryzopsis hymenoides*) had two and a half times greater cover in ungrazed areas of Navajo National Monument (Brotherson et al., 1983). Sheep and goats were also pastured in the Valley at times.

Military training activities during World War II may have reached the Ant Hill and created some of the first roads. This was mentioned by older residents of the Valley and the prescence of old large shell fragments on site supports these recollections.

The primary human impacts on the site were caused by off-road vehicles in the late 1970's and early 1980's. Use and damage was very heavy during this period from both motorcycles and 4 wd vehicles. Photographs from 1979 clearly reveal damage patterns that presage current gully and erosion problems. The areas of major damage doubled between 1979 and 1990. Fencing in 1990 has greatly limited access to the site but fresh tracks have been observed from time to time. One of the challenges of this area has been finding undisturbed areas for reference sites.

The soils at the site are predominantly sandy. The site includes sand dunes created from sand moving from Coyote Canyon and the Borrego Valley. These dunes are relatively plastic, and change shape and location in reponse to wind patterns. Seventyone soil samples from 25 sites were collected to evaluate soil properties over a wide range of environments and levels of disturbance at the Ant Hill. The Ant Hill soils are sandy (typically around 90% sand) with limited silt and clay.

The pH of the soil samples ranged from 8.4-9.1, basic but not too basic for plants to grow. The soils in less disturbed open areas (n=9) have moderate salinity, and low levels of potassium (6 ppm), nitrate nitrogen (av. 1.6 ppm), and available phosphorus (av. 0.7 ppm) [Methods: nitrate N (Keeney & Nelson, 1982) $NaHCO_3$--extractable P (Olsen & Sommers, 1982)]. These levels are very low and would limit plant growth if water was readily available. However, they are higher than other desert soils sampled in areas disturbed by mining or construction activity (Virginia et al., 1988).

The soils under plant canopies (n=14) are more fertile with nitrate nitrogen (av. 4.8 ppm) and phosphorus (0.9 ppm). Soil from the wash (n=3) was very low in phosphorus (0.3 ppm) and nitrate nitrogen (0.8 ppm) in line with previous studies of similar washes in the Coachella Valley (Bainbridge & Virginia, 1990). Saturation percent (an indication of moisture holding capacity) of selected soils ranged from 18-24%, except for a small patch of Badland decomposed shale with a SP of 58%.

The surface soils of the desert usually contain the highest nutrient levels and the Ant Hill is no exception, figure 2-1. This makes these soils extremely sensitive to disruption, as removal of the surface layer removes a large percentage of the total nutrient supply (Charley & Cowling, 1968) and soil biota.

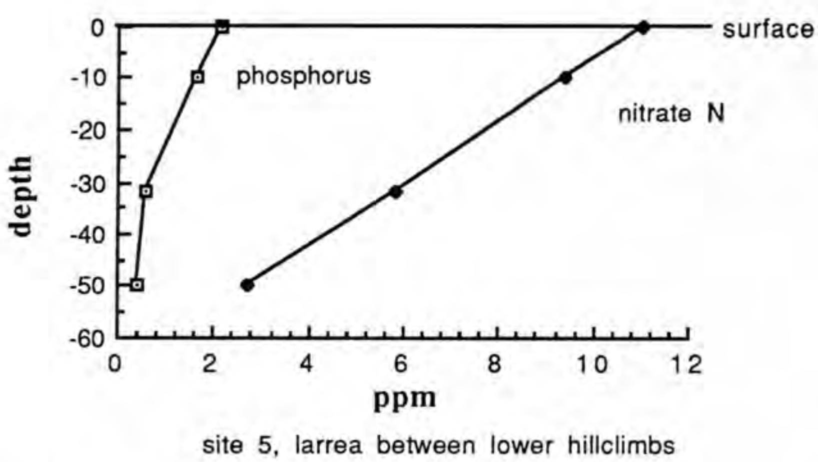


Figure 2-1. Soil fertility and depth at a creosote bush at the Ant Hill

The low fertility of these soils makes soil symbionts important if not essential. Mycorrhizal fungi improve phosphorus uptake and may play a critical role in soils with very low levels of available phosphorus and moisture. Bethlenfalvay et al. (1984) found that all 38 plant species studied in Anza-Borrego Desert State Park were mycorrhizal, with a total of six different species of fungi. Soil samples from a creosote bush root zone at the Ant Hill revealed large numbers of mycorrhizal spores. No sampling of rhizobia inoculum potential was done but it would be anticipated that it would be low in larger disturbed areas.

Plants strongly influence the soils in their vicinity by trapping fine soil from the wind, concentrating nutrients, and adding nutrient rich litter to the soil. This can be seen from the sampling of soils at the Ant Hill site, figure 2-2. The enriched soil and protective effects of plant canopies make establishment in plant canopies much easier than on open ground.

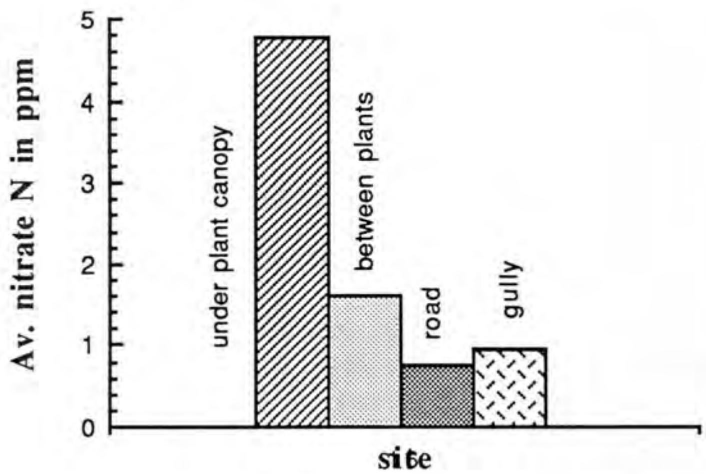


Figure 2-2. The affect of plants on soil fertility at the Ant Hill

Climate data are not available for the site. The change in climate over the short distance from Park Headquarters in Borrego Springs is dramatic and the data from Ocotillo Wells and Indio were more closely correlated than the Ocotillo Wells and Borrego Springs data. A composite data set from Ocotillo Wells and Indio was created to develop a probable rainfall pattern for the Ant Hill, figure 2-3. Average rainfall at the site is probably about 3 inches per year.

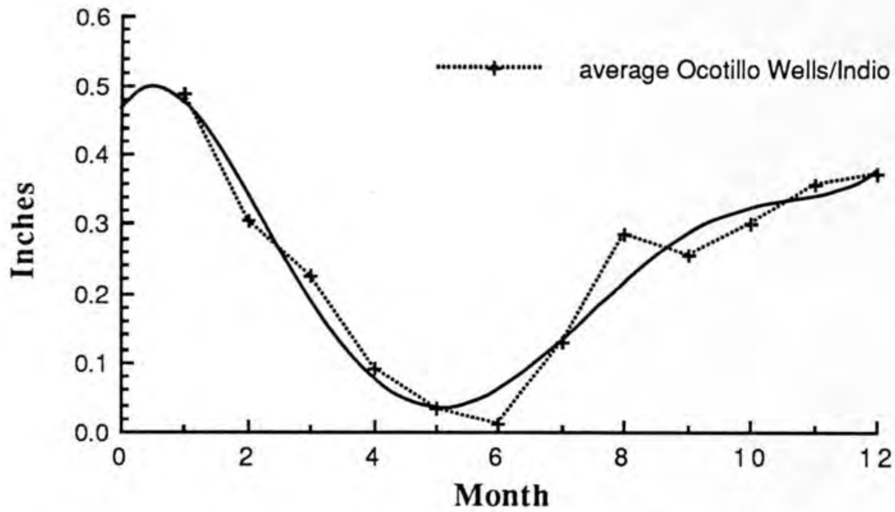


Figure 2-3. Probable rainfall pattern for the Ant Hill (solid line)

Significant rain events are plotted in figure 2-4. These are probably key factors in plant establishment, although it may require several storms within a period of one or two years to get plants past the critical stage.

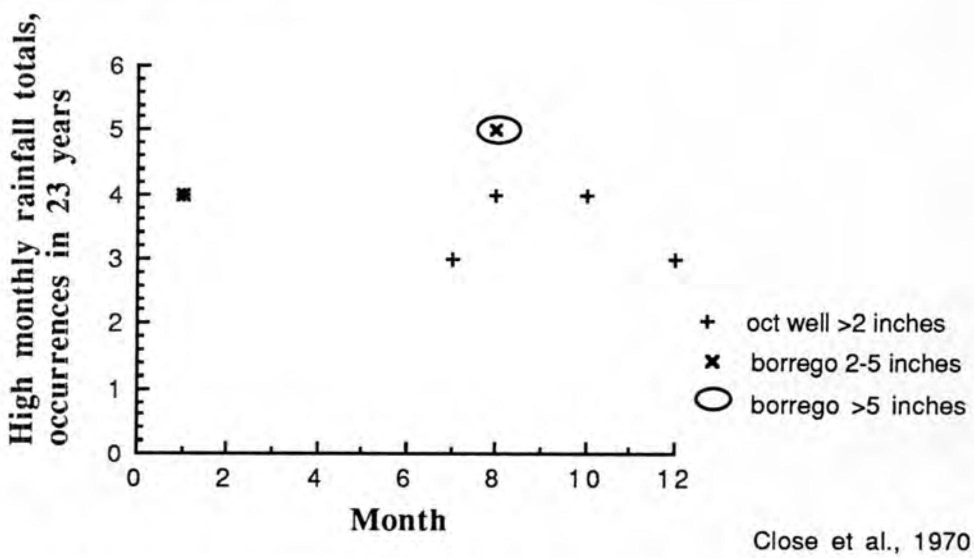


Figure 2-4. Significant rain events

The climate station in Borrego Springs is shaded by the mountains to the west and also is cooled by cold air drainage off the mountain slopes and canyons. The temperatures from Indio may be more representative of the temperatures of the Ant Hill in the fall-spring, figure 2-5.

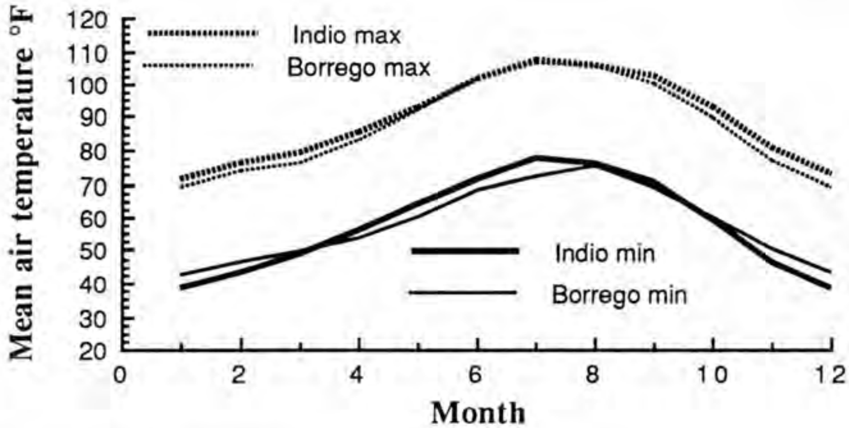


Figure 2-5. Air temperature

During the freeze of 1990 air temperatures reached 19°F in Indio and 23°F at Borrego Springs Park headquarters. Although these temperatures are low enough to damage many desert plants, and damage to palms and grapefruit occurred in much of the Valley, no freeze damage was observed at the Ant Hill. The excellent air drainage away from most of the Ant Hill slopes probably protected the area. The drought may have also protected plants from damage as dry plants are generally less susceptible to freeze damage.

Limited soil temperatures were taken and these reflect the general pattern of soil heating over the year described in Part 3. Optimum soil temperatures for plant growth for many species are not reached until April or May and last until October.

Vegetation and damage mapping (historical and present) at the Ant Hill was done from aerial photographs and ground observation. The extensive ORV and drought damage made it impossible to establish a pre disturbance vegetation map. Several years of drought had left the site in poor condition when this study began and extensive areas of soil were completely barren.

Understanding the plants of the Ant Hill is critical for planning revegetation programs to hasten natural recovery (see also Part 3). A series of plant transects were established by State Parks personnel. The Ant Hill is dominated by creosote bush (*Larrea tridenta*), white bur sage (*Ambrosia dumosa*), *Tiquilia palmeri*, Croton (*Croton californicus var. mohavensis*), sandpaper bush (*Petalonyx sp.*), and dye weed (*Psorothamus emoryii*). Many desert lilies (*Hesperocallis undalata*) and numerous patches of Indian ricegrass (*Oryzopsis hymenoides*) appeared after the Spring rains in 1991. Less common perennials include Indigo bush (*P. schottii*), Ocotillo (*Fouquieria splendens*), Orcutt's aster (*Xylorhiza orcuttii*), cholla (Opuntia sp.), salt bush (*Atriplex canescens),* desert holly (*A. hymenolytra*), desert marigold (*Baileya pauciradiata*), and Astragalus sp. Big galleta (*Hilaria*) may have been found here in the past. D. Hillyard also collected seed of

Hapolopappus acradenius, Chorizanthe rigida, and *Stephanomeria pauciflora* in the vicinity of the Ant Hill in 1990.

The density of the larger shrubs is generally very low, reflecting the aridity of the site. Creosote bush averaged only 15 individuals per acre (range 3-29) on 13 grid corners with creosote occurrences. This is approximately half the number predicted by the density/rainfall relation developed by (Woodell et al., 1969). This probably reflects the extensive damage on the site. Ocotillo averaged only 5 individuals per acre on plots chosen to include notable groups of ocotillo. Bur sage density was over 1,500 plants per acre in selected small, dense populations but generally much lower.

Winter ephemerals are common in some years at the Ant Hill. These short-lived plants may appear profusely only about once every 5-10 years when precipitation, soil moisture, temperature, and photoperiod are favorable (Went, 1948, 1949, 1979; Juhren et al., 1956; Tevis, 1958; Crosswhite & Crosswhite,1982). The dense floral carpets that can develop under these conditions are strikingly beautiful and provide seeds for succeeding rain events. Notable species at the Ant Hill include: sand verbena (*Abronia villosum*), evening primrose (*Oenethera sp.*), desert sunflower (*Garea canescens*), gray sunflower (*Helianthus niveus var. canscens*), desert dandelion (*Malacothrix californica?*), desert Spanish needles (*Palafloxia arida var. arida*), poppy (*Eschscholtzia sp*), lupine (*Lupinus sp.*), astragalus (*Astragalus sp.*) a non-native mustard (*Brassica sp.*) and non-native grasses (*Schismus sp.*). This mustard often obscured experimental plants and covered large areas of the site.

The Ant Hill is home to a wide range of animals, insects, reptiles and birds. The long drought and extensive ORV activity apparently reduced populations of many species, but populations recovered quickly after the wetter seasons of 1991, 1992. Lizards are the most commonly observed inhabitants of the area, including zebra tails (*Callisaurus draconoides*), western whiptail (*Cnemidophorus tigris*), the horned lizard (*Phrynosoma sp.*), and the desert iguana (*Dipsosaurus dorsalis*). Mark Jorgensen of ABDSP has found fringe-toed lizards (*Uma sp*) nearby. Probable desert tortoise holes were seen, but no living tortoises or tortoise tracks were observed. A few rodents (*Dipodomys, Citellus*), birds (*Phalaenoptilus nuttalli, Auriparus flaviceps*, etc.), and snakes (sidewinders (*Crotalus cerastes*) and a very large rattlesnake were observed. Ravens (*Corvus corax*) were the most common avian visitors. Coyote droppings and coyote (*Canis latrans*) and fox (*Vulpes*) tracks have been seen. Many kangaroo rats enlivened evenings and nights spent on the site in 1993.

Herbivory of native plants and transplants was predominantly by insects in 1991when populations of caterpillars of the sphinx moth and painted lady butterfly exploded. *Tiquilia palmeri, Oenethera* , and *Verbena* were severely grazed by the enormous populations of sphinx moth and painted lady butterfly caterpillars that developed after the March rains in 1991. Lizards and rodents became significant herbivores in 1992 and 1993. In addition to herbivory there also appeared to be clipping (often intensive) to maintain open areas, perhaps for improved sitelines for safety from predators. Rabbit pellets were observed in summer 1991 for the first time since the study began. Many plants were killed by herbivory, including a complete experiment involving desert lilies (1992) and many larger shrubs in 1993.

The site is in many ways representative of the type of site encountered in restoration work in the low desert. It is very dry, the soils are relatively homogenous, and the plant community is characteristic of the creosote shrub areas of the desert. Like most other sites it is also unique and the lessons learned here may not be applied with impunity to other areas nearby.

Part 3. The Desert Environment

Understanding the unique characteristics of desert ecosystems and the adaptations of plants to these severe environments is critical for successful restoration efforts. This chapter provides a general background for the later discussions. Despite growing interest in desert ecology and restoration many of the critical questions remain unstudied and unanswered. Developing a more thorough understanding of the structure and function of desert ecosystems and species is essential to improve success in restoring disturbed areas.

Desert soils and soil symbionts

Desert soils have resulted from the long-term interactions of climate, vegetation, fauna, and people on the material provided by geological processes. Desert soils are commonly infertile and have low moisture holding capacity and limited organic matter. Although they may appear barren they often include a complex microflora and fauna which are essential for their stability, nutrient and moisture retention, and nutrient cycling.

Plants that form symbiotic associations with the microorganisms that improve access to limited nutrients or from sources unavailable to the roots alone are common (Bainbridge & Virginia, 1990). The two root symbioses which are most significant in deserts are mycorrhizal fungi and rhizobia (bacteria). Many of the desert legumes can fix nitrogen when they are infected with rhizobia (Allen & Allen, 1981) and this is important in the desert where nitrogen is often limiting (Virginia & Bainbridge, 1986).

The more common nitrogen fixing plants of the Ant Hill include *Psorothamnus emoryii* and *P. schottii, Lupinus sp., Astragalus sp.,* and possibly *Cassia sp.* and other legumes. Little is known about nitrogen fixation in these species. However, nitrogen fixation by mesquite (which is found 1/2 mile west of the Ant Hill) has been studied in some detail (Rundel et al., 1982; Virginia et al., 1983, 1984) and mesquite woodlands (south and east of the Ant Hill) were fixing 40-50 kg/ha per annum with thirty percent canopy cover (Rundel et al., 1982). Nitrate accumulations under mesquite were comparable to the best agricultural soils (Virginia & Jarrell, 1983; Virginia, 1986) and mesquite soil is recognized as a fertilizer by traditional farmers in Mexico (Wilken, 1978).

The rhizobial ecology of smoke tree and mesquite has been studied by Jenkins et al. (1987, 1988). Nitrogen fixation in the mesquite woodlands is occurring at considerable depth with nodules at 5-6 meters or more (Virginia et al., 1986b; Jenkins et al., 1988). The depth of active fixation highlights the importance of deep soil studies.

Beneficial soil organisms also include fungi that form symbiotic (mutually beneficial) relationships with roots. The mycorrhizal fungi improve phosphorus and water uptake and may play a critical role in soils with very low levels of available phosphorus and moisture. Bethlenfalvay et al. (1984) found that all 38 plant species studied in Anza-Borrego Desert State Park were mycorrhizal, with a total of six species of fungi. Other field surveys have suggested that most perennial desert plants are mycorrhizal (Bloss, 1986). The endotrophic vesicular-arbuscular mycorrhizal (VAM) fungi are most common.

Studies have showed that VAM can increase water uptake by plants (Nelson, 1987). Careful comparisons of mycorrhizal and non-mycorrhizal soybeans showed that the infection increased hydraulic conductivity by seventy percent and these changes were primarily related to physiological changes in the roots. Mycorrhizal plants are also able to extract soil moisture down to lower water potentials (Hardie & Leyton, 1981). Much of this improvement may be linked to improved phosphorus status. Mycorrhizae may also increase the efficiency of water use in photosynthesis, perhaps by producing growth regulators or hormones (Levy et al., 1983; Bowen, 1985; Nelson, 1987).

Mycorrhizae may also reduce problems with plant pathogens. The mycorrhizae may protect the root from infection by blocking pathogens or simply by improving nutrition and plant health (Dehne, 1987). Mycorrhizae can act as nutrient bridges between plants, both of the same and unrelated species infected by the fungus (Miller, 1987). These hyphal bridges can transfer carbon and phosphorus (Heap & Newman, 1980; Francis & Read, 1984). These nutrient bridges may be important in the low fertility soils of the desert, particularly for seedling establishment. A young seedling may be able to draw nutrients from a well-established older plant. Research is needed to explore the possible impacts of hyphal bridges on other nutrients and water. Ecosystem disturbances that break these hyphal bridges may make the ecosystem less resilient to further impacts (Miller, 1987).

Mycorrhizae also contribute to improved soil aggregation. Recovery of soil structure can be aided by mycorrhizae (Jastrow et al., 1987). Aggregation of soil particles can increase infiltration of rain water, improve root growth, and enable greater hyphal extension. These factors combine to improve plant resistance to drought and may also reduce problems associated with soil salinity.

The nitrogen fixing legumes can be infected with both mycorrhizae (Bethlenfalvay et al., 1984) and rhizobia (Virginia et al., 1988). The combined effects of the two symbionts can be synergistic. The improved N and P nutrition and moisture uptake can provide substantial benefits for growth and survival. Plants strongly influence the soils in their vicinity in other ways as well. They trap fine soil from the wind, concentrate nutrients, add nutrient rich litter to the soil, and improve soil structure and fertility.

Climate

The variation in rainfall amounts and patterns from year to year in the low desert is very high. Rainfall at Indio has varied from as little as 0.12 inches in 1886 to almost 8 inches in 1927 (US Weather Bureau, 1956).

The most intense rains are associated with storms spawned by tropical air masses moving north from the Gulf in the summer. These storms may drop rain equal to the yearly average in a matter of minutes, with resulting sheet and stream flow and flash floods. These events are important for deep recharge of soil moisture. Even in the best years evaporation far exceeds rainfall, with more than 100 inches of evaporation possible.

Long-term data provide some indication of the dry and wet periods that shape the vegetation in the desert. Six severe droughts occurred in California between 1600 and 1990 (Lenz & Dourley, 1981). Precipitation records and tree ring data suggest that favorable patterns for establishment may have occurred during wetter periods in the early 1940's, 1905-1910, 1833-1840, and 1769-1776 (Lynch, 1931; Lenz & Dourley, 1981). The long-lived creosote bush may only establish well once every one or two hundred years.

Annual and seasonal temperatures are marked by very wide variation. Summer high temperatures commonly exceed 100°F [38°C] with night lows around 80°F [27°C]. Winter high temperatures are commonly in the 70°s [20'sC°] with lows between 40°-50°F [4-10°C] (NOAA; Felton, 1965; Lenz and Dourley, 1981). Freezing temperatures are not uncommon on winter nights with clear skies, but hard freezes occur only about every 10 years. Temperatures below 26°F [-3°C] with duration's of several hours can damage sensitive plants and freezes in 1978 and 1990 resulted in wide-spread damage. Temperatures during the 1990 freeze reached 19°F [-7°C] in Indio and 23°F [-5°C] at park headquarters in Borrego Springs. Microclimate variation and cold air drainage can produce much lower temperatures than the climate station data would suggest and many crops, non-native landscape plants, and native species were injured or killed.

Bare soil temperature in the sun may reach 30°F [16°C] or more above ambient air temperature unless the wind is blowing (Wallace & Romney, 1972). Soil temperature in the shade are commonly about air temperature. During the summer surface soil temperatures may reach 140°F [60°C] and deep soil temperatures are also high. Mean soil temperatures at 20 cm depth in August under grass cover at Brawley were 88°F [31°C], dropping to 84°F [29°C] at 50 cm, 82° [28°C] at 100 cm, and 79° [26°C] 200 cm (Fox & Hatfield, 1983). The mean temperature under bare soil at Indio in August is 100°F [38°C] at 10 cm and 95°F [35°C] at 20 cm (Fox & Hatfield, 1983). The bare soil temperatures more accurately reflect the conditions in the low desert were used to develop figure 3-1. Few studies of deeper soil temperatures in the desert were found, but August temperatures declined from 84°F [29°C] at 1.5 m to 73°F [23°C] at 3 m and 72°F [22°C] at 6.1 m at Tucson (McClatchie, 1904). The temperature fluctuation over the seasons decreases with depth and at some point approaches a constant (Smith, 1932). McClatchie (1904) felt this would occur at about 15 m in Tucson.

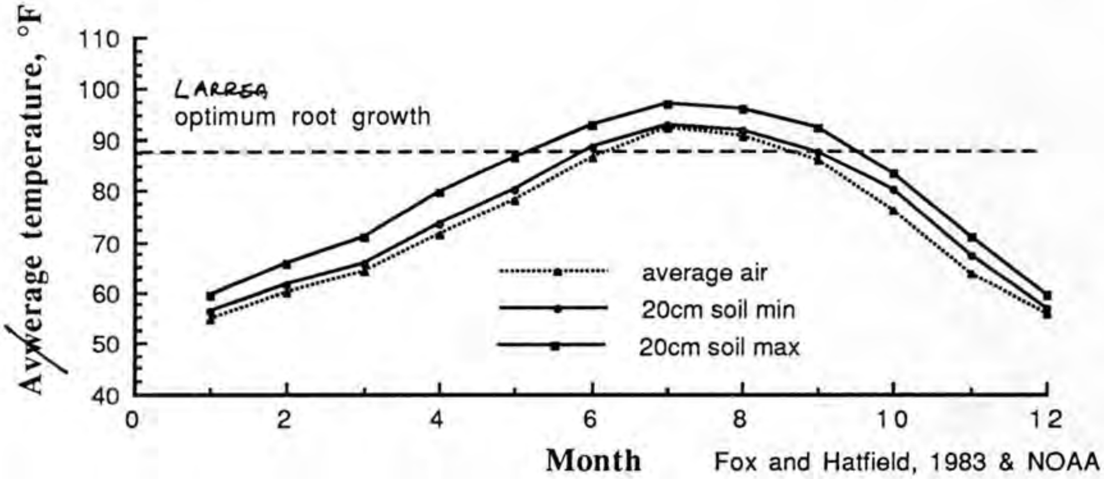


Figure 3-1. Soil temperatures

Soil temperatures in the spring and fall, when establishment of creosote bush and bur sage appears to be more likely (Went, 1949, 1979), are likely to be between 70 and 86°F [20 and 30°C]. Spring rains seem more favorable for long term survival (Went, 1979). Root development of desert plants at these higher temperatures is little studied, but Cannon (1917) found that the root of a velvet mesquite (*Prosopis velutina)* seedling grew 5.1 cm in 12 hours at 91°F [33°C] in sand. Cannon (1917) determined that the minimum temperature for root growth in velvet mesquite was 54°F [12°C] and the maximum was 108°f [42°C]. Wallace and Romney (1972) reported creosote bush roots grew 2-3 cm day and bur sage (*Ambrosia dumosa*) root grew 32 cm in 19 days (soil temperature not stated).

Plant communities

Plants vary widely in form, life history, and adaptation to the desert. Some plants compete for water and nutrients while others provide improved micro-sites for germination and establishment. Mammals, reptiles, insects and birds modify plant community structure through seed dispersal, flower pollination, herbivory, inoculation, etc. Although this section emphasizes the dominant shrubs, the problems faced by other plants during germination and early establishment are similar and treatments to improve conditions for shrub establishment often result in improved germination of annuals as well.

Several strategies are involved in plant response to the lack of water in this environment (Levitt, 1972). Many annual plants are drought escapers and avoid the worst conditions by having very short lifetimes, germinating and growing only when conditions are good, maturing rapidly and setting seed before the soil dries out. Competition for water and nutrients often affects distribution of these plants. These plants have many different mechanisms to reduce germination when it may be moist, but conditions are unfavorable. These include various types of seed dormancy which may be broken by mechanical scarification, heat, stratification, leaching, after-ripening or other mechanisms (Went, 1979).

One of the interesting findings in several studies has been the difficulty in fooling seeds with irrigation, "...this artificial rain did not induce germination of even one single seed of shrubs, dwarf shrubs or any other desert plant even when the irrigation was quite considerable" (Evenari et al., 1982). Tevis (1958) found that the plants of the low desert in California were more responsive to sprinkling that mimicked rain, but that natural rain "demonstrated an extraordinary superiority over the artificial variety..."

Shrubs and perennial plants

The seeds of most of these desert shrubs have very tough coats that require scarification or leaching to germinate. They are adapted for long-term survival between rains and remain viable for many years or decades. These seeds germinate after being scarified in the tumbling sands of a flood, tumbling in the wind, passing through the gut of an animal, or being repeatedly wetted. Seeds may require high temperatures (50°C) to ripen (Capon & Van Asdall, 1966). Soil temperature extremes influence the germination of some desert species (Went, 1979).

Perennial shrubs must endure severe conditions between soaking rains. The long-lived desert plants are usually drought avoiders, using deep rooting, exploitation of unique site conditions, and phenological adaptations to increase access to available water and to minimize water requirements. However, creosote bush is more of a drought-tolerator than a drought-avoider (Morton & Hull, 1973; Shreve & Wiggins, 1964). Runyon (1934) found that creosote bush leaves could survive being dried below 50% moisture content, and it is sometimes hard to determine if a plant is alive or dead. Creosote bush leaf water loss is limited by resinous leaf coatings.

The most water efficient plants of the desert utilize crassulacean acid metabolism (CAM) (Hall et al., 1979). The agaves and related succulents are able to fix CO_2 at night when

water losses through open leaf stomata are
much lower.

Most desert plants can respond quickly to improved conditions. For example, creosote bush remains metabolically active all year and will flower and grow opportunistically when conditions improve (Chew & Chew, 1965). The value of this is clear in an area with such unpredictable water availability. Rapid improvement in plant condition of many species is often observed after rain or irrigation. Many of these desert shrubs are also able to endure long periods with minimal water, and while little or no growth takes place the plant endures. If only a few cells are left alive the recovery may be very slow.

While most of these plants can tolerate severe drought many are very sensitive to wet soil and flooding. Many of these desert plants are also very sensitive to pathogenic fungi and molds in wet soils. In contrast white bur sage grew well under similar conditions, reflecting its tolerance of low oxygen conditions (Lunt et al., 1973).

Deep or extensive root development may be one of the more common mechanisms for avoiding drought. Recent research has found active root symbionts deeper than 5 meters in the Sonoran Desert (Virginia et al., 1986; Jenkins et al., 1988), and living roots of mesquite trees have been found at 80 meters (Solbrig & Cantino, 1975). However, little is known about the development of root systems in general (Russell, 1977), and even less is known about deep roots (Virginia & Jarrell, 1987). Key questions remain unanswered about the rate of development of these root systems, the conditions required for establishment, and the factors influencing symbiont movement and development in the deep soil.

Root elongation of up to 6 cm day has been reported for some plants (Lyr & Hoffman, 1967). Desert plant roots may grow several cm per day at higher soil temperatures in loose moist soils, figure 2-2.

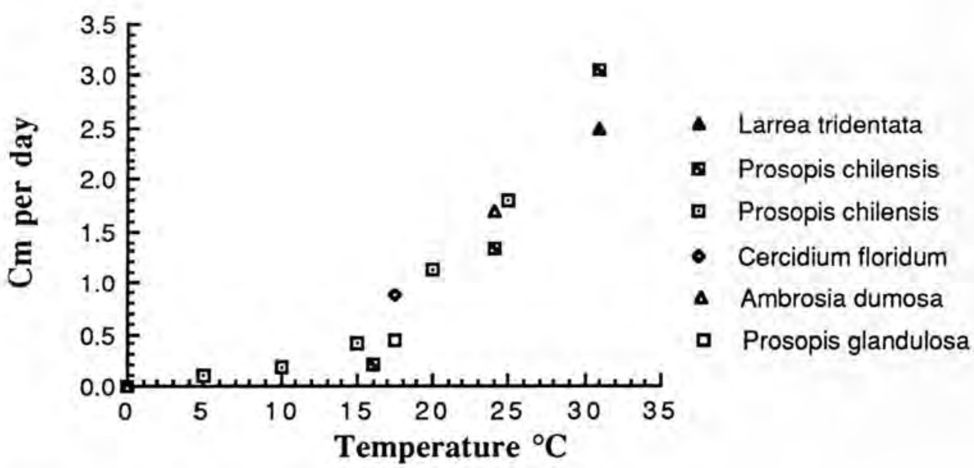


Figure 2.2 Root growth at different temperatures

It may not be unusual for a plant root to grow a meter in a month. Ecotypic variation and secondary experimental effects of light intensity, soil strength, moisture, plant nutrition, and related factors may influence study results and account for the variation in root development reported in various studies.

The pattern of root and shoot development in these plants is often very conservative, with high root:shoot ratios. Wallace and Romney (1972) reported creosote bush seedlings 3 cm tall with roots 100 cm deep. Went (1948) found seedlings of smoke tree (*Psorothamnus spinosus*) 3 cm tall with roots 40 cm deep and Mozingo (1986) found *Psorothamnus polydenis* seedlings 3 cm tall with roots 30 cm deep after one year. Excavations near Travertine Point in the Coachella Valley showed that roots of transplanted mesquite reached more than 2 meters depth after less than two years.

Plant profiles

The following plant profiles provide more detailed information on key species. Limited information was found on many species at the Ant Hill.

Creosote bush. Scientific name: *Larrea divaricata*
Other: *Larrea tridentata*

Creosote bush is one of the most drought tolerant higher plants in North America and dominates more than 350,000 square kilometers in the southwestern United States. Creosote bush is a multi-branched evergreen shrub. It appears in a wide variety of habitats often spaced with remarkable regularity with from 500-1,000 plants per hectare (Chew and Chew, 1965). As Frank Vasek has found, *Larrea* clones may live a very long time, more than ten thousand years (Steinburg, 1985). It has a strong creosote odor on hot still days, after rain, or when burned. Five petalled flowers are 2 cm [3/4"] across, white to sulfur yellow. Leaves are leathery and divided into leaflets. Gray stems are banded in black at the nodes. There is a small commercial market for creosote bush stems for interior decorating. These are harvested under Bureau of Land Management (BLM) permits.

Creosote bush tolerates a very wide range of environments but does not like standing water or saline soil. Spalding (1904,1909) suggested that *Larrea* is extremely drought resistant, deep and wide rooted, and may take up moisture from the atmosphere through the leaves, but does not grow where water persists for a long period. Creosote bush and others may die if flooded for more than a short time. Livingston (1910) suggested that creosote bush may be limited on dense moist soils by oxygen deficiency.

Runyon (1934) reported that *Larrea* leaves can survive being dried below 50% moisture content. Shreve and Wiggins (1964) showed that creosote bush is extremely drought tolerant but did respond to irrigation. Spalding (1909) found that transpiration increased 8-9 times when creosote bush was irrigated. Optimum growth occurs in slightly acid loamy soil but in a natural setting Larrea doesn't appear on acid soils due to competition from other plants.

Growth of creosote bush is more rapid at higher temperatures. Wallace and Romney (1972) found that dry weight was 10 times greater in plants grown at 28°C [82°F] than at 16°C [61°F]. Growth at 37°C [99°F] was reduced but still higher than at 21°C [70°F] or 10°C [50°F]. Cannon (1918) found that 32°C [90°F] was the optimum for root growth and 15°C [59°F] the lower limit. Kurtz (1958) found 30-35°C [86-95°F] was optimum for creosote bush seedlings from the Sonoran desert. Barbour (1968) found optimum root growth in creosote bush occurred at 29°C [84°F] but that some root development occurred from 12-40°C [53-104°F]. These differences may reflect ecotypic differences or differences in soil mix and experimental setups. Barbour (1968) found root growth was 1 cm day while Wallace and Romney (1972) reported creosote bush root growth of 2-3 cm day.

Temperature appears to be a limiting factor in the distribution of creosote bush. Shreve (1940) reported that 6 consecutive freezing days will kill creosote bush plants. Wallace and Romney (1972) observed freeze damage of young shoots when temperatures were -10°C [14°F].

Ripe seeds may be found at almost any time of year. Seed ripens first in early summer and new seeds continue to ripen until fall. Approximately 80,000 seeds per pound with 28% PLS was reported as an average (S&S Seeds). Viability of seed has been correlated with rainfall during the growing season, with higher germinability correlated within rainfall between 3 and 6 inches (Beatley, 1974). Both higher or lower rainfall reduced germination. Bush collected seed had twice the germination rate of ground collected seed (Kay et al., 1977).

Seeds can be cleaned but some studies have showed that the germination rate is the same with the mericarp intact (Barbour, 1968). Handling characteristics of the seed have been improved by hammer-milling at 1750 rpm using a number 6 round screen and number 25 base screen (Kay et al., 1977). The hairs have also been burned off (Ban, 1988). Graves et al. (1974) found that an alfalfa belt harvester worked acceptably with creosote bush seed. Hand hulled seeds germinated better than either belt or hammer-milled seeds (Kay et al., 1977). Cold storage at 0°C [32°F] appears to be most effective. Viability retention of 89.5% was reported at 7 years by Valentine (1968) but more significant declines were observed by Kay et al. (1977).

Creosote bush seeds germinate readily in the glasshouse without special requirements (Went & Westergaard, 1949). Shreve & Wiggins (1964) reported that the seeds germinate in the field during July or August if moisture is available. Went reports plants were likely to germinate in Fall or Spring rains with temperatures ranging from 20-30°C (Went 1949, 1979). Germination of seeds is suppressed by light. Seeds should be planted 1 cm (1/2") or deeper to improve germination (Kay et al., 1977).

Shellhorn (1955) germinated creosote bush at 37°C [99°F] while Dalton (1962) reported 35°C [95°F] as the optimum temperature. Went and Westergaard (1949) reported germination after a rain at temperatures of 15-16°C [60°F] but not at 8-10°C [47-50°F]. Germination temperatures appear to vary depending on ecotype, optimums have been reported from 15-35°C [60-95°F], lower limits from 15-20°C [60-68°F], and upper limits from 33-37°C [91-99°F] (Kay, 1975; Kay et al., 1977; Wallace & Romney, 1972). Creosote bush is a warm season germinator, limited data suggest survival is higher from Spring (than Fall) rains (Went, 1979). Overhead sprinkling of 2-3 cm of water per month led to germination and establishment of creosote bush seedlings in a test conducted in the Nevada desert (Wallace & Romney, 1972).

Creosote bush has few pests, but herbivory can be a problem. Plants should be screened in most areas. Rabbits are known to clip and eat parts of creosote bush (Wallace & Romney, 1972). Jaeger (1948) reported that rabbits clip off creosote bush to sharpen their incisors. The woodrat, *Neotoma spp*., and kangaroo rat, *Dipodomys meriami*, also use creosote bush (Jaeger, 1948; Reynolds, 1950). The kangaroo rat may be important for seed dispersal as it prefers creosote bush seeds and stores small subsurface caches (Reynolds, 1950). Considerable grazing of creosote bush has been observed on site and few plants outside screens survived in a comparable site in the Coachella Valley.

A well-drained planting mix is essential. Tall narrow containers and a soil mix with considerable organic matter tested at the Center for Arid Systems Restoration at Joshua Tree National Monument in the winter of 1990 appeared to be causing oxygen and moisture problems for creosote bush due to inadequate drainage. The initial soil mix (40% sand: 40% perlite: 20% humus) did not work well in tall, narrow containers although it had worked in larger diameter containers. Soil removed from the middle of a 7.5 cm tube had a very high saturation percent 73% (low drainage compared to the site SP 20%), very high nutrient levels (~100 times site soils), moderate salts, and a very low pH (5.7 v/s 7-8 on site). A series of tests have been undertaken to develop better mixes--see research chapter.

If rapid transplanting from small containers is not possible, deep containers may be preferred--because root growth may reach 2.5-3 cm per day after germination (Wallace & Romney, 1972). Seedlings 2-3 cm tall may have roots 100 cm deep (Wallace & Romney, 1972).

creosote bush responds well to pruning. Severe pruning resulted in the greatest new shoot growth (Wallace & Romney, 1972). The success of transplanted creosote bush in a previous study (Virginia & Bainbridge, 1988) may reflect the benefits from extensive pruning of transplants in the glasshouse a month before transplanting. Tops were cut back more than 50% to provide a root:shoot ratio of >5:1.

Creosote bush is mycorrhizal (Bethlenfalvay et al., 1984) and the association is believed to be important. Desert litter added to test plots aided in establishment of creosote bush (Sheps, 1973). Examination of the root zone soils of creosote bush at the Ant Hill site showed many VAM spores.

A heavy rain or series of moderate rains may stimulate germination under natural conditions. Once established creosote bush can survive very severe drought (Cable, 1977). Although creosote bush showed little response to irrigation and fertilizer in a study conducted in Nevada (Wallace & Romney, 1972), mature creosote bush showed a response to nitrogen fertilizer when irrigated in a wash at the Living Desert Reserve (Sharifi et al., 1988). Rapid growth of creosote bush after transplanting in Joshua Tree National Monument may be related to fertilizer used in the tall pots.

Creosote bush has survived with limited irrigation after transplanting in a number of studies (Bainbridge & Virginia, 1990; Bob Moon pers. comm.; Ruffner et al., 1986). Although transplants received only a few liters of water in the first year studies at the Ant Hill more than 90% of the plants with twin-walled plastic treeshelters (TUBEX) survived. The best treatment was TUBEX and deep watering. However, the treeshelters had adverse effects on creosote later and they should be removed after the first few months. Pruning before outplanting and allowing the plants to recover from pruning stress may have improved survival of creosote bush plants in previous trials when plants were held in small containers for several months.

White bur sage. Scientific name: *Ambrosia dumosa*
Other: Bur sage, Burro-weed, burrobush (*Franseria dumosa*)

White bur sage is a much branched, low, rounded, shrub usually less than 1 m tall (Shreve & Wiggins, 1964; Benson & Darrow, 1981; Munz & Keck, 1973). Bur sage has broad grayish green clustered pinnate leaves commonly 1.5-2 cm long with stiff short hairs. Hairs on the leaves and intricately branched white stems largely obscure the green color. The older branches are spiny. Bur sage has inconspicuous flowers with staminate and pistillate heads intermixed in the terminal and lateral spikes of the panicle. Flowering occurs primarily in Spring (February-June) or following rains (September-November). Fruiting heads resemble cockleburs.

The thick crown of the shrub accumulates windblown silt, sand, and organic debris improving the soil under the plant. White bur sage improves the soil under its canopy (Virginia et al., 1988), and at the Travertine Material site near Oasis the soil saturation percentage, surface soil moisture, soil nitrogen were higher than under other plants. Soil phosphorus was also elevated. White bur sage shares the rhizomatous growth habit of creosote bush and may live a long time (Muller, 1953). The dense, rounded, younger shrubs become irregular as the individual aerial shoots die and an intricate crown of independently rooted shoots develops, that may spread to about 1 m diameter.

The species is predominantly diploid, although chromosome numbers of n=18, 36, and 54 have been recorded (Payne et al., 1964). The diploid form is the typical low, rounded, gray-green shrub. The less common polyploid form is a larger, darker-green plant with coarse bipinnate leaves (Geissman & Matsueda, 1968). The dominance of the diploid form supports its placement near the beginning of the evolutionary scheme for the genus (Payne et al., 1964).

White bur sage is abundant on well-drained soils through much of the Colorado Desert and common in creosote bush scrub (Munz 1974). Cable (1977) found that white bur sage was able to endure severe drought. Lunt et al. (1973) found that *Ambrosia dumosa* has a lower soil-oxygen requirement than *Larrea*. White bur sage grew well in soil mix and containers that had damaged creosote bush. Coville (1893) noted that white bur sage had a similar altitudinal limit to creosote bush, and it may be equally sensitive to freezing. Romney and Wallace (1972) observed freeze damage on irrigated white bur sage at 14°F [-10°C], but dry bushes were not harmed.

White bur sage is an excellent forage plant and is preferred by livestock and wild animals. Coville (1893) noted that horses preferred white bur sage over all other desert shrubs when grass was limited. White bur sage is a valuable forage plant on western range lands (Stark, 1966), and it has been recommended for landscaping, especially on poor soils (Johnson & Harbison, 1985). It is an important pioneer species and in areas disturbed by pipeline construction creosote bush and white bur sage made up 60-100% of the long-lived plant cover (Vasek et al., 1975).

This suggests why many annual plants appear to be dependent on white bur sage and are often found only under the bur sage canopy (Muller, 1953). These species include: *Malacothrix californica var. glabrata, Rafinesquia mexicana, Phacelia distans var. australis, Ellisia membranaceae, and Chaenactis fremontii.*

Seed matures in May to June (or late fall) and can be hand stripped from the plants (Clary, 1983, Kay et al., 1977). Collecting burs from the ground beneath plants is impractical because the light burs are rapidly blown away. Generally no cleaning was attempted by Kay et al. (1977) because the burs are spiny. The impurities in the seed were mainly male flower parts (male and female flowers are borne on the same raceme). However, Clary (1985) recommended hammer-milling and fanning.

Table 1. Seed characteristics

	K1971	K1973	K1974	Blane89
Seed per kg	303,600	374,000	161,000	
Seed per lb	138,000	170,000	73,000	
Purity	--	63%	64%	90%
Fill	27%	16%	44%	
Initial	20%	8%	8%	20%
germination at	17-21°C	at 20°C	at 20°C	
PLS		5	5	

Storage effects of different treatments were not initially significant in a study conducted by Kay et al. (1977). The limited germination was maintained for more than 3 years in the two collections they studied. The 1971 seed collection was stored at 10°C in non-sealed plastic bags for more than six years with minimal decline in germination. Long term storage also had little effect on white bur sage seeds, with an increase in germination after 111 months in all treatments (Kay et al., 1984).

Germination is mostly during the second and third weeks at 59°F [15°C] in moist paper towels. Optimal germination temperatures appear to be between 59-77°F [15-25°C], with no germination observed at 36°F [2°C] or 41°F [5°C] (Kay 1975). The warmer spring temperatures used by Williams et al. (1974) in depth of planting studies are apparently responsible for higher reported emergence than a similar fall test (Kay 1975). The optimum depth of planting was 1 cm, with little or no emergence from 2 cm.

In testing the effects of various seed treatments, Graves et al. (1975) found that 7 and 14 day germination was improved by activated carbon or stratification in moist sand at 36°F [2°C] for 30 days. Stratification in moist sand for 30 days is also recommended by Clary (1985). These treatments resulted in 24% final germination of seed of 26% fill compared to 17% with untreated seed. Heat treatments did not raise or depress the germination percentage significantly. Success from spot seeding was 0-4% at sites in the Mojave desert (Graves, 1976). Only 117 seedlings were found from more than 6,000 seeds planted by Brum et al. (1983), but 28 survived the first year. Scarification would probably be desirable.

Chase and Strain (1966) and Weiland et al. (1971) had no difficulty in vegetatively propagating cuttings of white bur sage. Rootone appeared to be the best treatment, with 70% rooting (Chase and Strain, 1966).

Grazing pressure may be very heavy on white bur sage, feral burros have eliminated bur sage on many thousands of acres in the Southwest. Screening and protection are desirable if not essential for seedlings. Treeshelters have improved survival but may distort plant shape. A wire cage 12-18" in diameter may be better. Mature plants should survive unless other forage is limited.

A well-drained soil mix is preferred. Sand or sandy loam is excellent. White bur sage tolerates a wide range of conditions and grew well in high fertility, low oxygen conditions that inhibited creosote bush. A deep container is required if plants will be kept in the greenhouse or nursery for more than a couple of weeks. Root elongation of 32 cm in 19 days has been observed (Wallace & Romney, 1972).

Plants are very tolerant of grazing and herbivory gives plants the hedged rounded form common in many areas. As Welles (1961) observed, "The close-cropped, hedged appearance of many (white bur sage) plants in the vicinity of Corkscrew Spring had been puzzling for many years until a chuckwalla was observed to crawl up into a bush and, spreading on all four legs, to move about on top of the plant in a sort of swimming motion, snipping off the newer shoots in a hedge-clipping effect".

Wallace et al. (1973) found that plants of white bur sage grown in soil collected from their native habitat gave much poorer yields if the soil was steam-sterilized. Plant analysis revealed that phosphorus was deficient in plants grown on sterilized soil, and they speculated that this deficiency might have been due to the effects of the steam-sterilization on the mycorrhizal association. This conclusion was supported by Bethlenfalvay et al.'s (1984) finding that white bur sage was mycorrhizal with *Glomus epigaeum* in Anza-Borrego Desert State Park.

White bur sage is drought-deciduous but can maintain high photosynthetic and transpiration rates during favorable conditions and has considerable ability to withstand temperature stress when sufficient moisture is available (Bamberg et al., 1975). Kay et al. (1977) found that a one-time irrigation treatment did not improve results of either transplanting or spot seeding.

Although complete leaf death was observed at -60 bars, white bur sage was able to recover when irrigated 4, 8, and 16 days after onset of severe drought, but plants irrigated only after 32 days died (Clark et al., 1974). Irrigated white bur sage remained green and growing virtually all year but was more susceptible to freeze damage (Wallace & Romney, 1972). *Ambrosia dumosa* has done well on deep pipe irrigation at the Ant Hill and benefited from treeshelters.

White bur sage is easier to establish by transplanting than spot seeding (Graves, 1976). Transplanting nursery-grown seedlings at two Mojave test sites following the coldest winter period (in February) resulted in 42% and 54% establishment. Survival of 90-100% was achieved for

Ambrosia deltoides transplanted near Tucson, Arizona (Ruffner et al., 1986). Brum et al. (1983) transplanted more than 400 white bur sage plants into a power transmission line. Initial survival was highest for those transplanted in February and March and almost 2/3 of these were still alive in mid-September.

Indian ricegrass. Scientific name: Oryzopsis hymenoides

Other Sand grass.

A densely tufted perennial bunch grass, 1 to 2 feet tall (Stefferud, 1948). Plants up to 19 years old have been found (West et al., 1979). It has many narrow, elongated leaves almost equal to the culm length. The inflorescence is an open panicle with paired branches bearing one-flowered spikelets at ends of dichotomous, spreading, flexuous branchlets. Glumes are broad, roundbacked, taper-pointed with spreading tips, thin and papery (Cronquist et al., 1977). Plump millet-shaped seeds account for the name.

Indian ricegrass was once widespread in dry areas of the west but has been greatly limited and often eliminated by over-grazing (Stefferud, 1948). It was still common on the Algodones dunes in the 1950's (Jaeger, 1967). Indian ricegrass was a favored food of the Native Americans (Ebeling, 1986; Jaeger, 1965). Seven of fifteen groups of Shoshone surveyed by Steward (1949) saved and planted grain, including Indian ricegrass. The seeds contain 16% protein and 46.5% carbohydrates (Wagoner, 1986). The seeds and grass are highly palatable to livestock, game, and rodents (Stefferud, 1948). The seeds are a preferred food of the Kangaroo rat (Stutz, 1975).

Indian ricegrass ranges from Mexico to Canada, most commonly in dry sandy places (Munz & Keck, 1973). Indian ricegrass does best on soils with little competition, especially loose, coarse sands; sandy soils; and thin, fractured shale and sandstone parent materials (Jaeger, 1965; Wasser, 1982). It is often a pioneer plant, is intolerant of shade, and not very compatible with other species in seeding mixtures (Shaw and Cooper, 1973; Valentine, 1971; Wasser, 1982). Indian ricegrass can be competitive on harsh sites and will increase as less adapted species die out (Monsen & Plummer, 1978). Webb et al. (1983) found that Indian ricegrass had established relatively well on a road abandoned for 18 years in Nevada. It is one of the few sand binding species for the low desert (Jaeger, 1965).

This species is drought-tolerant, tolerates weak salinity and alkalinity but prefers near neutral conditions (Stefferud, 1948; Valentine, 1971; Wasser, 1982). This plants tolerates fire when they are dormant. They are sensitive to poor drainage, flooding, and high water table. Ricegrass can be grazed out with heavy pressure but tolerates moderate grazing (Shaw & Cooper, 1973).

The wide geographic range and large variation in seed size suggests there are many ecotypes of Indian ricegrass. A local variety should be used where possible. Seed is commonly available commercially, including developed cultivars. To harvest hand-strip seed from native stands or wild harvest with a combine. It is relatively easy to grow Indian ricegrass for seed (Stefferud, 1948; Fisher et al., 1987). There are from 97,000 to 235,000 seeds per pound (Stefferud, 1948; Wagoner, 1981; Wasser, 1982; Valentine, 1971; S&S, 1987). The larger seeded varieties may be the result of semi-domestication.

A hammer mill followed by recleaning in a fanning mill will remove fine hairs for drill seeding. Seed is often 95 percent pure. Although it is traditionally credited with low germination, ten percent PLS (Wasser, 1982); much better purity and germination are not difficult to obtain (98% PLS with 80% germination) (S&S, 1989). Seeds store well and storage may improve germination substantially (Conard, 1962). Dormant seeds may germinate in 56 days in standard seed testing (Wasser, 1982). Slow and poor germination of untreated seed may occur due to seed coat and dormancy. Dormancy is apparently complex and varies with ecotype, age, and seed cleaning (Zemetra & Cuany, 1984; McDonald, 1987). Phillips (1987) recommends temperatures of 50-70°F [10-20°C] for germination.

Germination can be increased by mechanical scarification, acid treatment , or early planting to get stratfied by a winter in the moist soil (Stefferud, 1948; Plummer & Frischknecht, 1952; Hafenrichter et al., 1968; Merkel et al., 1973; Young et al., 1985; Young & Evans, 1984; McDonald, 1987; Griffith & Booth, 1988;). Acid treatment required 20 minutes with 70% sulfuric (Wallace & Romney, 1972). Very good germination has occurred with seed double-cleaned for cooking (Bainbridge, unpub.). In tests in 1989 60% of the seed (1986 from Cortez, Colorado) germinated without treatment in 5 days, 70% in nine days, at 16-21°C.

The seed can be drilled up to 4 inches deep in sand, 1.5 to 3 inches deep on medium to coarse-textured soils. Similar soil coverings are needed for broadcast seeding. Drill 5-20 pounds PLS per acre (Stefferud, 1948; Valentine, 1971; Wasser, 1982). Double or more for broadcasting and stabilization. Phillips (1987) suggests 1 pound per 1,000 sf for landscaping.

Sow seed before the most favorable conditions for rapid germination and seedling growth. Seedling vigor is fair to moderate but stands develop somewhat slowly and may require 3 to 5 years to develop. Hardy and persistent after well established. Controlled burns may be of value as Indian ricegrass is only slightly damaged to favored by fire (Valentine, 1971).

Rabbits, rodents, livestock and grasshoppers may damage stands (Wasser, 1982). Rodent damage to seeds is reduced when seed is planted deep, 3 to 4 inches acceptable. There can be minor stand or forage losses from a variety of seed and root rots, blight, rust, and smut organisms (Wasser, 1982). Indian ricegrass tolerates moderate grazing but can be killed out by intense and prolonged Spring or yearlong grazing (Wasser, 1982). Graze stands moderately in Spring and before the seeds heads are fully formed. Moderate winter grazing may encourage thickening of stands (Hafenrichter et al., 1968). Stands may take 3-5 years to fill in.

A well-drained sand mix is preferred for container growing ricegrass. Ricegrass has survived over a year in sand filled supercells with the tip of the container in water, despite the plants general intolerance of waterlogging. A deep container is probably advisable if the plants will be kept in the nursery long. Root length was up to 3 cm at the end of 5 days and roots were growing 1 cm per day. Supercell transplants at the Ant Hill were healthy and vigorous but needed more than 2 supplemental irrigations to establish.

Indian ricegrass is mycorrhizal and might benefit from inoculation in low fertility sandy soils with limited infection potential. However, Stark and Redente (1987) found that Indian ricegrass showed less response to mycorrhizae than shrubs in a study using stockpiled loam in Northwest Colorado.

It exhibited a moderate response to light irrigation and fertilization, which commonly increase seed production. It had a lower response to water-spreading systems than many species (Valentine, 1971).

Annuals of the low desert

There are two primary groups of annual plants, winter ephemerals and summer ephemerals. Winter ephemerals appear to be more common at the Ant Hill. These short-lived plants may appear profusely only every 5-10 years when precipitation, soil moisture, temperature, and photoperiod are favorable (Went, 1948, 1949, 1979; Juhren et al., 1956; Tevis, 1958; Crosswhite & Crosswhite, 1982). The dense floral carpets that can develop under these conditions are strikingly beautiful and provide seeds for succeeding rain events. Extensive annuals grew and flowered in 1991 but were hard hit by caterpillars. Despite high rainfall in 1992-93 few annuals germinated and grew. The regulation of these plant communities is complex and may involve not only rainfall timing and amount but mineralization of nutrients and availability of these nutrients when rain falls.

Mammals, insects, tortoises, birds, and reptiles

The low desert is home to a wide range of animals, insects, birds, reptiles and amphibians. The long drought and extensive ORV activity apparently heavily impacted populations of many species. Insects, lizards, and rodents are significant herbivores and seed dispersers. The desert iguana for example, relies on vegetation for up to 94% of its diet (Pianka, 1971; Minnich & Shoemaker, 1970) and lizards may have significant effects on plant communities and plant shapes. The compact rounded shape of white bur sage was observed to be caused by grazing of chuckwallas in Death Valley (Welles & Welles, 1961). The kangaroo rat may be important for dispersal of creosote bush seeds which it collects and stores in small subsurface caches (Reynolds, 1950). Rabbits have been the most damaging herbivore in other study areas near the Ant Hill (Bainbridge & Virginia, 1990). Ants also collect and redistribute seeds and harvest plant material. Birds are important seed dispersers and the raptors may help control rodent populations.

F. Natural disturbance and resilience, lessons for restoration

The low desert is an unpredictable environment shaped by natural disturbance from extended drought, excess moisture, herbivory, freezing, and fire. Response of the key species to these different stresses are not well understood. Some events, like freezes and fires may kill long-lived species like creosote bush. Recovery from these events may be very poor even without human disturbance, with increasing damage the recovery period becomes longer and longer.

Part 4. Damage and Disturbance by ORVs

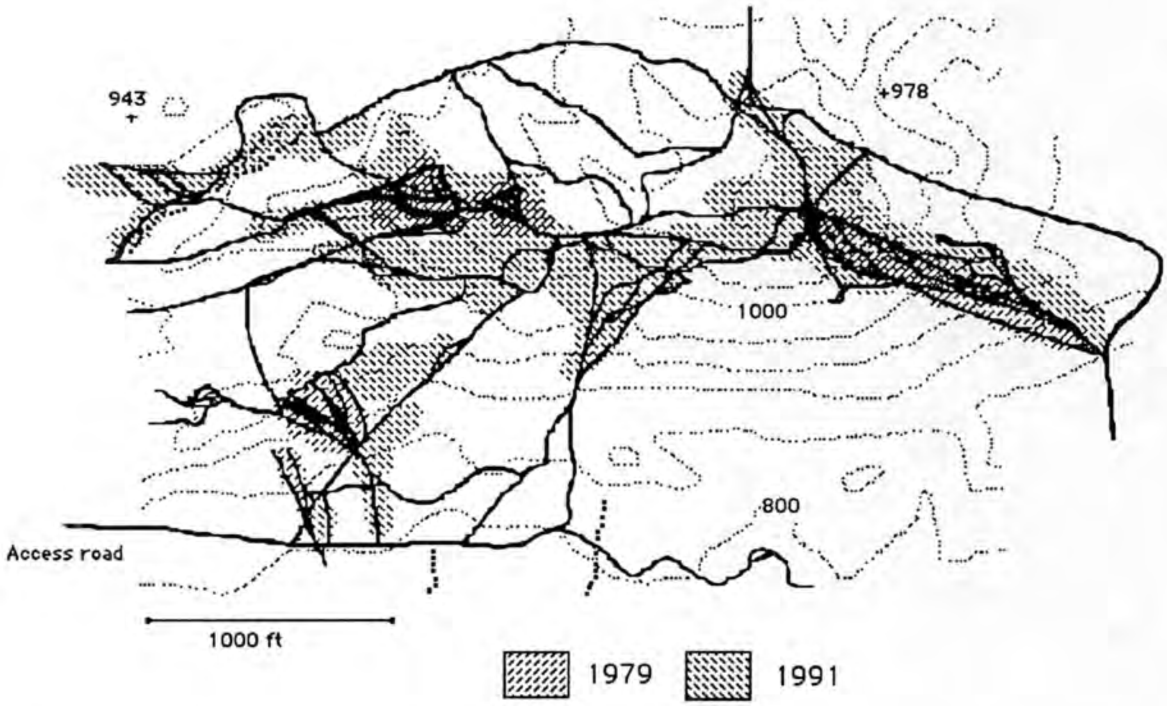
The rate at which an ecosystem recovers from human or natural disturbance is a function of the nature, magnitude, and frequency of the impacts. Seeds and related symbionts (mycorrhizal fungi, for example) may no longer be abundant and critical aspects of soil structure and air/water interchange can be adversely affected. Extreme temperatures, herbivory, limited moisture and low fertility soils in the low desert combine to make plant establishment very slow even without disturbance. Conditions for re-establishment in the deserts of California are infrequent (Zedler & Ebert, 1977; Bainbridge & Sorensen, 1990) and shrub establishment may occur only a few times a century when precipitation patterns are favorable.

Vegetation recovery after disturbance in deserts is poorly understood. Studies in the less severe conditions of the Mojave Desert suggest that without intervention it may take 180 years for reasonable recovery of species diversity on non-compacted soils (Webb et al., 1983). Lathrop (1983) calculated a recovery period of 112 years in the Mojave Desert for roadways to reach predisturbance density and 212 years to reach predisturbance cover. The rate of recovery would be considerably slower at the Ant Hill.

The Ant Hill area has been very highly disturbed. More than 15% of the area has been affected by off-road vehicles. The disturbed areas (more than 30 acres) include roads, trails, hill climbs and erosion gullies, table 4-1. This damage is also shown on map 4-1, comparing 1979 and 1991.

Table 4.1. Damage and disturbance at the Ant Hill

Year	1979	1991
Main roads	5 miles	5 miles
	0.9 legal until 1987	0.5 in use for access
Gullies		0.7 miles
Trails, roads, and hill climbs	15 acres	30 acres



Map 4-1. ORV related damage at the Ant Hill

The area was base mapped from USGS topographic maps and county aerial photographs. Disturbance was assessed using aerial photos from 1979 and 1990 and field work. The damage assessment was complicated by the serious drought which increased the difficulty of characterizing the degree of disturbance. The rain in spring 1991 and subsequent seed germination made it easier to see some types of disturbance. These estimates are approximate but indicate the nature and size of the problem faced in restoring this site.

Extensive literature reviews were done to determine the impacts of disturbance on similar sites and to develop an approach for the treatment of these different problems. These are described in greater detail in the next chapter.

Soils

While the desert soils appear lifeless much of the year, living organisms, from bacteria to animals and plants, strongly influence soil fertility and structure. Although they have not been widely studied and are rarely considered by the public and policy makers, small organisms such as ants, bacteria, fungi, microarthropods, nematodes, protozoans, termites and yeasts play important roles in the ecology of desert soils (Bainbridge & Virginia, 1990). Many of these little noticed organisms are easily disturbed or destroyed by ORV activity and their elimination can lead to undesirable changes in soil moisture relations, soil fertility, and plant and animal communities. While desert restoration requires replacing the structural characteristics of mature ecosystems, more research has been conducted on the above ground interactions than on the critical characteristics of the soil and soil ecosystems (Allen, 1988).

Some of the most important impacts of construction and human activity are the often unseen effects at and below ground level. Roots and microorganisms are common even in the intershrub areas and even conscientious or considerate ORV operators who avoid damaging shrubs are doing considerable damage to the fragile desert ecosystem. The impacts of ORVs on soil physical, chemical, and biological factors are increasingly well understood and recognized. Key factors include reduced infiltration and fertility, increased compaction and soil strength, increased erosion, and reduced biological activity. Assessing these factors at the Ant Hill required the development of special tools as conventional agricultural instruments proved unsuitable for this site. The impact penetrometer (after Malcom, 1964) and small double-ring infiltrometer (after Malik et al., 1985) are working well and should prove useful on many other remote sites.

Soil structure

ORV's can quickly degrade soil structure. Some of the most serious problems in restoration are the adverse effects of compaction caused by the vehicles or equipment operation (Bainbridge, 1993). Even limited ORV activity can have significant adverse effects on soil structure. Loamy soils are most sensitive to compaction than sandy soils (Bodman & Constantin, 1965), and wet soils are much more vulnerable than dry soils (Adams et al., 1982). The strength of soils that have been compacted increases much more quickly than undisturbed soil as the soil dries out. Enough ORV operation occurred at the Ant Hill to seriously compact the predominantly sandy soils. These effects can be seen in the following penetrometer data from the Ant Hill, figure 4-1. The decreased depth of penetration per impact indicates increasing soil strength. Increasing soil strength reduces root growth and survival and limits growth of microsymbionts.

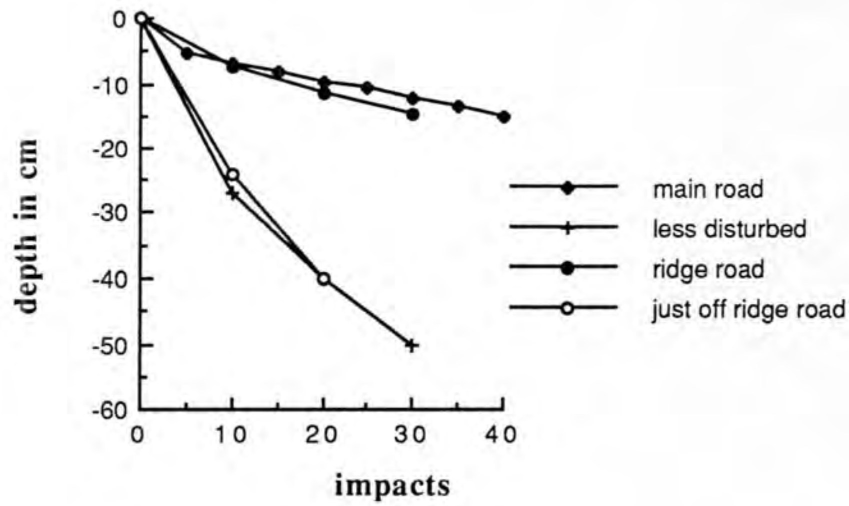


Figure 4-1. Penetrometer data

The changes in soil structure can reach considerable depth (Iverson et al., 1981). Significant adverse changes were observed at 25 cm depth from as little as three passes with a 4wd vehicle over moist soil (Adams et al., 1982). In some cases soil strength can be significantly increased by one pass, but more commonly the soil strength increases with repeated passes (Adams et al., 1982). Values of soil strength after 10 passes of a 4 wd vehicle on one test day all exceeded 67 kg/cm^2, more than three times the minimum amount causing serious reduction in root growth (Adams et al., 1982), figure 4-2.

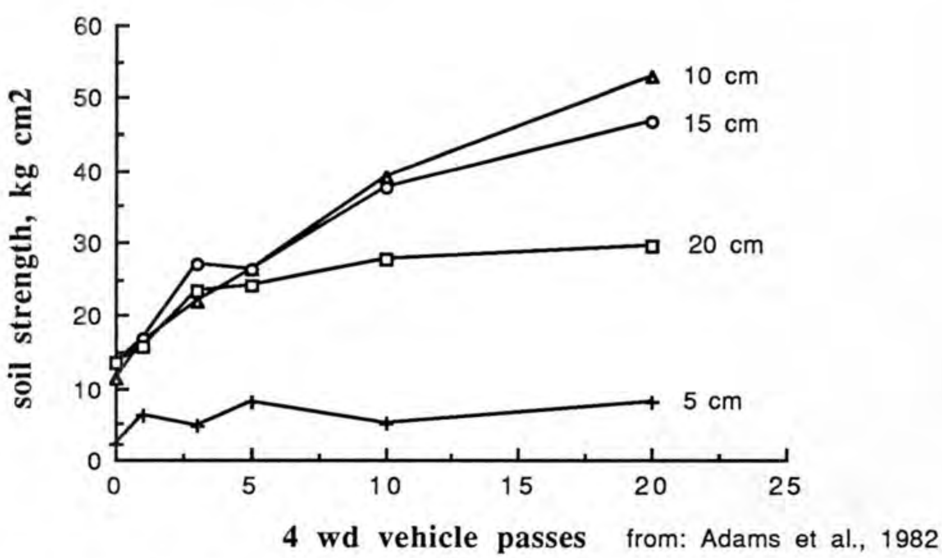


Figure 4-2. ORV effects on Soil Strength

The effects of compaction on shrub establishment have not been studied extensively in the desert, but Rowlands (Bureau of Land Management, 1980) observed that compaction of a loamy desert soil by off-road vehicles resulted in significant reductions in the growth of desert annuals. This is also true in the roads at the Ant Hill, where loosening the soil with a garden fork dramatically increased annual cover. The effects of compaction are significant even in much more favorable environments. For example, equipment operation which increased soil bulk density only 12% on logging decks and skid roads reduced seedling survival 88-91% (Lockaby & Vidrine, 1984).

Soil infiltration

Most of the increase in bulk density in compacted soils appears to result from the destruction of larger soil pores (Iverson et al., 1981) with related, detrimental changes in infiltration. The changes in infiltration in the sandy soils of the Ant Hill were most notable in the roads, figure 4-3. Infiltration in some hill climb areas increased as erosion removed the more fertile fine particles and left mainly larger grains of sand.

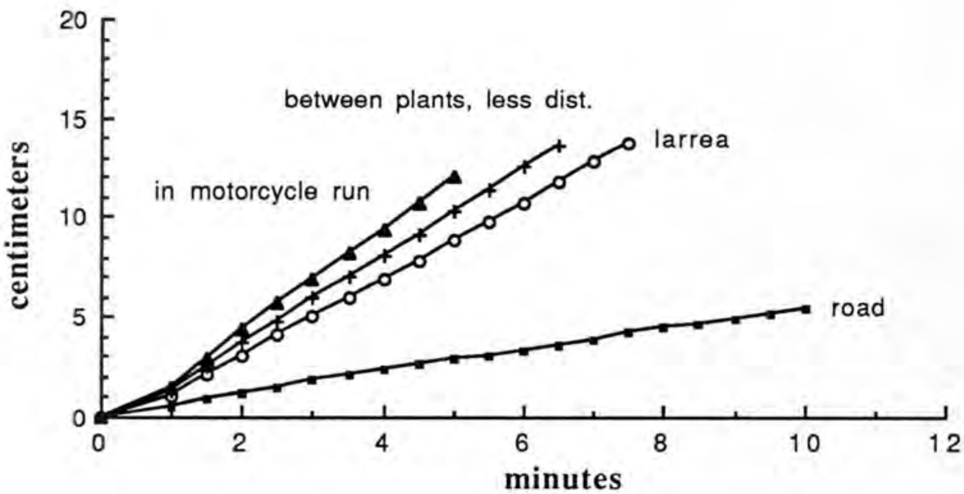


Figure 4-3. Infiltration at the Ant Hill
The Larrea measurements do not include the benefits of stem flow and other effects that can increase infiltration under shrub canopies.

Data from a creosote scrub plant community in Nevada clearly illustrates the impact of vehicle operation of infiltration, table 4-2.

Table 4-2 . The Impact of ORVs on infiltration

	terminal infiltration	
	cm/hr	change
Shrub area		
Control	3.2	--
Motorcycle	2.7	-15%
Truck	2.1	-33%
Between plants		
Control	0.9	--
Motorcycle	0.2	-77%
Truck	0.6	-33%

from Eckert et al., 1979.

Recovery from these changes can be very slow. Infiltration of desert soils in a vehicle parking lot used for military operations decades earlier was only about half that of undisturbed soil (Prose, 1988).

The removal of vegetation can also reduce infiltration as the plant mediated infiltration benefits (stem flow, litter, etc.) are eliminated. For example, infiltration in creosote bush soil was double that in dry bare soil and infiltration in wet creosote bush soil was almost five times greater than in wet bare soil (Tromble, 1980).

During intense summer rains these differences are accentuated. Areas with good plant cover may hold and save much of the rain while areas that have been disturbed can trigger flooding and severe erosion. While the entire Ant Hill site was able to absorb 1 inch of gentle winter rain in 24 hours without runoff, erosion and runoff have occurred in more intense storms and almost three-fourths of a mile of erosion gullies developed between 1979 and 1991. Most of these are directly in old ORV tracks (seen in the earliest aerial photos), as a result of compaction, reduced infiltration, and channeling of water and erosive forces.

Soil moisture

Soil saturation percentage (SP), the amount of water that it takes to saturate a soil sample expressed as a percentage of the soil dry weight. SP is a useful indicator of the water and nutrient holding capacity of a soil. SP from samples at the Ant Hill ranged from 17-24 and averaged 20.8 (n=4). Sandy soils commonly have a low SP (18-24 percent), reflecting limited water holding capacity and low fertility. The SP of surface soils under the multi-stemmed creosote bush and bur sage at a similar site in the Coachella Valley was much higher (31-37 percent) than in the sandy soil between plants (19-24 percent), suggesting that the fine soil particles and organic matter accumulating beneath the plant canopies are improving the water and nutrient retention capacity of these soils.

Soil fertility

Nutrients in desert soils are usually concentrated near the surface (Charley & Cowling, 1968) and this was true at the Ant Hill, figure 4-4. Disturbing the surface can dramatically reduce the already low soil fertility as wind and water erosion quickly remove these more fertile surface soils. Extensive erosion in some hill climb areas has removed several feet of soil over large areas. These denuded areas are particularly difficult to revegetate.

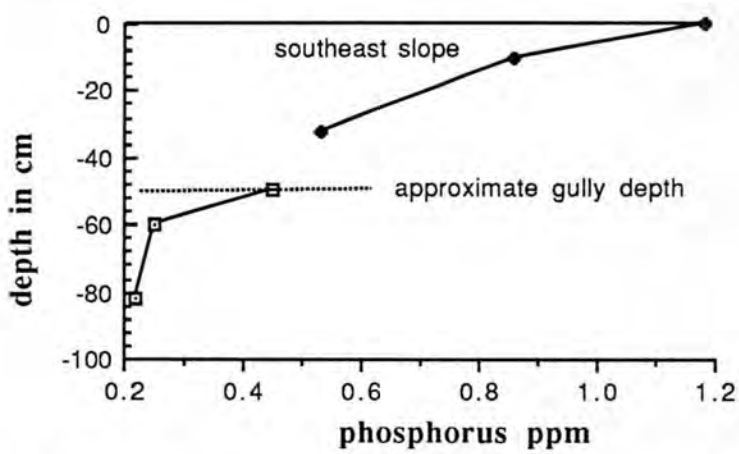


Figure 4-4. Soil phosphorous fertility with depth, the SE slope is less disturbed adjacent to the erosion gully.

The fertility of the soils at the Ant Hill has been seriously affected by disturbance, as shown in table 4-3. Little is known about the best method for restoring fertility for this type of disturbance. It deserves further study, exploring the benefit of adding slow release nutrients and recalcitrant (slow to degrade) mulch materials such as bark and wood chips.

Table 4-3. Soil fertility as affected by increasing disturbance at the Ant Hill

PPM (average)	Less disturbed		More disturbed		
	Plant canopy	Between plants	Trail	Gully	Road
	n=14	n=9	n=12	n=6	n=21
Nitrate N	4.77	1.59	1.16	0.96	0.75
Extractable P	0.91	0.72	0.63	0.44	0.36
Percent orig (av. N&P)	--	57%	47%	35%	28%

Soil taken from an ant mound in a disturbed area in the Coachella Valley had twenty to forty times as much available phosphorus as adjacent soils, confirming the wisdom of traditional farmers in Mexico who used ant mounds as a soil amendment for their gardens (Wilken, 1987). Ants also increase infiltration and can be one of the only natural agents for improving disturbed arid areas.

Root symbionts

Compaction can also reduce soil microorganism populations. Total numbers of fungi, bacteria, nematodes, and macroarthropods are much lower on compacted soils (Smeltzer et al., 1986). Pathogens were more common on the compacted soils but rarely isolated on control plots. Changes in soil moisture caused by reduced infiltration may make also make nodulation by rhizobia difficult or impossible. The increased soil strength caused by compaction can reduce infection and growth of beneficial mycorrhizae. Changes in soil structure and elimination of rodents and soil organisms may also limit movement of inocula in the soil.

Vegetation changes

The most immediate impact of ORV operation is the reduction or elimination of shrubs that are repeatedly run over. While shrubs may initially resprout repeated damage will cause the plants to die and disappear. Plants whose roots are affected by changes in soil properties between shrubs from ORV operation may also die over a longer time period. Large bare areas have developed at the Ant Hill from the combined impacts of ORV operation. Less dramatic but significant changes in plant community composition may occur as a result of even light use (Kleiner & Harper, 1977). These changes are difficult to assess at the Ant Hill because no predisturbance data on plant communities was available.

Subtle but important change in the this area may result from the reduction in hunting pressure on grazing animals from a decline in the numbers of predatory birds and mammals (from hunting pressure and environmental contamination) and the elimination of the hunting pressure from the Native Californians that once lived in this area. Significant increases in perennial grasses have been observed in other areas when several species of Kangaroo rats were limited (Brown & Heske, 1990). This may be offset to a certain extent by the destruction of burrows and animals by ORVs. Even the sound of ORVs can adversely affect populations of mammals and reptiles (Brattstom & Bondello, 1983).

Microclimate

Disturbance by ORVs markedly increases the severity of the microclimate. Temperature swings are larger on disturbed sites, radiation is more intense, evaporation is increased, and wind speeds and sand blast are more severe. Bare soil temperature in the sun may reach 18°C [32°F] or more above ambient air temperature while soil temperature in the shade of nearby plants stay around air temperature (Wallace & Romney, 1972). Vegetation removal by vehicle operation eliminates sheltered microsites and makes plant establishment more difficult. Plants in the open are more likely to suffer from sand blast, herbivory, drought, and radiation frost. Plants that do become established are often found in the shade or protection of plants or rocks which moderate the extremes of the environment and provide protection from grazing.

One the most important factors may be the increase in wind speed at the ground and the related increase in sand blast. High winds in December 1988 literally blew transplants out of the ground in the Coachella Valley, a phenomenon observed by Tevis on natural seedlings (1958).

Protective shelters have markedly improved survival of transplants at the Ant Hill, figure 4-5. The 20 cm treeshelters (TUBEX) were very effective, but if left on too long they distorted plant shapes.

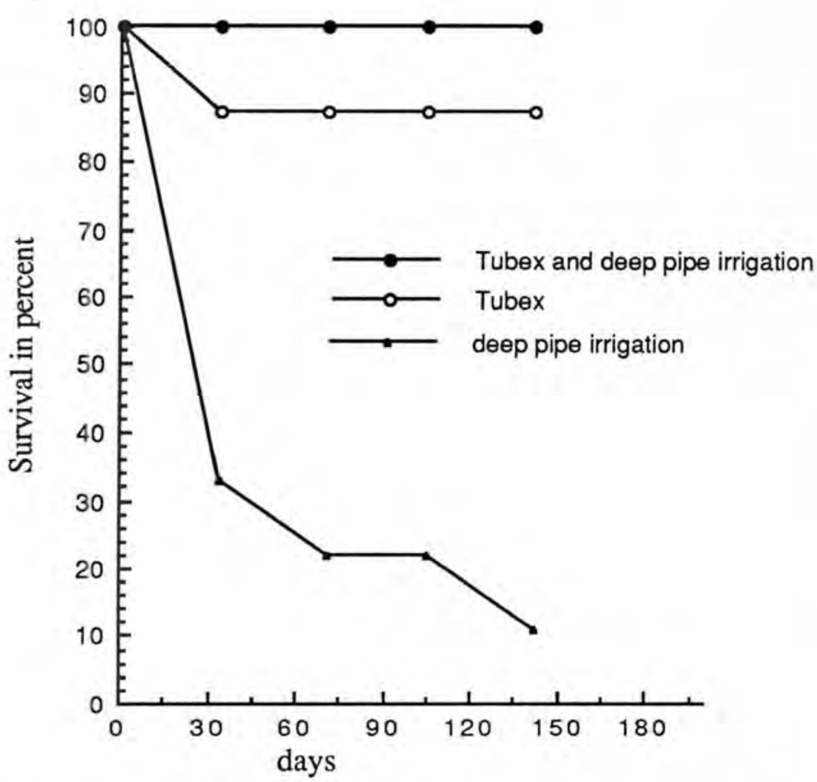


Figure 4-5. The value of plant protection
Ambrosia dumosa from paper pots at the Ant Hill.

Herbivory (grazing)

Disturbance can increase herbivory by reducing food supplies and increasing visibility of seedlings. Restoration work often increases herbivory by introducing succulent, nitrogen rich plants to an otherwise barren environment. Irrigation and transplanting in the midst of a long-term drought produces a "salad bar" effect.

Although few studies of plant establishment and long-term survival have been made herbivory may be a common factor limiting survival of desert plants. Where detailed studies have been undertaken herbivory is often the major determinant (McAuliffe, 1986; Tevis, 1958). While herbivory may pose a problem in the establishment and survival of some species, most species tolerate moderate grazing (Nilsen et al., 1987; Virginia & Bainbridge, 1988).

Grazing pressure on plantings was virtually absent at the Ant Hill site during the winter of 1990-91 but some rabbit pellets were observed in June, 1991. The long drought may have greatly reduced herbivore numbers but the populations can bounce back quickly and increasing herbivory was experienced in 1992 and 1993. Herbivory by insects (moth and butterfly caterpillars) was severe in Spring 1991, and both natural seedlings and transplants were eaten. Caterpillars particularly favored the Atriplex and were observed to change direction toward the plants as they were planted. Herbivory decimated desert lily plantings and also eliminated many larger transplants, both Ambrosia and Larrea. Grazing pressure on transplanted creosote bush seedlings in the Coachella Valley has generally been high and native creosote bush is also browsed (Bainbridge & Virginia, 1990). Rabbits eat creosote bush (Blair, 1981; Hayden, 1966), and unprotected creosote bush seedlings will generally not survive long in the low desert.

The synergistic effects of disturbance on plant establishment and survival

The adverse effects of disturbance on existing plants and plant establishment are interactive and in many cases synergistic, i.e. together they can make recovery much more difficult than evaluation of each impact by itself would suggest (Bainbridge et al., 1993). These interactions are not well understood. Plant establishment becomes increasingly difficult as the number of important environmental factors deteriorating increases.

The following formula is an attempt to assess these interactions and to relate them to plant establishment. It is based on methods used to analyze machine reliability. These are a first attempt to develop quantitative estimates of the challenge of revegetation. Unfortunately, no study has evaluated all of these factors and related them to establishment.

INTEGRATED DAMAGE EFFECTS = $[\ (d_1)\ (d_2)\ (d_3)\ (d_4).....(d_n)\ ]$

D_1. soil compaction and infiltration, where $\dfrac{[(Ud)\ (Id) + fn]}{n}$

Ud = undisturbed soil strength/compacted soil strength
Id = reduced infiltration/undisturbed infiltration
fn = other factors

D_2. soil fertility where $\dfrac{[(\frac{Nd + Rd}{2}) + (\frac{Pd + Md}{2}) + Kd + Od + Td + ...fn]}{n}$

Nd = Available nitrogen disturbed/N undisturbed
Pd = Available phosphorus disturbed/P undisturbed
Kd = K disturbed/K undisturbed
Td = T disturbed/T undisturbed
Od = Organic matter disturbed/Organic matter undisturbed
fn = other factors
Md = mycorrhizal inoculation potential disturbed/mp undisturbed
Rd = rhizobial inoculation potential disturbed/rp undisturbed

D_3. loss of plant materials $\dfrac{(wd + mcd + smd + fn)}{n}$

wd = windblast undisturbed/ windblast disturbed
mcd = max temperature undisturbed/ max temperature disturbed
smd = soil moisture bare soil/ soil moisture under plants

D4. herbivory (hd)

hd = reduced shelter and increased pressure, as herbivory undisturbed/ herbivory disturbed

Cumulative disturbance caused by ORV roads

Data from the different studies at the Ant Hill and related studies in the Coachella Valley have been combined with estimates of feedbacks and unstudied effects. For example, D_1 multiplies compaction and infiltration because of the clear relationship between increasing soil strength, reduced soil moisture and root extension and plant survival. Some factors are clearly more important than others and a better understanding of these factors should make it possible to develop constants to properly weight these differences.

D_1. soil compaction and infiltration, where $\frac{[(Ud)\ (Id)\ ]}{2} = \mathbf{0.17}$

Ud = undisturbed soil strength/road soil strength = 0.53 (PENETROMETER)
Id = road infiltration/undisturbed infiltration = 0.66 (DOUBLE RING)

D_2. soil fertility where $\frac{[(\frac{Nd + Rd}{2}) + (\frac{Pd + Md}{2}) + Kd + Od + Td + ...fn]}{n}$

$$\frac{[(\frac{0.16 + 0.1}{2}) + (\frac{0.40 + 0.1}{2})]}{n}$$

$$\frac{(0.13) + (0.25)}{2} = \mathbf{0.19}$$

Nd = N road/N undisturbed = 0.16 (NITRATE N)
Pd = P road/P undisturbed = 0.40 (EXT. P))
Md = mycorrhizal inoculation potential disturbed/undisturbed = 0.1 (estimate)
Rd = rhizobial inoculation potential disturbed/undisturbed = 0.1 (estimate)

D_3. loss of plant materials $\frac{(wd + mcd + smd + fn)}{n} = \mathbf{0.66}$

wd = windblast undisturbed/ windblast disturbed = 0.5 (estimate)
mcd = max temperature undisturbed/ max temperature disturbed = 0.9 (open/shade)
smd = soil moisture reduction (SP open/SP plant) = 0.6 (SP)

D_4. herbivory reduced shelter and increased herbivory(hd) = **0.80** (estimate)

DISTURBANCE = (0.17) (0.19) (0.66) (0.80) = **0.017** or roughly **2%** of predisturbance potential for plant establishment.

Unfortunately the understanding of these disturbances and their interactions is limited. These preliminary projections may be wide of the mark, but knowledge is so limited it may be in either direction. If this simple formula is close to correct plant establishment may become fifty times more difficult after ORV roads are created. Developing a better understanding of the interactions between these different factors is essential to predict damage and to plan restoration activities. The fact that disturbances caused by Anazazi farmers more than 900 years ago are still visible (Sandor & Gersper, 1988) suggests these may be reasonable.

The goal of a restoration project is eliminating these disturbance effects and optimizing conditions for plant establishment and site recovery. It may sometimes be possible to modify some aspects of the environment to better than original conditions. Even making one factor much better than pre-disturbance condition may have a notable effect on recovery. Considering the example used above, if soil structure, infiltration, and fertility are made better than before disturbance and full protection is provided for young plants the difficulty of establishment may be improved from 50 times worse to close to predisturbance conditions. This is not perfect of course, as natural establishment can be rare, and restoration usually will involves more active intervention with transplanting and irrigation to provide seed and inoculum sources in disturbed areas.

Summary

Disturbance by ORVs makes revegetation and restoration challenging in the desert. A wide range of environmental factors are degraded by ORVs. Assessing the nature and magnitude of changes in key factors makes planning restoration operations more accurate by enabling limited resources to be directed at critical problems. Ongoing studies of the effects of these changes and their correction through biological, chemical, or mechanical means will improve the understanding of which factors are critical, and those that are relatively unimportant.

The most important lesson from these studies is obvious, but often neglected--**minimize the area of disturbance and limit the intensity and frequency of disturbance**.

Part 5. Restoration work 1990-1993

The following section provides a description of the work that has been done as a part of this project. The research components which were the foundation of this project are described in the next chapter. Work in the early stages of the project was aided by support from both Mark Jorgensen and Deborah Hillyard from A-BDSP. Students and staff from SDSU provided most of the labor for experimental plantings and treatments.

Volunteers working on site

Volunteers

More than two hundred volunteer days were worked at the site. Volunteers from the Sierra Club, the California Native Plant Society, the Crisis Kids, the Audubon field school, Restoration Ecology Class (SDSU), the University of Baja California, Ensenada, and many others, including many gracious and enthusiastic volunteers from Borrego Springs, provided essential field work and assistance. Volunteers without plant skills often had reduced survival of transplants even with training sessions. Work involving soil treatment and watering are often better for people with limited experience in the field. Although volunteer labor is a great benefit the cost of administration should not be ignored, there is a probably a 20% cost for supervision (or as much as 40 days of preparation, training and supervision time involved in the volunteer labor). Organizing volunteers was much easier from within the park than from SDSU.

Fencing

The critical factor in this project was the completion of the west boundary fence in 1990. This was the most cost effective part of the project and a tribute to the park staff and volunteers who constructed it. Additional signing and fencing on the south side is still desirable as some riders still make it into the area from the Rainbow Wash.

Seed collection

Seeds and plant material for vegetative propagation have been collected from the site by park staff, volunteers, project staff, and professional seed collectors. Almost a hundred pounds of seed were ultimately collected. Most has been used but seed for several species is being maintained in a collection at SDSU with the intention of using it for future research on the site. While volunteers are suitable for general collection, only well-trained people should be used for critical collections. Time studies demonstrated that professional collection was less costly than staff collection, but some of the hired collectors used unskilled laborers who did some damage to the plants. A supervisor on site would increase the cost but would minimize the risk to plants and would certify seed collection under guidelines of genetic maintenance.

Soil preparation and ground shaping

Treatment for compacted soils have been evaluated by test and/or observation. Garden forking and augering holes appear to be worthwhile. Annual plant establishment was much better in these treated soils in 1991. Marginally better establishment of annuals also occurred in 1992. With the exception of exotic grasses and mustard the timing of the rainfall and temperatures did not favor establishment of annuals in 1993 so larger test plots (map 6.1) that had been treated showed no effects.

Easily eroded soil surfaces have been shaped to concentrate and save water, improve infiltration, and reduce erosion. Areas pitted during this work are shown on map 5.1. Pitting appears to have improved establishment of direct seeded saltbush, particularly with bark amendment of the soil (used on the once barren peak top). Pitting on the eroded north side improved establishment of annuals. A large scale test with direct seeding, including pitting, had no establishment of seeded species so no effect was noticed. Pitting in the sand bowl seemed to have a very positive effect on establishment of *Croton*, but this was not quantified.

Pitting tests in 1993 were not followed by sufficient rain to induce germination. These pits may provide benefits later. In a test of labor cost thirty yards of road were pitted and seeded in 1 hour (18 pits). This would translate to 1,000 pits per acre at a labor cost of 60 hours. Pitting with students in 1993 treated much of the upper south side road in 2 hours (60 hours labor << one acre).

Gully erosion control in 1991 was generally very effective but building multiple small rock dams is very labor intensive. While several of these have failed, most are filled in with soil and providing needed stability for the north side gullies.

These physical treatments are good activities for volunteers.

Direct seeding

Direct seeding rates should generally be based on a goal of 100 live seeds per square meter (for example this would be about 0.1 oz seed per sq. meter for *Larrea* (80,000 seeds/lb x 50% purity x 15% germ.)and *Ambrosia* (200,000 x 60% purity x 10% germ.). Direct seeded areas are shown on map 5-2. Several tests were conducted on direct seeding (see following chapter) with limited success. Long-term studies in the Sonoran desert suggest success is likely only in one of ten years.

Transplanting

Transplants were grown at Joshua Tree National Monument and at SDSU. More than two thousand transplants were ultimately planted, ranging from supercells to tall pots. Considerable research was done on plant preparation and management. For reasonable survival protection from herbivory, wind, and temperature extremes, and supplemental irrigation must be provided for transplants.

Planting areas during 1990-1993 are shown on map 5-3. Initial planting goals were densities of 300 creosote and bur sage plants per acre (~12 x 12 ft spacing). The first planting was concentrated on the most obvious trail scars and with good survival these have become more or less permanent plant trails. Even with good survival the soil differences still delineate areas. Future research on soil treatment to eliminate or reduce this discrepancy is now underway.

Later planting used much wider spacing in an effort to reduce the plant trail effect and to improve a larger area of the site. Much of the spacing was also adjusted for experimental purposes. Transplanting was concentrated on the areas with the best access. Plant protection with rock mulch, peat collars, and treeshelters was evaluated. The benefits and timing of different methods of supplemental irrigation were also tested. Early watering, within 2-3 weeks of outplanting and watering in summer is most important--yet most difficult. The excellent survival of the supercell plants set out in April 1991 is in due in part to watering with a liter per plant in July, August, and September.

Catchment basins and water tanks were placed by volunteers and have worked better than expected. The size and tank capacity were well matched for rainfall during these seasons. The catchment area would provide water to the tank with as little as 0.5 mm of rain. These tanks of water greatly assisted irrigation on sites away from vehicle access. Original plans for irrigation were scrapped after severe, persistent animal damage problems in irrigation in the Coachella Valley.

Protection of natural seedlings

Natural seedlings were protected and watered in several places. This seemed to be very effective and may be the least costly way of improving recovery of damaged sites.

Maintenance and monitoring

The site should be monitored for 10 years if possible. Treatment and plant labeling on key plots is permanent (aluminum tags) to facilitate follow-up studies by subsequent resource managers. Some tag removal by ravens appears to be taking place. Future tags will be nailed down. The permanent markers will help provide much needed information on what succeeds over the long term. The maps included in the chapter on restoration research should provide sufficient detail to reacquire the sites.

Part 6. Restoration research

Students and staff from SDSU provided most of the labor for experimental plantings and treatments. NaDene Sorensen was involved in research projects at the Ant Hill from 1990-1993, for full details see Ms. Sorensen's 1993 MS thesis in Biology SDSU (138 pages). Carol Miller and the staff at the Center for Arid System Restoration at Joshua Tree National Monument cooperated on several research projects. Laurie Lippitt at the CDF Center for Reforestation in Davis assisted on seed analysis and participated in field planting trials. Most of the research and administration support was provided by David Bainbridge with assistance from Ross Virginia, Walt Oechel, and Mike and Edie Allen. Matt Fidelibus, Steve Netto, Robert MacAller, Robin McBride, Debbie Waldecker, Marcie Darby, Kris Conners, Julie Green, and Nicki Rorive provided assistance on research project plantings and irrigation, literature searches, data analysis, and write-ups.

Seed research

Seeds and plant material for vegetative propagation were collected from on and near the site. Almost a hundred pounds of seed were ultimately collected, primarily *Ambrosia* and *Larrea*. Germination data and seed quality were evaluated on many lots of seed. The large collection of *Larrea* and *Ambrosia* by S&S Seeds in 1991 was of relatively high quality with 30% fill of *Larrea* and 60% fill of *Ambrosia*.

Decompaction

Soil compaction affects plant establishment and growth primarily through its effects on soil moisture availability and root elongation. The physical resistance of soil to root growth can be significant in compacted soils. The overall resistance of a soil to root penetration is dependent not only on bulk density and soil texture but also to a large degree by soil moisture content (Taylor & Gardner, 1963). Soil compaction reduces infiltration, increases runoff and reduces aeration and water movement in soils (Hillel, 1982; Iverson et al., 1981). Natural soil and vegetation recovery following compaction of desert soils may take decades or centuries (Iverson et al., 1981; Webb et al., 1983; Webb and Wilshire, 1980; Prose et al., 1987). Ripping or scarification of the soil to break up compaction should therefore provide some benefit to plants through decreased resistance to root growth and improved moisture storage and retention.

Treating compacted soils with a garden forking was evaluated in 1991. The fork treatment significantly reduced soil strength (figure 6.1). With the exception of exotic grasses and mustard the timing of the rainfall and temperatures did not favor establishment of annuals in 1993 so larger research plots set up in 1993 (map 6.1) showed no effects.

Ripping was also a treatment in an irrigation and treeshelter study in 1991. An area of approximately $1m^2$ was ripped to a depth of 1' with garden fork or shovel and the transplants were then planted in the center of these plots. Effects were minor, but positive. The establishment of annual seedlings was striking in some ripped plots.

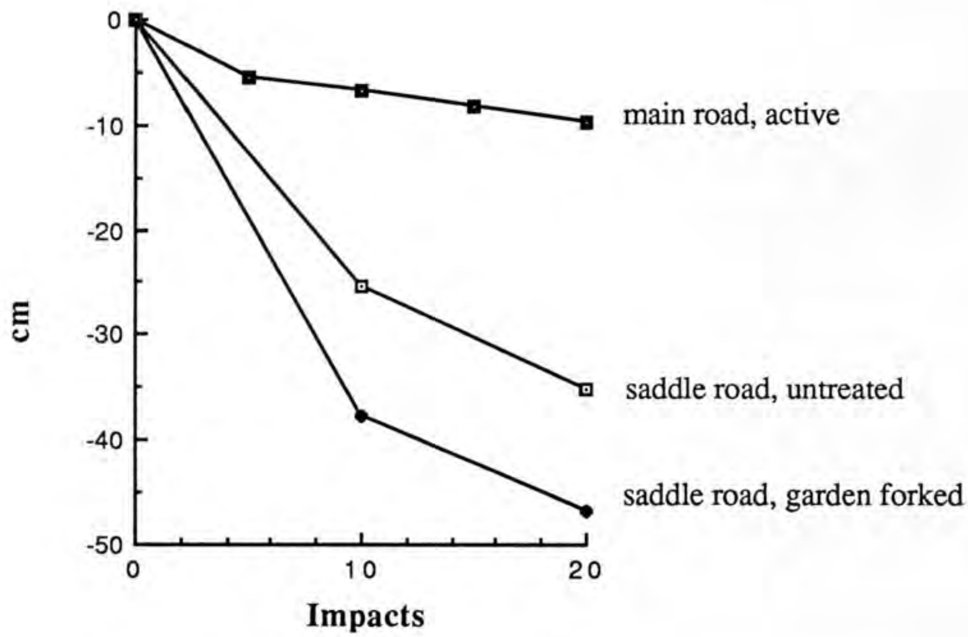


Figure 6.1 Treating compaction with a garden fork

Soil pitting

A large scale test of direct seeding, including pitting, unfortunately had no establishment of direct seeded species. Pits for these trials were made with McLeods or shovels. Labor cost tests suggest that 50 to 60 hours of work are involved in pitting each acre. Observation of soil moisture in test holes sunk in pits at the top of the hill suggest that the moisture retention in the pits is a major factor in success. Barnes (1950) found that pitting was superior to all other treatments from a standpoint of ease and economy in improving shortgrass range. A comparison study of pitting sowing and conventional tillage sowing systems on degraded rangeland in western Australia was conducted by Gintzburger (1987). Pitting was most effective. Soil pitting is a simple process but like most arid land treatments it encompasses a complex set of relationships and many uncertainties.

Direct seeding 1990-1993

Tests of direct seeding met with limited success. Long-term studies in the Sonoran desert suggest success is likely only in one of ten years. Direct seeding can be a low cost alternative to transplanting if seeds germinate and plants successfully establish. Seeding can speed recovery of damaged areas and hasten recovery from disturbance. It is particularly important for areas with limited seed sources. Seedling root systems are undisturbed and growth will often quickly surpass transplanted plants. However, direct seeding in the desert has usually been unsuccessful (Kay, 1979; Cox et al., 1982). Beginning in 1890, experiments in the Sonoran and Chihuahuan deserts involving 83 species and 400 sites suggest direct seeding may work in only in one of ten years (Cox et al., 1982). When annual precipitation falls below 250 mm, seeding may be very difficult (Vallentine, 1980; Roundy and Call, 1988).

If the planting must be done when the soil is dry, irrigation may help but survival may be poor even with supplemental irrigation. Brum et al. (1983) only achieved 0.3% establishment of several species even with supplemental irrigation. Grazing by rabbits and rodents is often a serious problem for direct seeding trials (Kay, 1979). Harvester ants may also collect young seedlings and limit establishment.

Seed collecting by rodents may also adversely affect seedling establishment from direct seeding (Kay and Graves, 1983). Collection of seed by harvester ants can be a very serious problem in many parts of the desert. Seeding small areas with supplemental irrigation may be difficult without measures to reduce ant activity.

Seed should be planted on the basis of pure live seed not total seed (McKell, 1986; Roundy and Call, 1988). High seeding rates should be used, with from 100 to 500 live seeds per square meter recommended (Kay, 1979; Herbel, 1986).

Seasonal distribution of precipitation is a major factor in determining the best time for seeding in arid environments. Soil and air temperatures must also to be considered. Seeding a complex mix with winter and summer annuals will involve a series of compromises and guesses.

Seeding in the Southwest has been recommended from May to June, before the beginning of summer rains (Vallentine, 1980); but M. Washington at the University of Arizona found that early seeding failed as plants germinated with light early summer rains and died before more consistent fall rains. Therefore planting in the low desert of Arizona was recommended just before late summer rains.

Even with all the difficulties involved, the relatively low cost of direct seeding from less than \$20 to more than \$1,500 acre (Dixon, 1988; Pizatella, 1986b) may make it worth trying (Bainbridge and Virginia, 1990). If conditions are favorable for a sufficient time to allow seedlings to establish, they may be able to survive until a subsequent rain event. Direct seeding may be very successful in a year with favorable rainfall and can be considered as the sole treatment where funds are limited or as an adjunct to more intensive treatment involving transplanting.

Experimental design: A

Because of the uncertainties involved in direct seeding several small and one large experiments were set up. All direct seeding at the Ant Hill was done by broadcasting seed by hand. Species sown included largely *Atriplex canescens* in 1990/early 1991 and *Ambrosia* and *Larrea* from late 1991-93. Different treatments including raking, surface pitting, were used to improve the chances of establishment. Trampling by walking on seed was used in these trials.

The major experiment was set out in February 1992 south of the mid Y. This included four circles (100 meter square) on a comparable south facing slope. Original plans for three replicates on other exposures were ruled out because of illness of the investigator. These four plots were cleared of major dead debris but living plants were left. *Ambrosia dumosa* seeds were placed to provide 100 PLS per m^2. Four treatments were used: garden weasel, weasel and trampling, pitting with a McLeod to create pits approximately 25-30 cm long and 5-10 cm deep, pitting and fertilizer. The fertilizer used was a 10:10:4 dry fertilizer applied at 10 pounds for the entire plot, broadcast to lie primarily in the pits.

No seedling establishment of bur sage was observed in the test plots despite almost 2 inches of rain shortly after seeding. The establishment of volunteers seemed to be better in the pitted area but no quantitative analysis was done.

Experimental trials

Direct seeding was tested on the hill top with *Atriplex* (bark/pits) in 1990, near the Y in 1991 (weasel v/s weasel and trampling) with *Larrea* and *Ambrosia*; pitting along the north and east slopes of the peak with the same species in 2/93, pitting along the north road in 2/93, and direct seeding with pitting along the upper part of the main road and the west facing main slope with 12 volunteers covering several acres (4/93).

Discussion

Although direct seeding can be a low cost method of revegetation that can develop stronger and more vigorous plants than transplanting, it is very difficult and problematic in arid environments. Techniques such as pitting and imprinting can be used to increase water retention and infiltration. Noticeable seedling establishment only occurred from the *Atriplex* seed in pits on the peak top. Survival and establishment of these plants has been good. The bark treatment appeared to give a slightly better strike than the pits alone but this was not quantified. The other seeds may still be viable, waiting for a favorable moisture and temperature pattern.

If seed is available direct seeding is worth considering. Pitting, bark mulch, and fencing can improve establishment in direct seeded areas.

Transplanting

Because direct seeding is unlikely to succeed in a given year considerable research was done on plant preparation and management for successful transplants. Transplanting was concentrated on the most obvious scars with the best access. Key questions included container shape and size, soil mix, and transplant handling costs and options.

Container size and shape comparisons 1990-93

Transplants are likely to remain a key component of revegetation and restoration programs in the desert. One of the critical questions that research at the Ant Hill has addressed is, "Which container is best? Unfortunately, the answer is "It all depends on the conditions of the year, the handling process, and the species."

One of the most important considerations for restoration planning is which size (from 10 cu in to 850 cu in) and depth (from 8"-32") is most cost- effective. Obviously the bigger containers will be more expensive, both to grow and plant but if they provide a significant improvement in survival it may be a good investment. Data on results is provided after a discussion of the major types of containers evaluated.

Supercells

An individual container that is part of a larger set of containers is termed a cell or tube. The Ray Leach (R/L) Single Cell System is the most common in North American container tree nurseries. The capacity of the various cells ranges from 3-10 cubic inches, and the growing density ranges from 49 to 100 per square foot. The ten cubic inch cell, commonly referred to as a supercell, is one of the most commonly used containers for desert plant production and was tested for a variety of species.

One of the biggest advantages of the individual cells is that the containers can consolidated during culling. It also enables seedlings to be sorted or selected by class size and vigor for outplanting or special treatment in the nursery.

The hard plastic trays that hold the cells are relatively fragile and easily damaged if they are repeatedly handled while loaded with seedlings. They are also heavy, weighing about 50 pounds with 98 plants in supercells.

The seedlings can be removed containers by gently squeezing the supercell or rapping the top of the cell on a hard surface (using momentum to dislodge the plant/soil). Plants with fragile roots can be more gently removed by kneading the cell under water. In general with the sandy soil mixes the soil falls away from the plant the seedling is effectively bare-rooted.

GOOD for predictable planting programs where delay is unlikely for either biological or bureaucratic reasons. Seedlings for some species should be outplanted in 8 weeks or less.

Plant bands

Plant bands made with folded and glued waxed, plastic, or foil coated cardboard. They have been used for a wide range of container plant production, ranging from conifers to buckeyes at the L.A. Moran Reforestation Center to jojoba seedlings for the lower desert. Heavy stock with foil on both sides is preferred but has become increasingly difficult to obtain. Stock with foil on the inside and plastic or wax coated material are suitable for short rotations. Heat set glue may loosen in the low desert, so seams should not face to the outside of planting blocks.

Plant bands can be placed on screen over pallets and banded, boxed in open bottom boxes or placed in open bottom racks. They can be stapled together at the top to make handling easier. At planting time the cardboard is usually soft enough to rip open. The opened cell can be held together as it is placed in the planting hole, backfilled loosely and then the paper can be pulled up.

A wide range of plant band sizes have been tested with generally positive results (up to 3 x 3 x 24 inches). Only stock shapes may be available for smaller orders. A 14 or 16" tall, 1.5 or 2" square cell seems most appropriate. The flexibility of the plant band dimensions (special orders in almost any shape) and relative ease of handling make them good candidates for further experimentation. They have proved very effective in other semi-arid trials (Felker et al., 1988).

BEST BET. Economical and easy to plant. Plants may be held for more than a year with larger cells.

Newspaper pots

Rolled newspaper pots have also been used. These are made from a single sheet of newspaper which is folded and rolled and stapled to make a tube 2" in diameter and 8-12" tall. The paper cell is wrapped with kitchen wrap (plastic) to preserve the integrity of the cell over time. These have worked relatively well and are used regularly by the Center for Arid Systems Restoration at Joshua Tree National Monument. They are costly in labor to make and the round shape packs less efficiently than the square plant bands.

NOT RECOMMENDED

Pipe sections

Plants have been grown in plastic pipe sections ranging from 3/4" x 30" to 6" x 32". Plant removal is difficult with smaller diameters, and if the pipe must be sawed open it becomes labor intensive. This has been done in the field with a battery powered circular saw and in the nursery with a larger circular saw. Pipe greater than 3 inches in diameter seems to be a better choice for removing an undamaged plant. The choice of pipe is also important, a smooth-walled PVC is desirable. Rougher textured plastic, like drain pipe, causes more root damage as the finer root hairs become entangled with the plastic container wall.

The Center for Arid Lands Restoration at Joshua Tree National Monument has pioneered the development of a Tall Pot made with 30 inch tall, 6 inch diameter PVC pipe (APACHE 2729) with a wire mesh base held in by cross wires (Moon, 1991; Nursery Staff, 1990; Moon et al., 1992; Holden, 1992). The soil mix commonly used is 2 parts sand, 2 parts perlite, and one part organic matter with slow release (12-14 month) Osmocote(17:7:12).

Plants are commonly grown in the pot for at least a year in a drip irrigated shade house, resulting in large plants with very well developed root systems. They can be held for several years if necessary. Before planting the tops are pruned to provide an excellent root/shoot ratio and to enable the container to be pulled up around the shoot during planting. Just before planting the screen at the bottom of the container is removed and the container is placed in an augered, wetted hole and carefully back-filled. The container is then pulled out using two hay hooks inserted in holes previously drilled in the top rim. The large volume of soil protects the roots during planting and the fertilizer and water provide conditions for rapid root growth.

Typical weight of 30-40 pounds per container limits transport distance by hand from vehicles and increases minimum crew size. A planting crew of 5 people can plant 50 plants per day under average conditions (10 plants per person per day). The cost per plant is high (~$10-25 at the nursery gate), but survival has generally been good and rapid growth following rains is common. Creosote bushes (*Larrea divaricata*) two or three years after outplanting may be 3 feet tall.

GOOD. Recommended for a small percentage of total plants. Provides a very tough plant with a larger shoot earlier than other methods. Proof against much bureaucratic and biological uncertainty.

Rolled film tubes

A recent addition to the container market is a rolled tube of plastic. These are made with recycled x-ray film stock after the emulsion/silver is removed. Very large quantities of this material are available at very low cost. The plastic can be taped or tied in a tube. This is very similar to the veneer tubes described by Goor (1963).

UNKNOWN

Block containers

Block containers are single, lightweight units that are easy to handle and have no individual cells or sleeves of cells that can become dislodged. The drawback to these systems is the inability to consolidate plants. They are most useful for plants that are well understood where very high quality seed is available. Styrofoam blocks made of expanded polystyrene foam come in a wide variety of container capacities, ranging from 2.5 to 30.0 cubic inches, and growing densities ranging from 25 to 103 per square foot. CFCs are not used in manufacturing Styrofoam blocks, but they can pose a disposal problem after their 5-7 year life is over.

The inherent insulating value of the foam can protects seedling root systems against extreme temperatures--a potential problem in both summer and winter in desert nurseries. Roots of some species grow into the pores in the cavity walls making the seedlings difficult to extract and the blocks difficult to clean and sterilize between crops.

UNKNOWN Tests now underway

Pots

Standard landscaping pots appear to work reasonably well for some species. Both ocotillo and cholla were planted out from standard 1 and 2 gallon pots. The ocotillo is deep planted so the limited depth of the container is not a problem. The cholla is so resistant to water loss that the small root mass also seems to be tolerable.

Conclusions

There is no one container or production system suitable for all conditions and species. Much will depend on the users involved and what is already available in the nursery and in the field. In general the tall containers will be more successful with desert plants. Plant bands are perhaps the first option to be considered. If plant production, planting and watering are under good control the smaller supercells will generally be sufficient. However, if there is any uncertainty involved in the project a medium size plant band may be much safer. A larger project may benefit from the use of a range of sizes with, 50% in supercells, 40% in plant bands, and 10% in tall pots. If conditions are favorable very low cost establishment of a large number of plants can occur, if conditions are very harsh a few from the smaller cells and most of the plants from tall pots might be expected to survive.

Soil mix experiments 1990-93

Growing desert plants in containers can be a challenging proposition. Many of these species have limited defenses against root rots, damping off, and other pathogens. In addition they commonly have higher oxygen demands than many traditional landscape plants. On the plus side desert plants are usually able to tolerate very large water deficits, creosote bush for example, may survive -50-60 bars of water stress, and irrigation can be less critical than for common commercial species. Developing a suitable mix for desert plants often requires experimentation and trials to ensure that the mix is appropriate for early growth and development and for long-term survival in the field.

The fit of the soil mix to the container, the plant species, the irrigation regime, and the operation of the nursery is essential. This fit includes both the physical, chemical, and biological properties of the mix. Almost all of the major ingredients (sand, perlite, pumice, vermiculite, humus, etc.) are natural materials (even if they have been cooked, expanded, etc.) and as such may vary sufficiently from batch to batch or source to source to cause problems in the plant production process.

While almost any soil mix can be made to work with sufficient attention to water and nutrient management the key is finding a mix that is forgiving and requires as little attention as possible. Species that are tolerant of a wide range of soil conditions may require little customizing, but species that are more sensitive may require careful mix development and nursery management. Maintaining a successful program may require careful attention to mix components as they come into the nursery and monitoring of pathogen or pest buildups in the nursery.

Several experiments have been conducted on the Ant Hill project in conjunction with the Joshua Tree Center for Arid Systems Restoration. We much appreciate the assistance of Carol Miller, Mark Holden, and Bob Moon.

1991 Preliminary Trial

One of the problems of a sand rich mix is the weight, almost 50 pounds for a rack of 98 supercells. This first series of comparisons looked at a variety of amendments that could reduce the weight of the mix. This contrasted 7 mixes with two species (*Larrea divaricata* and *Ambrosia dumosa*) , including: sand, sand and large bark (1:1), sand and small bark (1:1), sand and rice hulls (1:1), perlite and sand (1:1), moisturelite, a pumice, and sand (1:1) and Supercell mix, a modification of Joshua Tree's standard tall pot mix (7 sand:7 perlite:1 humus & Osmocote slow release fertilizer). The modification of the Joshua Tree soil mix was made after leaf tissue analysis of previous AHD plants grown in their standard mix revealed total Kejldahl nitrogen levels of 16-68 ppm (normal field levels 10-20) and phosphorus levels of 3-20 ppm (normal 1-2). A sample of the plants were evaluated and analyzed as they were received for root and shoot health and growth and then planted in a field trial at the Ant Hill.

After 414 days the overall survival of bur sage was 53%. By mix survival was 100% in sand, 66% from SCMix, and 33% for perlite, ricehull, and pumice mixes. Overall survival of creosote bush was 10%, with 50% survival in the SCMix. While plant numbers are low (n=2-4) the differences suggested that the best soil mixes might be pure sand or SCMix for *Ambrosia* and SCMix for *Larrea*.

1992 Field experiment

The clear differences in the 1991 study led to a larger field study comparing soil mixes that looked promising. Plants were grown in 6 cm x 6 cm x 41 cm tall cardboard plant bands at Joshua Tree. They were started in early Spring. The creosote bush was grown in sand/pumice/*Larrea* sand (7.2:1.8:1), SCMix, sand/pumice (4:1), sand/*Larrea* soil (9:1), and pure sand. The *Larrea* sand was collected from beneath a healthy plant at the Ant Hill and banded into the containers at approximately 1/4 of the way down from the top. The bur sage was grown in sand/vermiculite (1:4), SCMix, sand/pumice (1:4), pure sand, and Borrego Valley Growers mix (a very organic matter rich mix).

Plant bands other than SCMix received a liquid fertilizer Dynagro (1.25 tsp per 2 gal) twice weekly, intended to provide a moderate amount of N (50 ppm) and P (25ppm). Plain water was used for the other two irrigation's per week.

Plants were moved to Borrego Springs in July and a random sample of plants were taken for analysis at SDSU. Five plants from each treatment were removed from plant bands, root and shoot length and caliper were measured, and plants were evaluated for health and vigor on a scale from 0-4 (dead-excellent). Plant mixes revealed substantial differences:

Table 1. Soil mix comparison

	Av. rating	Length, cm Root	Shoot	R:S	Caliper, mm
Ambrosia					
Sand/vermiculite	4	40	25.3	1.6	3.4
SCMix	4	42	32.5	1.3	3.6
Sand/pumice	4	40	27.9	1.4	2.8
Sand	3.4	40	26.3	1.5	2.7
BVG	2.6	40	11.0	3.6	1.8

Larrea					
Sand/pumice/larreas	3.8	40	10.7	3.7	1.7
Sand pumice	3.6	40.4	10.7	3.8	1.4
SCMix	3.8	41.8	19.2	2.2	2.9
Sand	4	40	7.6	5.3	1.7
Sand/larrea sand	4	40.7	11	3.7	1.6

Plants were held at the BVG nursery until planting in early Spring 1993. They were planted in several blocks in disturbed areas at the Ant Hill. After 111 days the results were as follows, Table 2.

Table 2. Soil mix survival

	n	Starting Av. rating	R:S	Percent survival
Ambrosia				
Sand	3	1.5	1.5	100
Sand/vermiculite	16	2.3	1.6	69
Sand/pumice	12	1.8	1.4	67
Sand/pumice/jellyrolled	11	2.3	1.4	64
SCMix	13	1.3	1.3	69
Larrea				
Sand	10	2.8	5.3	100
Sand/larrea sand	15	2.5	3.7	80
Sand/pumice	14	2.3	3.8	79
SCMix	13	2.4	2.2	77

Discussion

The results suggest that using a pure sand mix may be reasonable. It would be the lowest cost and provides good survival for both species. The addition of vermiculite and pumice may reduce the sensitivity of plants to irrigation scheduling. Unfortunately there is no perfect mix and the actual performance of a soil mix will depend on a number of factors, some not under the control of the nursery or transplanting crew. Only 3 sand only Larrea survived the 6 month holding period at the Borrego Valley Growers, the high root:shot ratio may be a significant factor in improved survival.

Plant handling

Outplanting seedlings will be an important element of almost every desert restoration project. Data on planting rate and cost were maintained. The planting rates varied widely depending on temperature, wind speed, volunteer or paid labor, soil moisture, and the difficulty of the site. Typical costs and planting rates are shown in table 6.1.

Table 6.1. Container costs and characteristics

Container type	Cost	Other source	Wt. Lbs	Wt rack(#)	Per pers.day
Supercell	0.09	to 2.75	0.5	45 (98)	70-100
Supercell jellyroll	0.10			44 (1000)	100-200
Plant band 1.5x1.5x16	2.70		2	125 (30)	40-50
1 gallon pot	3.25		7		50
2 gallon pot	5.50		14		40
3" pipe	3.15		8		sawed out 10
6" Tall pot	8.70	25.00	30-40	800 (20)	10

Although many of the dominant trees and shrubs of California's deserts are relatively easy to grow in a nursery, container grown seedlings are heavy and awkward to ship and handle in the field, making outplanting expensive (Bainbridge and Virginia, 1990). The economics can be improved by utilizing "jellyrolling, a technique which decreases shipping and handling costs without significantly reducing survival.

"Jellyrolling", or wrapping bare-root tree seedlings in moist fabric for shipping, has been widely used in forestry for nearly a century (Laird, 1992). Jellyrolling was experimented with during the Ant Hill desert revegetation project because it has the potential to greatly reduce the weight, bulk, labor, and costs associated with transportation and handling. This is important for a remote site where most of the water must be trucked in. While a rack of 98 sand filled super cells weighs almost 50 pounds, an ice chest holding 1000 jellyrolled plants and ice may weigh only 30 pounds, a significant decrease in weight and volume per plant.

Jellyrolling increased planting speed and efficiency. Workers are usually fatigued and less efficient in the hot and dry conditions of desert planting sites making it important to minimize field labor. Jellyrolled seedlings require less handling, thus, fewer workers working less hours are needed to plant the same number of seedlings. Preliminary field studies suggest that planting desert shrub seedlings from jellyrolls is 1.5-2 times faster than planting from supercells.

Removing plants from their containers is one of the most time consuming processes of any outplanting technique. Jellyrolling is advantageous in that the seedlings are removed at the nursery where the job can be completed more quickly and efficiently. Jellyrolling requires some extra labor at the greenhouse, but workers can work comfortably and efficiently at a bench top in the nursery setting. The extra labor at the nursery is compensated for by labor savings experienced in the field.

To be suitable for arid land revegetation projects, jellyrolling must provide suitable protection from root desiccation and damage. Deans et al. (1990) found that root growth of Sitka spruce bare root seedlings was reduced 59% by desiccation, 85% by rough handling, and 98% by a combination of the two. Similar reduction of root growth would result in complete failure of a desert outplanting operation where quick root growth is the key to plant establishment.

Preliminary outplanting survival data for jellyrolled seedlings compares favorably to containerized plants. Several plantings of the jellyrolled *Ambrosia dumosa* and *Larrea tridentata* were compared to seedlings planted from containers to determine field success. After 45 days, survival of jellyrolled *Larrea* was not significantly different (p>>.20) than *Larrea* outplanted from containers. This result has subsequently been confirmed in other tests at Red Rock Canyon State Park. Not all species are as responsive to jellyrolling, brittle roots, or easily torn fine roots, appear to be an indication of risk in jellyrolling.

Larrea inoculation/fertilization 1991

This experiment used 300 *Larrea* from supercells to evaluate possible benefits and costs of using fertilizer, soil inoculum, or litter with transplants in these low fertility soils. There has been considerable interest in the benefits of mycorrhizal fungi in plant establishment in arid lands. *Larrea* has demonstrated an apparent response to inoculation in previous studies (Sheps, 1973); but it is not still not certain if it is a facultative or obligate mycotroph.

The experimental design

Seedlings from supercells were planted out on January 22-23, 1992 with standard planting methods (Bainbridge et al., 1993). Each seedling received a 20 cm treeshelter and approximately 1/2 liter of water. The plants consisted of 2 age cohorts, here designated as 'old' and 'young'. Five different treatments were applied to each age group. These treatments involved addition of particular soil amendments to the planting holes just before the seedlings were planted. A randomized complete block design was used with 4 blocks of 75 plants each.

Each block consisted of 45 ‘old’ plants and 30 ‘young’ plants with equal numbers receiving each of the 5 treatments. This resulted in a total of 24 ‘young’ and 36 'old' plants per treatment (6 ‘young’ and 9 ‘old’ per block). ‘Old’ plants were started at Joshua Tree between August 20, 1991 and October 6, 1991, making them approximately 3 1/2 to 5 months old at outplanting. 180 were put into the field experiment and 20 were harvested in order to assess initial condition and size at outplanting. 'Young' plants were started at Joshua Tree on November 26, 1991. 120 plants were planted for the field experiment and 20 were harvested in the lab.

Treatments included addition of fertilizer, plant litter from beneath mature and healthy *Larrea*, addition of biota rich soil (soil inoculum) from beneath mature and healthy *Larrea*, addition of sterilized soil inoculum, and no amendment. These amendments were added to the bottom of planting holes.

For the fertilizer treatment, approximately 30 cc, with a dry weight of approximately 27 g., was mixed in with loose soil in the bottom of each planting hole. The fertilizer used in the experiment was 'Bandini Citrus Food' with a guaranteed analysis of: Total N 6%; 5% ammonical N; 1% water soluble urea; Available phosphoric acid (P_2O_5) 10%; Soluble potash (K_2O) 6%; Calcium (Ca) 7%; Sulfur (S) 7%; Iron (Fe) 1.50%; Manganese (Mn) 0.12%; and Zinc (Zn) 0.12%.

Litter was collected with a rake from beneath mature *Larrea* shrubs. This was thought to be a potential source of mycorrhizal inoculum as well as organic matter. 60 cc or approximately 45 g (dry weight) was added to the bottoms of the planting holes.

The soil used as a soil inoculum had been collected from a depth of 0-.5 meters from beneath 2 mature *Larrea* shrubs the week before outplanting (*wear a mask for any handling of soil or litter due to risk from coccidioidomycosis, Valley Fever, see Appendix 3*). Soil collected in a similar fashion had been shown previously to contain a large number of mycorrhizal spores. Soil from beneath mature shrubs also contains higher concentrations of N, P and other nutrients. The soil was mixed well and half was sterilized in a steam sterilizer. Sterile soil was included so that the effects of adding soils organisms could be distinguished from effects due to the higher nutrient content of the soil used for inoculum. Approximately 170 g (dry weight) of soil was added to each hole for these 2 treatments.

Plants in blocks 1 and 2 were planted on the 22nd but not watered until the 23rd when each plant was given 1 liter of water in the tubex. Blocks 3 and 4 were watered the same day thay were planted (the 23rd). All plants had treeshelters placed on them for protection from windblast, trampling and grazing by small mammals.

The 20 'old' and 20 'young' plants kept in San Diego to be harvested and described as representative of the stock planted out in the field were not harvested until 2/4/92. At this time the plants had grown and become somewhat more vigorous than the plants put out in the field. The tops were removed and the height, condition, number of leaves and basal diameter were recorded. The roots were separated from the container mix and measured and rated. The initial size and condition of the plants was almost identical for the 'old' and 'young' age classes. The roots of most of these plants were very fragile and showed signs of being too wet. Many of the containers of soil mix smelled mouldy. The perlite also had green algae growing on it in some cases. Osmocote could be seen in the mix as well.

Results and discussion

Plants were monitored for survival and plant condition. They were watered twice with one liter of water each time. Planned additional irrigation was not possible due to illness of field worker. Initial survival was good for all treatments. The majority of deaths occurred between the end of May and November. Blocks 3 and 4, covering the upper road, the deep sandy soils below the road and the more rocky, steeply sloped area above the road, had higher mortality than blocks 1 and 2 which were planted on hill climb 4.

Plants from the 'old' age class had slightly higher survival rates than plants from the 'young' age class. Survival over all treatments for each of these age classes was 33% and 21% after ten months. The long term survival was lowest 20% for the fertilizer treatment and highest 33% for the litter and control treatments. The sterilized soil inoculum survival was higher than the plain soil inoculum which suggests there was no inoculation effect. The health rating for surviving fertilized plants was higher 3.2 than any of the other treatments (range 2.4-2.6).

Treatment effects were limited and not statistically significant. The litter, control, and sterilized soil treatments had the highest survival. The reduced survival with soil inoculum may reflect pathogens in the soil, lack of mycorrhizal infection or that the mycorrhizal association itself represents enough of a resource drain to reduce survival when water is severely limiting. Fertilizer produced the lowest survival but the healthiest looking plants. This may also represent the problem of plant resource allocation under severe moisture stress. The higher fertility may have increased shoot growth sufficiently to stress the plant more than the low nutrient applications.

Survival was good given the low input level and minimal maintenance provided for these plants. Ideally water would have been provided 4 or 5 times rather than just twice, this should boost survival to better than 60-70%. This might elicit different responses to these treatments.

Species trials

Desert lily 1992

While most of the research has been on relatively well understood shrubs such as *Larrea* and *Ambrosia* it was felt that the application of these planting methods to other species would be instructive. Seed from Desert Lily (*Hesperocallis undulatus*) was collected in 1991 and used to start supercells at Joshua Tree National Monument in October 1991.

Experimental design

In February 1992 100 desert lilies in supercells were transplanted into a completely randomized plot with four treatments: TUBEX treeshelter, Water, Water and fertilizer, and control. These were planted in a sandy area with some volunteer seedlings and 25 of these volunteers were flagged to provide a comparison of transplants v/s native plants. The fertilizer treatment included dry fertilizer (10:10:4 and micros). This was mixed into the soil at the bottom of the planting hole. All plant received approximately 1/5 liter of water.

Results and discussion

Unfortunately the desert lily bulbs were a preferred food for rodents. After one month only one of the volunteers had been eaten but the transplants had been decimated. 88% of the no water, 100% of the fertilizer and water, and 88% of the water only plants were gone. Almost all of these were still fresh holes from digging. 12% of the TUBEX plants were still green compared to 72% of the volunteers.

Careful digging of volunteer seedlings showed that the bulbs were deeper and smaller. The plants from the greenhouse were richer in nitrogen and the bulbs were more accessible. Some evidence from studies at the Ant Hill has demonstrated a possible increased grazing risk from elevated nitrogen levels in plants. The TUBEX plants were not eaten but had gone dormant earlier and probably had little chance for survival. A tall plant band would be recommended for future planting with a low nitrogen soil mix. More water would also be recommended for future plantings.

Ocotillo 1992

Ocotillo (*Fouqueria splendens*) is often planted from cuttings but the form of these plants is rarely comparable to seedlings. Seed was collected by placing nylon stockings on ocotillo in the Ant Hill. This seed was used to start supercells at Joshua Tree National Monument in December 1991.

Experimental design

In February 1992 96 ocotillo seedling in supercells were transplanted in a paired plot design with two treatments: TUBEX treeshelter (20 cm tall) and control. These were planted in areas where existing ocotillo were growing or where ocotillo stumps were found. The planting pattern is shown on the accompanying map. All plant received approximately 1/2 liter of water at planting. .

Results and discussion

Although ocotillo is a hardy desert plant it responds well to increased moisture and fertilizer. Nursery grown seedlings are almost unrecognizable with large leaves and almost succulent appearance. The seedlings planted out in this experiment were very small with typically only two small leaves and a short stem (3-5 cm tall). After one month all of the plants were still alive. The condition of the treeshelter plants was significantly better, averaging a rating of 3.0 v/s 2.5. After one year 90% of the plants with treeshelters were alive, v/s 18% of the controls. In addition the rating of health was significantly better 3.4 v/s 2.4.

The treeshelters (TUBEX 20 cm) were very important for survival of the ocotillo seedlings and would be recommended for all future plantings. Growth was very limited and it appears likely that the taller ocotillo plants seen in the field are very old. Future experiments should explore the use of tall pots or plant bands to grow bigger seedlings before outplanting.

Ocotillo plants grown from cuttings have also been planted at the site. All plants on buried clay pots planted in 1990 have survived with intermittent irrigation. Many ocotillo plants from cuttings were planting in spring 1993. Root balls on the plants from cuttings are very weak and many roots were lost in transplanting. Many plants still had green leaves in June and good long term survival is anticipated if intermittent irrigation is possible the first two years.

Plant protection

Rock mulch, peat collars, and treeshelters were used for plant protection. No detailed comparisons were done between methods, but some 2 way comparisons with controls were done.

Treeshelters

Preliminary studies with Tubex™ Treeshelters have demonstrated improved plant establishment and growth for transplants in the desert protected by these treeshelters (Bainbridge et al., 1991b). Microclimatic conditions in these shelters and protection from wind and herbivore damage probably account for some of the beneficial effects (Potter, 1991; Potter, 1988; Frearson and Weiss, 1987). The following graph compares survival of species in a series of trials in the low desert.

Peat Collars

Peat collars were evaluate in a paired trial near the north water tank. 24 *Larrea* seedlings were planted on 4/7 and watered twice. After 44 days there was no difference between collars and non-collar plants, but after 187 days only plants with collars were still alive. Peat collars were also placed on Indian rice grass and bur sage. Some survivors were seen in the second year.

Irrigation

The benefits and timing of different methods of supplemental irrigation were also tested. Early watering, within 2-3 weeks of outplanting and watering in summer is most important--yet most difficult. The excellent survival of the supercell plants set out in April 1991 is in due to watering with only one liter per plant once in July, August, and September.

Deep pipe irrigation improved survival in the major test, even with very limited irrigation. Non-experimental plants put in during 1990-91 in the Hill Climb 2 area had excellent survival, with virtually all surface irrigated plants dead and all deep pipe plants still alive in 1993.

One of the key advantages of the screened deep pipe is efficient watering. Water delivery only 5-10 seconds per pipe versus 60-90 seconds for surface basins. A drawback to caps is the time required to remove the cap for filling the pipe and the risk of having the cap left off or blown off, creating a hazard to wildlife. Cardboard tubes were tested but degraded too rapidly. Bamboo or rolled plywood veneer may provide similar benefits from a biodegradable tube.

Treeshelter and Irrigation 1991

The first large field experiment was established to test the effects of treeshelters and deep pipe irrigation in road scars and other denuded areas at the site. Treatments included seedling protection using solid tube treeshelters (Tubex) and irrigation with vertical pipes placed to deliver water about 30 cm below ground. Three plant species were included in this experiment: *Larrea divaricata, Ambrosia dumosa* and *Atriplex canescens*. Most of the seedlings were grown in supercells with the addition of some *Ambrosia dumosa* seedlings which had been grown in larger containers, either 2" diameter x 18' tall PVC pipe or 3" diameter x 12" tall rolled newspaper pots. Seedlings were outplanted in April, 1991.

Individual treeshelters are especially appropriate for arid regions where plants occur widely spaced apart making fencing prohibitively expensive for most revegetation projects. Because the cost of transplanting is already high, the additional cost of treeshelters can be overcome if they provide even modest increases in survival percentages. Costs of watering may also be reduced because treeshelters reduce the desiccating impacts of wind.

The deep pipe irrigation involved placing a PVC pipe vertically in the ground to a depth of 30 or more cm. This system for watering is especially useful for remote sites where water must be brought in by truck and/or carried. Water is delivered to the rooting zone of the plant and by getting the water a few inches beneath the surface, evaporation will be reduced. Less water should be needed for establishment as it will be used more efficiently.

Treatments were assigned in a completely random design. Each treatment was replicated 11-13 times. The planting was done at approximately 1 meter spacing in the tire tracks of two sections of road showing significant compaction and little or no natural vegetation recovery. Soils ranged from sand to loamy sand in texture.

Deep pipes for irrigation were installed using a treeplanting auger with a 2" diameter bit. The bottom of the pipe was set at approximately 14-16" below the ground surface with 2-4" protruding above the ground. The treeshelters (TUBEX) used in this study are 8" tall and 3 1/4 to 4 1/4" diameter brown, twin-walled polypropylene, UV stabilized to last 5-7 years under northern conditions. Light transmission for the brown TUBEX used here is specified at 27%, but no data on %PAR admitted by the treeshelters was found in the literature. Following planting treeshelters were placed over seedlings designated to receive a treeshelter and then pushed down so that the bottom of the shelter penetrated the soil surface. Some soil was also placed around the outside of the shelter bottoms to ensure a tight seal which would allow water to be poured into the treeshelter and directed to the root zone with minimal lateral flow at the surface. Plants which received TUBEX but no deep pipe were watered by pouring water into the treeshelter. Plants which had deep pipes with or without TUBEX were watered through the deep pipe. Plants without deep pipes or TUBEX were watered by making a very small basin to hold the water near the plant and slowly pouring the water so that it had time to infiltrate before running over the surface away from the plants. Plants were given 1 liter of water shortly after planting on April 25-26, 1991. Plants were again given 1 liter of water on July 5, 1991 and August 8, 1991. Plant growth and survival has been assessed on 8 dates since the initial planting.

Results and discussion

Almost half of the plants were still alive in late November, 1992. For *Larrea tridentata* and *Ambrosia dumosa* height, basal diameter, and the ratio of height:basal diameter all responded to the treeshelters. Treeshelter plants in the field had higher survival and growth rates over the first summer for all species. By the end of the second summer in the field all *Atriplex* in the no treeshelter treatment groups had died. For *Larrea*, survival percentages for all treatments were relatively high while *Ambrosia* suffered greater than 50% mortality for plants without either treeshelter or deep watering treatments. Survival of the *Ambrosia* and *Larrea* seedlings was improved with deep watering.

In all cases initial height increases in the first months after outplanting were greater with treeshelters while deep watering alone did not increase height growth. This pattern was maintained for *Ambrosia* over the almost 2 years of monitoring while only the combination of treeshelters and deep watering produced long-term height increases for *Larrea*.

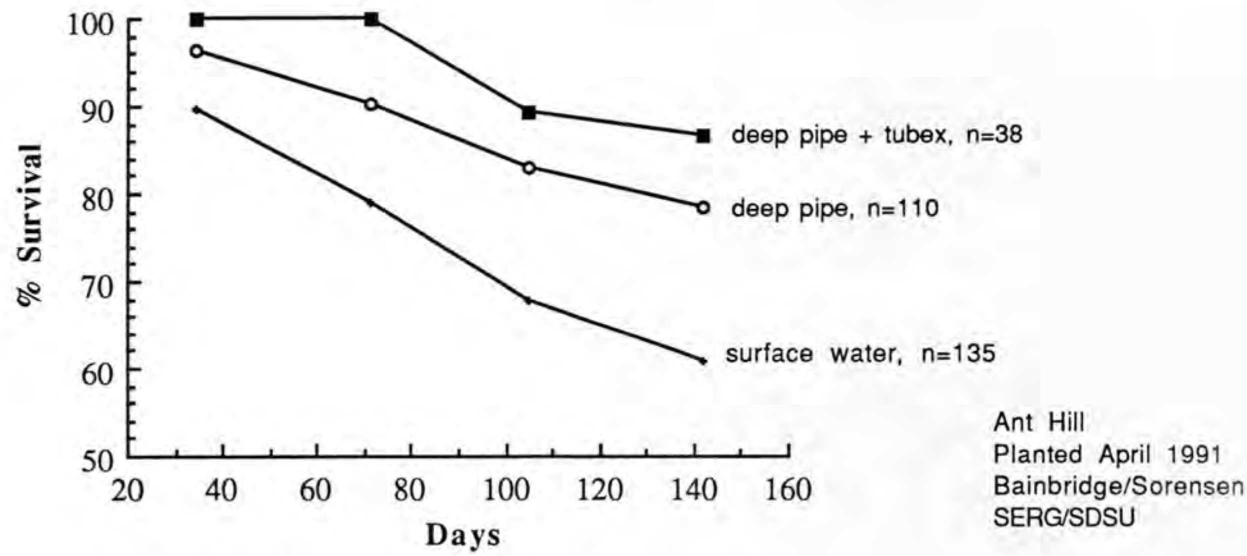


Figure 6-2. Deep pipe irrigation benefits for plants from supercells at the Ant Hill

Contrary to our expectations, the low rates of transpiration of these desert plants and increased temperature in treeshelters resulted in a daytime decrease in relative humidity around establishing plants. In addition, plant water potential was not improved by treeshelters. Significantly reduced light levels are thought to be the major factor causing decreased total biomass for plants in treeshelters relative to plants without treeshelters which received the same level of nutrient addition. During the summer months when direct sunlight may reach plants in the treeshelters and once plants grow tall enough to get above the treeshelters light will no longer be such a limiting factor. The use of treeshelters during the first weeks following outplanting and the use of treeshelters which admit a greater proportion of available light could provide significant benefits for plant establishment in arid regions but over longer time periods their effects could be detrimental.

Treeshelter and nutrient interactions

A number of plants were grown in tall pots in San Diego where more intensive monitoring of growth and physiology could be done.

Experimental design

This experiment was set up at SDSU in an effort to better understand the effects of treeshelters on desert plants. Controlled nutrient levels, water, and a single treeshelter diameter enabled more intensive and controlled monitoring. It also made it possible to examine the effect of treeshelters and nutrient addition on the growth and allocation patterns of Larrea. 1 species X 2 nutrient levels

X 2 tubex treatments (+/-) => 4 treatment combinations in a balanced 2x2 factorial. If, as hypothesized, treeshelters reduce water stress then nutrients may in fact become more limiting. The addition of nutrients to plants grown in TUBEX would then be expected to provide an additional growth benefit. The use of pure sand as the container mix facilitated root harvest and made more accurate determination of allocation possible.

The treeshelter environment was characterized by marked differences in light, temperature, relative humidity and water vapor pressure deficit of the air (VPD) relative to conditions outside the treeshelters. Averaged over the year just over 50% of potential photosynthetic energy will reach the midpoint of the treeshelter.

Daytime air temperatures were also increased by treeshelters. Differences of 5-10°C from ambient conditions outside treeshelters were consistently found even in San Diego. Relative humidity (RH) in the shelters generally fluctuated around the levels measured outside shelters, but occasionally dropped well below outside RH. A better measure of the drying power of the air is provided by the water vapor pressure deficit of the air (VPD). Daytime VPD in treeshelters was consistently higher than that outside the treeshelters.

Air temperature and VPD were considerably higher in treeshelters. Leaf temperature and LAVPD, however, were similar when plants were well watered but as plants began to dry out leaf temperature and LAVPD in the treeshelters began to increase. These results are consistent with those of Wallace and Romney (1972) who found that leaf temperatures in *Larrea* are generally similar to air temperatures but can be substantially reduced by irrigation. No strong CO_2 concentration gradient within treeshelters was detected. High nutrient-treeshelter plants had a daily average CO_2 concentration below ambient CO_2 while low nutrient treeshelter plants had a mean daily CO_2 concentration identical to ambient air.

Both nutrient treatment and treeshelters affected the allocation of biomass between roots and stems/shoots. Treeshelter plants had lower root:shoot ratios at both harvest I and harvest II regardless of nutrient treatment. The effects of nutrient addition on root:shoot ratio changed over time, however. After 139 days of growth under the treatment regimes the high nutrient plants had higher root:shoot ratios than the low nutrient plants. This pattern was reversed after an additional 7 weeks of growth. Over the 7 weeks between harvest I and harvest II the high nutrient plants, with and without treeshelters, allocated almost all additional biomass production to above ground structures. This resulted in a large change in root:shoot ratio for these plants between harvests I and II. Additional production of low nutrient plants between harvest I and II was distributed fairly equally between above and below ground components, although production overall was minimal for the no treeshelter plants. At the end of the experiment the low nutrient treatment produced plants with higher root:shoot ratios.

Leaf turnover was quite high. High nutrient plants had greater leaf turnover over the first 139 days of the experiment than low nutrient treatments. Treeshelters did not clearly affect leaf turnover. High rates of leaf turnover have also been reported for *Larrea* in the field (Nude Wash, Anza-Borrego Desert State Park, Nilsen et al., 1984), with complete leaf turnover occurring between years and over 70% leaf turnover between July and October.

Foliar N and P concentrations of the initial *Larrea* planting stock outplanted to the Borrego field site were 26 mg/g N and 5.6 mg/g P. After 1 year in the field foliar N and P concentrations for these field plants had declined substantially. Foliar nutrient values for a mature *Larrea* sampled on each date were comparable to the values obtained for plants without treeshelters. High nutrient plants did resorb a considerable amount of both nitrogen and phosphorus from senescing leaves. More than 50% of foliar N was resorbed by the high nutrient plants.

The fact that all of the container plants were given the same amount of water and/or nutrient solution over the course of the entire experiment has important implications for interpretation of studies of growth, morphology, and function. Because the low nutrient treatment plants were considerably smaller than the high nutrient treatment plants they utilized much less water and never experienced substantial drought stress between irrigations. The large differences in plant water potential that existed between high and low nutrient treatments may have confounded the effects of nutrients on physiology. Plant moisture status was not improved by treeshelters as expected. Pre-dawn (Ψ_{pd}) and midday (Ψ_{md}) plant water potentials were not affected by the treeshelters for either the container or field plants. The large nutrient affects on plant water status also reflected differences in plant size and availability of soil moisture rather than a more conservative water use strategy. Plant water relations of fertilized field plants or transplants grown under various nutrient levels in containers and outplanted would face conditions in the field of limited moisture availability and severe competition for available resources. Therefore they might show a considerably different pattern of water stress and water use than that found for the container plants here. Water-use efficiency (WUE), based on both gas exchange measurements and $\delta^{13}C$ values, further demonstrated that plant water relations were not improved by the treeshelters.

Effects of Nutrient Addition in the Nursery on Outplanting Success

A subset of these plants, which received either high (1/4 strength Hoagland's solution) or low (1/40 strength) levels of nutrient solution, were outplanted at the Ant Hill on November 15, 1992. Plants grown in high nutrient levels were anticipated to have reduced root:shoot ratios. Nutrients also interact with other plant adaptations to stress and the potential for survival in the field of plants receiving high nutrients levels in the nursery may be lower. Additionally, 6 plants grown in tall pots at Joshua Tree National Monument were included at outplanting as a comparison. In total 21 plants from tall pots were planted out in the tire tracks of the road behind hill climb 3.

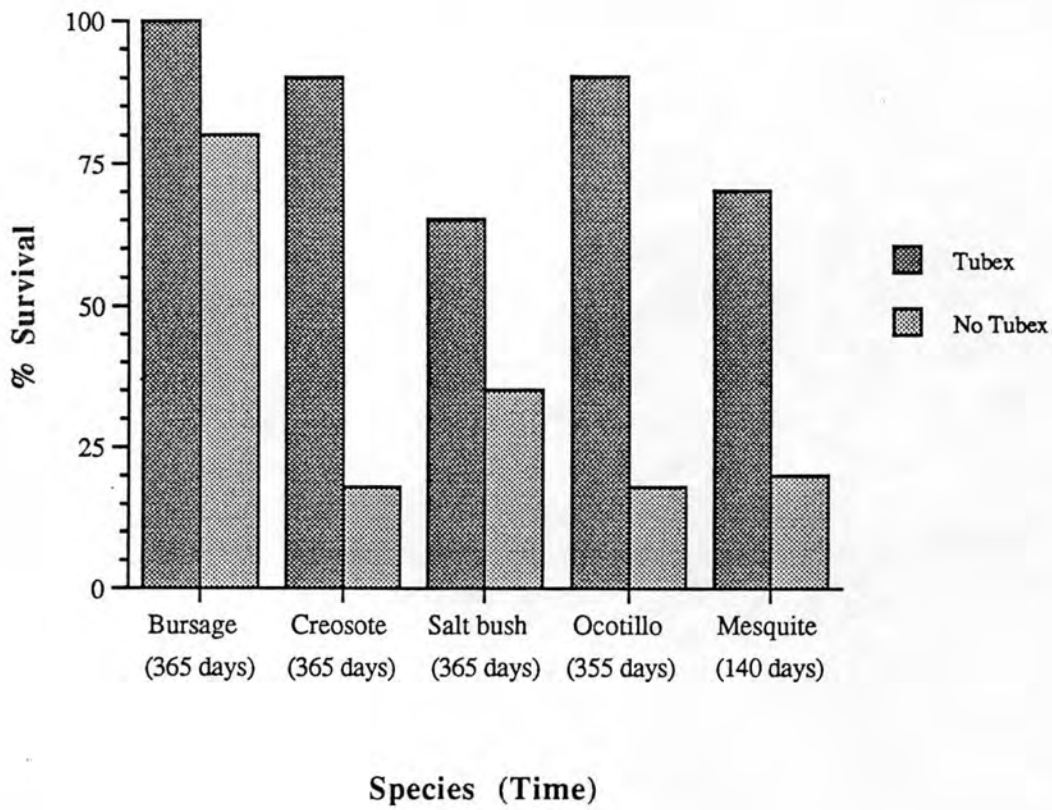
Results and discussion

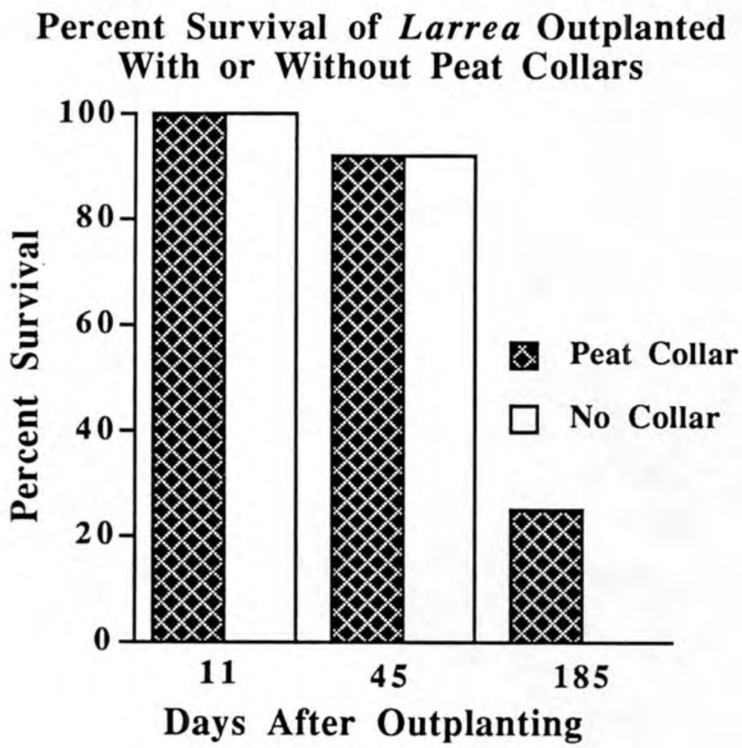
Measurements of height, basal diameter and volume have been made for these plants. All of the plants from the container experiment which were outplanted to the field were still alive and in good condition 4 1/2 months later. Pre-dawn plant water potential measurements 12 days after outplanting showed water status for the high nutrient treatment plants, -1.8 ± -0.1 MPa was better than the low nutrient treatment plants, -2.3 ± -0.2 MPa (means ± 1SE, $p<.05$, t-test). A subjective rating of plant appearance rated all high nutrient plants in very good to excellent condition but 75% of the low nutrient plants were rated as only fair to good in appearance. High nutrient plants also exhibited higher growth rates over the first 4 months in the field. For the high nutrient plants the mean length of the longest branch increased 7% and mean basal diameter increased 22% between initial measurements 2 weeks after outplanting and measurements taken at the end of March (4 months later). Over the same period mean branch elongation for low nutrient plants showed only a 1% increase while mean basal diameter increased only 3%. Long term monitoring will show if the greater growth is a benefit or risk.

Summary

The research program involved many of the key questions of desert revegetation. There were clear answers to several questions, but several studies (such as the Treeshelter study in SD) introduced new questions that were not answered. The overall experience has been positive and advanced the knowledge about revegetation and restoration of these severely disturbed sites. The general approach remains: transplanting with excellent plant protection and supplemental irrigation. Other information on restoration is presented in part 8.

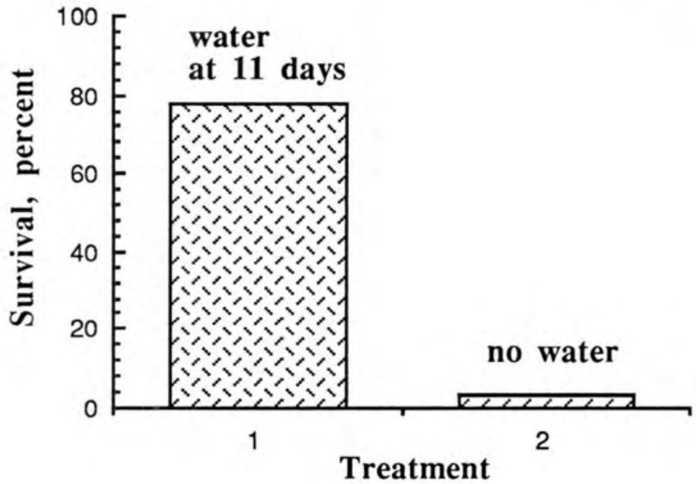
% Survival of Species Planted With and Without Tubex



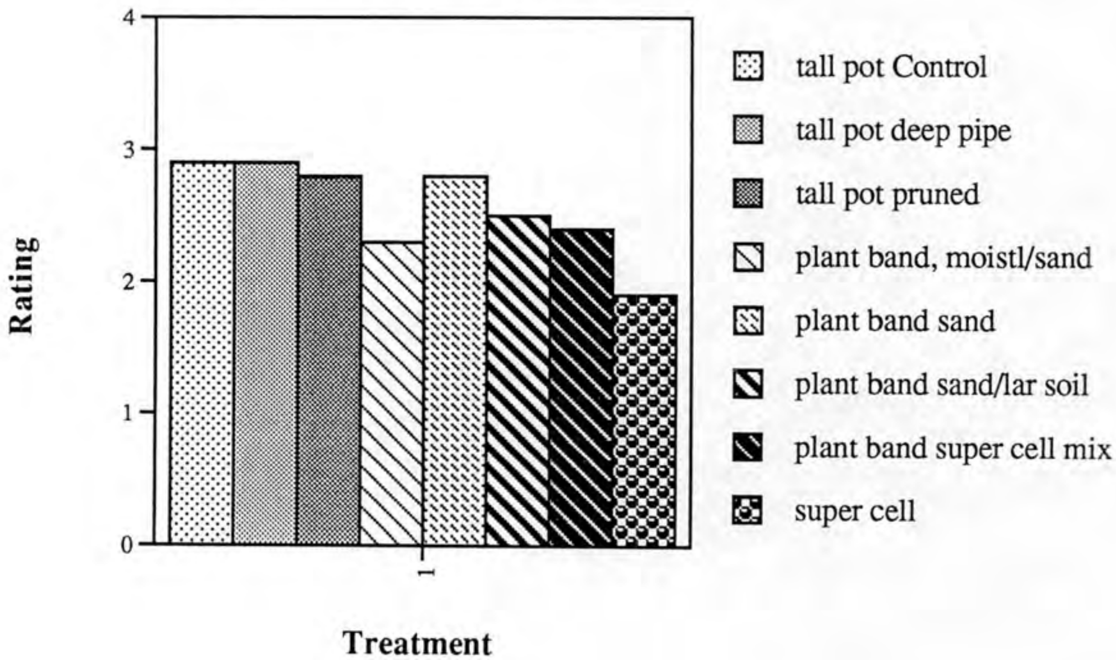


Percent Survival of *Larrea* Outplanted
With or Without Peat Collars
Percent Survival
100
80
60
40
20
0
Peat Collar
No Collar
11
45
185
Days After Outplanting

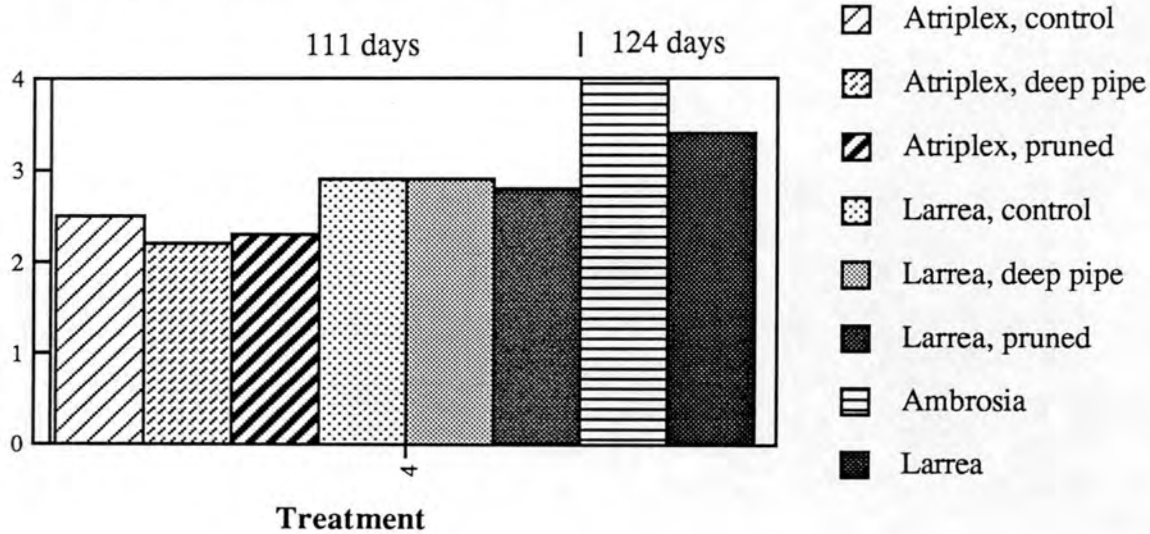
The importance of early irrigation,
Ambrosia from supercells with collars



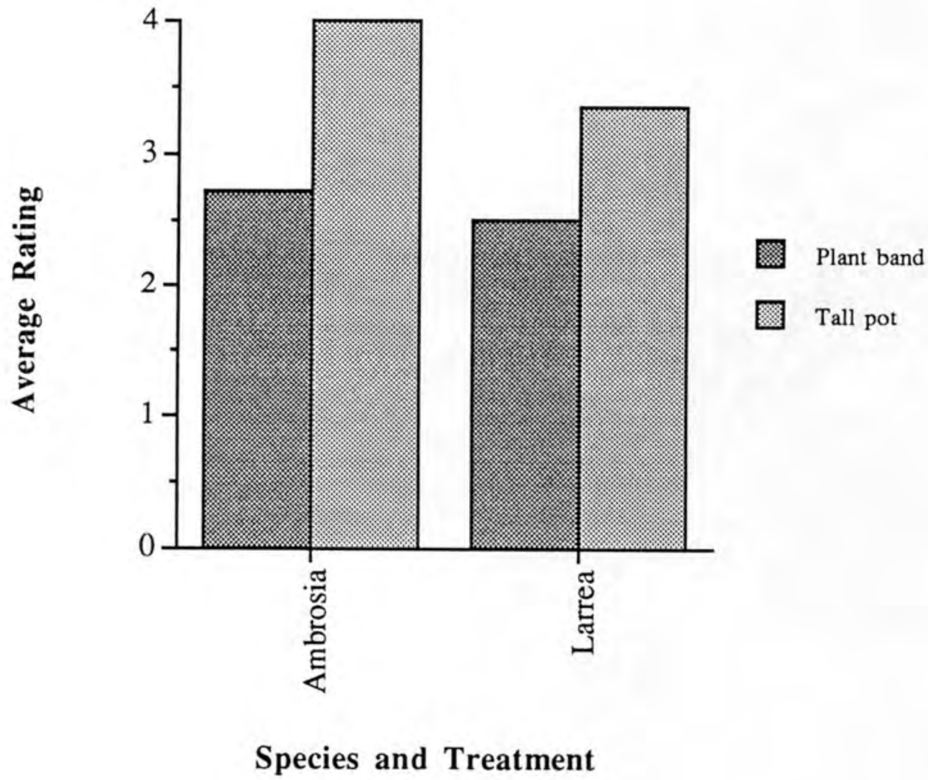
Container comparison, Larrea
111 days Ant Hill ABDSP



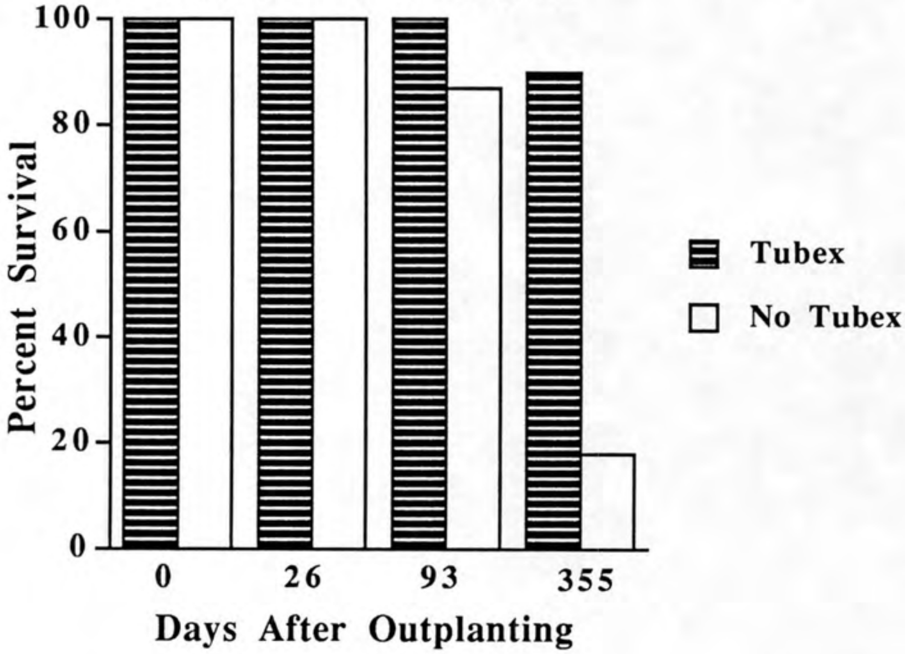
Tall pot, plant ratings Ant Hill



Average Health Ratings of Species Outplanted from Plant Bands and Tall Pots After 59 Days



Percent Survival of Ocotillo Outplanted
With or Without Tubex



Part 7. Future work

While much has been done to improve the recovery of the Ant Hill site, much remains to be done. The development of a permanent corps of restoration volunteers for the park would be useful, not only for the Ant Hill site.

The following recommendations are prioritized:

Fencing

Signing and fencing should be placed on the south side to discourage riders from Rainbow Wash. The western fence is nearly buried with sand in places and should be monitored occasionally.

Cleanup and removal

The deep pipes, treeshelters, and cages now in place will be removed in Fall 1993 and Spring 1994. The catchments will be left in place. The park signs prohibiting ORV activity on specific hill climbs could be recycled out of the project area.

Seed collection

Seeds should be collected by park staff, volunteers and project staff as time and funding allow. Emphasis should be placed on developing a collection of some of the common plants that would be useful for seeding and replanting the remaining bare areas. *Croton, Tiquilia, Oryzopsis, Hilaria,* and *Psorothamnus* would all be good candidates. Annuals could also prove useful.

Soil preparation and ground shaping

Garden forking the remaining bare spots and roads appears to be worthwhile. Easily eroded areas and large barren areas should be pitted periodically (every two years until plants establish). Bark or wood chunks should be added to the pits where possible. Gully erosion check dams are effective and many days of dam building could be done. These physical treatments are good activities for volunteers.

Direct seeding

Most of the remaining seed will be placed in early Spring 1994. An ongoing direct seeding program in conjunction with garden forking is recommended.

Transplanting

Transplanting medium size plant bands (2x2x16") with plant protection and early watering will be desirable. The emphasis should continue to be on *Larrea* and *Ambrosia*, with *Psorothamnus* added if seed can be obtained. It would be desirable to conduct further tests on transplanting *Oryzopsis* and *Hilaria*. The north road and north east road would be logical areas for future planting.

Research

The basic research already conducted at this site makes it an excellent site for follow-up studies. It should be considered as a test site for establishing a long-term ecological research program in the park. The plant document and a related information bulletin could be provided to institutions in Southern California to attract new research in restoration ecology to this site.

Research on the following topics is suggested:

- the effects of bark, wood chips and vertical straw bundles on soil recovery
- a detailed study of the benefits of ripping and garden forking on annual establishment
- the use of annual vegetation plugs for reactivating denuded areas
- herbivory and clipping/clearing by mammals and lizards
- the effects of pitting and amendments of soil moisture and plant establishment
- the effects of incorporating low level fertilizer in irrigation water
- the mycorrhizal ecology of the less disturbed and more disturbed areas on site (populations, diversity, etc.)
- tests of shrub seeding with imprinters and rangeland drills should be conducted

Maintenance and monitoring

Research trials placed in early 1993 will be followed until spring 1994. Monitoring should continue for several years to provide better information on what succeeds over the long term. Photo points should be established to follow recovery of a few key areas. Suggested points include: Hill climb 2, the sand bowl, and the peak top. It would be very helpful to shoot another series of aerial photographs of the site.

Part 8. Restoration for desert projects

The desert may take centuries to recover from damage and disturbance by human activity without active restoration work (Kay & Graves, 1983; Webb et al., 1983; Prose, 1986,1988; Prose & Metzger, 1985; Virginia & Bainbridge, 1986; Bainbridge & Virginia, 1990). This is not surprising as establishment and succession of any kind in this severe environment is naturally slow and damage and disturbance makes these conditions much worse (Part 4). The uncertainty of the climate and the extreme conditions make restoration challenging even if adequate resources are available for mitigation work.

The goals of restoration are generally to return the area as close as possible to its predisturbance condition. With small areas in the remote desert this is usually not difficult to determine, but for unique, highly disturbed sites or areas with extensive use since 1900 this is more difficult. This work is further confused in areas where native Americans lived and managed the environment (Bean & Saubel, 1972; Bainbridge, 1985b; Shipek, 1990). Understanding the effects of removing these active land managers may prove important in evaluating changes in ecosystems now being observed and in reestablishing preferred plant species.

Although the ultimate goal is to restore the damaged areas of the desert to predisturbance conditions of biological richness and stability, the high cost of intensive restoration (up to $50,000 per acre/$1.5 to $2 million total for a small areas like the Ant Hill alone). Recovery includes both visual (often primary shrubs only) and ecological components, including the full complexity of soil and aboveground ecosystem structure and fucntion. With limited money and time the primary objectives are improving soil and microsite characteristics to facilitate natural establishment and transplanting key species that are both visually and ecologically important, including creosote bush, bur sage, and ocotillo.

Restoration or research?

This project has illuminated the potential conflicts between research and restoration for limited money and time. All three elements of this project (literature research, field research, and restoration) were often constrained by funding, personnel, and equipment. Carefully controlled field research is expensive, and even the relatively modest research planting in 1991 (300 plants) ended up costing almost $6,000.

The emphasis on literature review and compiliation of exisiting knowledge recognizes the high cost of field research and the benefits of learning as much as possible from previous studies. The goal in this work was developing a plan that would aid restoration work at the Ant Hill <u>and other desert sites</u>. With this background information a less controlled observational level of research will often be sufficient, although not ideal.

Much has been learned about the functioning of desert ecosystems in the last few years, but much remains to be learned about virtually every aspect of these fragile lands. This is particularly true for the complex interactions involved soil restoration, soil hydrology, and plant establishment. Applied research involved in restoration work provides the perfect method for developing and testing new strategies and ecological theories and models. It also provides information about the fundamental properties of these desert ecosystems.

General guidelines for restoration implementation

The relationships between seed collection, plant preparation, planting, and after-care make it desirable to have one person responsible for the entire project if possible. An on-site manager is highly preferred because field time and on-site observations are critical for success. The on-site (or close to site) production of plants is desirable, but the demands of operating a nursery are often more easily met by an existing facility.

The Ant Hill project has been hindered by the distance to the site (2 hours), access to the site (limited availability of 4wd vehicles at SDSU), split responsibility, multiple committments of primary managers, and the normal conflicting demands of research and implementation. Despite these problems it was a successful project, much has been learned, and many plants have been established on site. Based on the research described here and observations in the Coachella Valley and Mojave Desert the following steps are recommended for restoration:

Inventory and diagnosis

Site evaluation is expensive but often useful. A detailed map of the site and intensive ecological analyses are desirable. Soil studies are particularly important, to characterize soil chemistry, structure, and soil biota on undisturbed sites and damaged areas. Aerial photos are of special value and many historical pictures going back to the 1940's exist. Historical studies utilizing newspapers and records may help determine predisturbance characteristics (Bahre, 1992?). If funding is very limited the inventory and diagnosis step can be limited (two or three soil tests) and simplified plant community analysis (perhaps from the aerial photos) leaving most resources for treatments.

Planning

Developing a comprehensive plan is deirable, but this can also be expensive and limited funding may make implementation of a complex plan difficult. Field studies and small scale experiments should be included in the planning stages, small test plots (even if only observational rather than tightly controlled) and nursery trials are very useful. Expect the unexpected.

Seed collection

Seeds and plant material for vegetative propagation should be collected from the site for several years. Seed should be analyzed carefully by x-ray, cutting, stain, and/or ggermination tests (Lippitt & Bainbridge, 1993). Supplemental watering may improve seed set and improve viability of plant materiasl for cuttings and transplants.

Professional seed collecting may be more economical than collecting by staff. Large collections should not be made until seed quality is understood and predictable. Protection of collected seed is critical. Long term storage can be challenging when staff is primarily intermittent. A complete site collection report and storage form (Appendix 2) are essential.

Soil preparation and ground shaping

The adverse effects of ORVs should first minimized by limiting access with fencing and signing and visual barriers. Soil physical properties must also be restored to "native" soil characteristics of soil strength, infiltration, saturation percentage, and soil fertility if possible. When soil structure is improved natural recovery will also be facilitated.

Compacted soil recovers very slowly (Froehlich & McNabb, 1984; Voorhees et al., 1986; Sandor & Gersper, 1988). Compacted soils may be aided by breaking up the soil as deep as possible (Bainbridge, 1993). This should be done without inverting the soil layers to maintain a natural fertility gradient. If equipment operation is possible (cost and access limit potential use) deep ripping is desirable. Deep ripping facilitates infiltration and rapid root growth and needn't be expensixe on larger sites. Deep ripping minespoil (to 0.85 meters) reduced bulk density 26% in the surface soil, 44% in the deeper soil (Philo et al., 1982). Taproot length increased 92%, rooting depth increased 81%, and survival increased 33%. Deep ripping also improved tree survival and growth in western Australia (Schuster, 1979). Seedling growth in a mine reclamation project almost doubled with deep ripping (Burrows, 1986). Penetrometer resistance was decreased for more than 30 months after deep ripping (Steed et al., 1987).

Deep ripping can also improve infiltration (Bainbridge & Virginia, 1990; Tromble, 1980). It is most effective on compacted soils with poor structure. In one study, moisture from 1.6 cm of rain in 20 minutes reached 63-127 cm depth in land ripped to 46 cm, while it reached only 30-36 cm in untreated land (Bennett, 1939). Infiltration after root plowing was 3.4 cm/hr, considerably better than untreated bare soil, 1.4 cm/hr; but far below undisturbed conditions, 6.7 cm/hr (Tromble, 1980). Chisel plowing and subsoiling alleviated the detrimental effects of compaction in a loam (Alegre et al., 1986) with infiltration rising to 14.8 cm/hr on the treated soil versus 0.9 cm/hr on the compacted soil.

Ripping can be difficult on roads, trails, and hillclimbs that ignore contours or in areas where extensive root systems may be damaged by ripping between plants. Equipment operation is likely to do other collateral damage and to emphasize linear patterns.

Augering holes up to 3 meters deep has improved establishment and survival of plants in the low desert (Anderson, 1988). The Arizona Department of Highways augers a hole 18-24" deep for planting spots. For transplants an even deeper hole may be advisable. If access was better and funding was available a tractor mounted posthole digger with a modified auger should be used to auger holes (Virginia & Bainbridge, 1986). The Cannon tree planting auger, a gear box mounted on a chain-saw power head, (International Reforestation Suppliers--see Appendix 1) was ultimately selected and has met all expectations in the field.

A garden fork can also be used to break up soil compaction without disturbing soil layers. This can be important with the fertility profile found in many desert soils. A deep, relatively narrow cross-section tine is desired. The most appropriate garden fork is made by Bulldog tools in England (sold by Smith and Hawken). This has been effective but longer tines would be desirable to increase treatment depth.

If budgets are limited simply roughening the soil surface may be worthwhile.

Soil amendments

Soil amendments can improve soil recovery. Long-lived mulches such as bark and wood chips are most effective. These recalcitrant muclches have worked better than more decomposable materials such as straw for desert restoration (Elkins et al., 1984). The bark chunks deteriorate more slowly and do not blow away as easily as lighter materials. They provide better food supplies for soil microorganisms (Whitford et al., 1989). Material with higher C:N ratios appear to be desirable in the desert soils, providing a durable food for fungi and subsequent grazing by microarthropods (Whitford et al., 1989). This grazing makes mineral nitrogen available to plants.

Bark mulch also preserves soil moisture and this can improve seedling establishment and transplant survival. Pasternak et al. (1986) found that wood chips quadrupled germination using saline irrigation water. These can be very economical if tractor access is possible.

Fertilizer

Fertilizer may reduce long-term survival in severe environments and is rarely used in the desert (Virginia & Bainbridge, 1986). Fertilizer may increase growth and enable the plant to use up the available water more rapidly. High nutrient levels can also decrease the root to shoot ratio and limit root spread. These factors may interact to increase moisture stress on plants and reduce survival.

Nitrogen and phosphorus in fertilizer can also depress microbial symbionts and prevent natural inoculation by soil symbionts(St. John, 1985, 1987). This can limit plant nutrition and water availability. However, Jarrell et al. (1987) found that it was possible to speed plant growth in container experiments while maintaining microsymbionts by isolating the upper plant roots from the fertilizer. This has not been translated into field or nursery practice but it may be possible.

Ground shaping

Ground may also be shaped to concentrate water, to improve infiltration, and to reduce erosion with pitting or imprinting. Soil strength is also a function of soil moisture. Improving moisture retention on slopes is critical. Slopes at the Ant Hill were pitted with McLeods and shovels to create pits that will reduce erosion. The goal was pits that would endure and would also trap blowing silt, seed and soil symbiont inocula. Pitting can also be done with a wide range of equipment.

Pitting can be done with a variety of different machines (Barnes, 1950; Vallentine, 1980) or by hand using a shovel, hoe or McLeod. Pitting machines leave a number of discontinuous pits in the soil which concentrate water and improve infiltration. Vegetation often establishes well in these pits (Jordan, 1981; Cox et al., 1982). By increasing surface roughness the pits also reduce wind speed and facilitate sand, seed, and inoculum deposition (Vallentine, 1980; Kay, per comm). Bigger pits may also discourage ORV traffic.

Offset disks (>3 foot diameter) with the mounting hole offset or eccentric disks with sections of the disk cut away are economical and require relatively low drawbar power. Disks should be large to get sufficient bite to make larger pits. Similar results can be achieved with a dish shaped blade on a hydraulic hitch.

Shaping the ground to concentrate available rainfall has been very effective for vegetation establishment in deserts (Evenari et al., 1982; McKell et al., 1979). Microcatchments have been used in North Africa since Roman times and are now being used in many arid regions (Jain & Singh, 1980; Shanan et al., 1970; Sharma et al., 1986). These basins can be irregularly shaped to appear more natural. The design of microcatchments has been studied in detail in the Negev Desert of Israel and guidelines are available to choose appropriate designs for selected species in given soils and climates (Shanan et al., 1970). A typical microcatchment might concentrate water from 30 m^2. Microcatchments can reduce salt concentrations at the planting spot. They proved more effective than one hand watering for the establishing saltbush in the Negev Desert (Evenari et al., 1982).

Surface barriers of plastic, asphalt, and wax have been used to concentrate water (Virginia & Bainbridge, 1986). Costs are high but the benefits may be substantial. These act much like the microcatchment basins and concentrate rainfall (Aldon & Springfield, 1975; Fink et al., 1973; Fink & Ehrler, 1981; Hillel, 1967; Schreiber & Frasier,1978; Xiang, 1991; Shanan et al., 1981). Weed barrier can provide similar benefits and has been useful in tree establishment on difficult sites

(1991). Problems discouraging their use at the Ant Hill include wind, eventual removal, and aesthetics.

Brush or rock dams across washes are widely used to spread flood water on adjacent lands (Evenari et al., 1982; N.A.S., 1974; O.T.A., 1983). Typically, these are permeable to allow some of the water and suspended soil through the structure. Rock dams have been built in some of the erosion gullies. More will be completed as labor allows. These should promote revegetation and reduce erosion.

Imprinting desert soils with a shaped roller has been very effective in increasing infiltration. The imprinter produces a pattern of pits and catchment areas that concentrate water and also trap blowing silt and seed (Anderson, 1987; Dixon, 1988; Dixon, 1990). Unfortunate the heavy roller and equipment can also compact the soil. While compacting the seeds and soil can improve germination in some cases by improving soil contact with the seed it is often more effective for grasses and less helpful for deep rooted shrubs. Tests of shrub seeding with imprinters should be undertaken to more carefully evaluate imprinting in the California desert.

Gully control

Gully control is difficult in any environment and particularly hard in the desert. High intensity rains, rapid runoff from denuded areas, and steep slopes at the Ant Hill make it very challenging. These gullies, which follow old ORV roads, are up to 4 feet deep. Many tons of soil material have been lost and cannot be replaced. Stabilization methods are being explored to minimize further soil losses. These include check dams (rock) and bypass drops to move water off the slope rapidly (Hillborn & Stone, 1988). Reestablishing shrubs on the slopes will also help reduce erosion (Wilcox & Wood, 1989).

Direct seed

A complex seed mix should be drilled if possible. Seed cost alone can be expected to reach $1,000 per acre for a complex seed mix. Key species can be direct seeded in strips or islands if funding is limited. Direct seeding is relatively inexpensive (cost commonly ranging from less than $20 to more than $1,500 per acre (Dixon, 1988; Pizatella, 1986a). A complex seed mix used in the Coachella Valley cost $1,000 per acre just for the seeds.

Direct seeding may appear to offer a number of advantages for reintroducing plants on this type of restoration site. Growth from seeds in a favorable year will often surpass transplants but direct seeding is extremely vulnerable to drought and seed harvesters (ants and rodents) and frequently fails completely. Direct seeding has generally been unsuccessful, even when seeds are selected carefully and drilled to the appropriate depth (Kay, 1979; Cox et al., 1982). Experiments in the Sonoran and Chihuahuan Deserts beginning in 1890 and involving 83 species and 400 sites suggest direct seeding can be expected to succeed only in one of ten years, mainly due to insufficient water in years with normal precipitation (Cox et al., 1982).

Seeds can be planted by broadcasting, drilling by hand or machine, or imprinting. The BLM has had relatvely good luck with direct seeding in the Palm Springs area (Pizatella, 1986), while projects in the Mojave desert have met more limited success (Kay, 1979). The most common method of direct seeding is simple hand seeding which allows species to be matched to specific site conditions. It also results in a more natural appearance than machine planting. Restoration projects in the Midwest have found that the Garden Weasel (a tillage tool) works well for incorporating seed. A chain link fence section or flexilbe harrow can also be used. Digging or forking the soil 25-50 cm deep to loosen the soil and back-filling to leave a small depressions or pits will often increase the likelihood of success.

Viability of desert seeds is often low and the sowing rate should be based on pure live seed count not total seed (McKell, 1986). High seeding rates should be used for most species, with from 100 to 500 live seeds per square meter (Kay, 1979; Herbel, 1986).

Ideally, direct seeding should be done before heavy rains or flood events. If planting must be done when the soil is dry irrigation may help, but Brum et al. (1983) got very poor establishment of several species even with irrigation.

Removal of seeds by rodents and harvester ants may limit seedling establishment (Kay & Graves, 1983; Bainbridge & Virginia, 1990). Harvester ants may be partially neutralized by using cracked wheat to satiate the colony before seeding.

Seed may benefit from inoculation with appropriate microsymbionts (Schiechtl, 1980; St. John, 1985; McKell, 1986; Virginia & Bainbridge, 1986; Bainbridge et al., 1989).

Transplant

Key species for transplanting may be grown by staff or contract in a range of containers. Protection from herbivory, wind, and temperature extremes, and supplemental irrigation is desirable. Planting is expensive whether it is done on contract or by staff and volunteers. Expect in the ground costs of $5-100 per plant.

The dominant shrubs of the desert are generally easy to grow in a nursery or maintained landscape setting but can be challenging to establish in the field in a low- or no-maintenance situation (Bainbridge & Virginia, 1990). A full appreciation of the ecological setting and adaptation of desert plants however, can make establishment less costly and more successful even on more challenging sites.

Fast deep rooting may be achieved by early out-planting or using deep containers for nursery stock to protect and encourage tap root development (Bainbridge, 1987). The meter tall, 15 cm diameter plastic containers (made from PVC pipe) developed and used by the Center for Arid

System Restoration at Joshua Tree National Monument work well, but even smaller 7.5 cm diameter plastic tubes are difficult to hand carry at the Ant Hill.

The benefits of longer taproots have been documented in reclamation after mining (Burrows, 1986). Survival with longer taproots increased in relation to root length, 29 cm 15% survival, 48 cm 75% survival, 68 cm 92.5% survival.

Larger container plants are more costly to grow and to buy and planting from small containers works well if the tap root has not been damaged. This can mean planting within 3-4 weeks of germination. Given the rapid root growth of desert plants such as Larrea and Ambrosia (3 cm+ per day in the summer) it may be cheaper to let the plant root reach >50 cm in the field rather than in the nursery.

Survival of transplants is sometimes improved by dipping the roots of transplants in a loam slurry, which mimics the natural accumulation of silt under a multi-stem shrub canopy, improves soil moisture holding capacity, and supplies added nutrients. This did not appear to benefit creosote bush.

A wide variety of containers have been used for transplants for desert revegetation, ranging from the small supercells up to meter tall 15 cm diameter tubes with costs ranging from 25-75¢ up to more than $10 per plant. No ideal system has been developed and the choice depends on budget, timing, access, and irrigation and project goals. Generally the money spent on plants will improve survival if roots are given priority.

Many of the desert species are very sensitive to reduced oxygen levels, mould, and fungi. Plants like creosote bush require rapid draining soil mixes. Sand is usually the major component of soil mixes, with a coarser size preferred.

Transplants should be hardened off if they are started in a glass or shadehouse. Plants should be gradually exposed to full sunlight and reduced water before outplanting. Use of treeshelters can reduce the importance of hardening off.

Pruning transplants (given some time for healing and hardening off) can provide a desirable large root to shoot ratio. This strategy is used at Joshua Tree National Monument (Moon, 1990). Modest herbivory may also provide some benefits to plants by reducing drought stress, but severe or repeated grazing is often fatal and screening is recommended. In a wetter environment Paige (1988) found that scarlet gilia plants that were browsed (or clipped) were as tall as controls within four weeks and they produced two and a half times as many flowers and seeds.

Research has made it clear that appropriate microbial symbionts can improve nutrient availability and plant performance (Aldon, 1978; Bloss, 1986; Read et al., 1985; St. John, 1985, 1987; Trappe, 1981). Since soil disturbance can reduce or eliminate soil symbiont populations (Allen, 1988; Virginia et al., 1988), inoculation of soil or seedlings should improve revegetation success. This is particularly true on extensive disturbance sites, less critical on linear disturbances such as roads and trails.

Inoculation can be done with native soil taken from under healthy plants of the same or closely related species or with commercial inoculum (Schiechtl, 1980; Bainbridge et al., 1989). Native inoculum is preferred for restoration work. The most important symbiotic partners are rhizobia, which enable many leguminous plants to fix nitrogen, and mycorrhizal fungi which improve root characteristics and phosphorus uptake (Bloss, 1986; Crofoot, 1985). Double inoculation of leguminous plants with both rhizobia and mycorrhizae may be important if field populations of microsymbionts are severely depleted or absent (Carpenter &Allen, 1988).

Some of the more prominent nitrogen fixing plants are not very specific in their requirements for rhizobial inoculum. For example, some species of mesquite will nodulate with standard cowpea mixes (Virginia et al., 1984). Other desert legumes may require more specific inoculum. Field based information about inoculation procedures and their effectiveness is lacking for most of these species, including the more common legumes of the Ant Hill (Psorothamnus, Astragalus, Cassia, and Lupinus).

Many desert plants (including the other species described in detail in this report) may depend on mycorrhizal fungi for successful establishment and growth in soils with low phosphorus levels (Aldon, 1978). Lack of needed symbionts is often revealed by plant failure after initial growth following germination.

Commercial experience with inoculation of woody species is limited in the desert. Materials can be developed from local species by a relatively capable nursery or biological lab but it can be expensive. Seeds can be then be inoculated by tumbling inoculum with seeds and sand in a cement mixer, preferably just before planting. A binding glue will help keep inoculum on the seeds.

Improving the conditions for the fungi may be even more important. Providing bark or some other food may improve colonization. Reducing compaction, improving infiltration, and increasing soil moisture storage all make conditions more favorable for soil symbionts and for the soil micro- and macro-organisms that move them around. Inoculation may not occur if soil moisture and temperature are inappropriate.

Plant adaptation to these high temperatures may make summer planting acceptable, contrary to normal expectations and recommendations to plant in the cool season. We have bare-rooted small mesquite seedlings successfully on a day when the air temperature reached almost 50°C [120°F] (Bainbridge, 1991). Survival from transplants in late April was excellent. Planting crews tolerance of heat may be more critical than plant responses.

Protecting natural volunteers

Protecting naturally established plants can be one of the most inexpensive options for improving vegetation. Protective screening and supplemental water for volunteer plants may be one of the most cost effective options available for restoration workers.

Resource islands

Multi-stemmed shrubs and trees such as creosote bush, bur sage, and mesquite are good candidates for revegetation and restoration efforts. Once they are established they will improve site conditions for other plants by trapping fine soil, organic matter, and symbiont propagules, by increasing infiltration and water storage in the soil, and providing protection from the sun and wind. The shrub mounds that develop under these multi-stemmed shrubs improve nutrient and water supply for the shrub itself, and provide the unique microhabitat required by many desert annuals (Virginia, 1986). Even small creosote bush seedligns were improving site conditions sufficiently to initiate germination of other plants.

Concentrating resources to create islands of fertility and seed and inoculcum sources may provide greater benefits than less intensive treatments over a larger area. These resource islands apparently play a major role in the development of these desert ecosystems. Transplanting clumps of shrubs into the center of barren areas is a low cost method of promoting resource island formation.

Transplants from the wild

Transplanting from the wild is also relatively easy. Results have not been good without aftercare--especially irrigation which may be required for several years. Transplants should be pruned to improve root; shoot ratio. Damaged roots should be cleaned up, cactii should be hardened by setting the rots in the sun for several days. Clay pot irrigation of transplants for a recovery period in nursery of field may improve survival. An *Encelia* plant which had been out in the sun for an hour and had most roots damaged (thinned from the Visitor Center landscape) recovered when pruned and planted in a clay pot irrigated container. Plugs of annual grasses and herbs can slo be trasnplanted with some success. They help break up the uniform soil color of damaged sites such as roads and trails.

Irrigation

Most desert plants respond well to irrigation. If irrigation is feasible survival and growth can be enhanced. Once the plant is established the irrigation can be tapered off and terminated. Pulsed irrigation may be more desirable than continuous irrigation for species that are very sensitive to over-watering. Hauling water toremote sites is expensive.

Drums or tanks used to store water should be disguised or buried to reduce vandalism. Metal drums and water tanks may rust, with potential harm to the plants from excessive iron. Plastic is better but if it is translucent the tank should be painted to limit algal growth. Plastic tanks at the Ant Hill were painted with latex paint with sand dashed into the wet paint for camouflage. Sand tanks, where water is stored in the pore space of sand, can also be built and may prove more durable (Bainbridge, 1986).

Timers have been very helpful for remote site irrigation systems. Several battery powered valves are available to fit hose fittings or pvc pipe. Some of these appear to work well only with several feet of head for pressure.

Plant collars to concentrate irrigation water

Impenetrable barriers around the seed or seedling have been effective for improving irrigation efficiency. A tin or plastic tube used as a plant collar will ensure that irrigation water reaches the plant roots (Harris & Leiser, 1977). A 3-6 inch diameter pipe collar 4-6 inches tall pushed 1-2 " into the ground has worked best in our trials. The pressed peat collars from International Reforestation Suppliers are less obtrusive and will eventually biodegrade. Treeshelters can also be used in this manner. This is particularly helpful on slopes where water otherwise runs off.

Deep pipe irrigation

Deep pipe irrigation uses an open vertical pipe to concentrate irrigation water in the deep root zone (Sawaf, 1980; Mathew, 1987; Bainbridge, 1990). Deep pipe irrigation has provided excellent survival and growth in the low desert (Bainbridge & Virginia, 1990; Bainbridge, 1991). Deep pipe irrigation commonly uses 5 cm [2"] diameter vertical pipe placed 30-45 cm [12"-18"] or deeper near the seedling. Cardboard tubes or bamboo may provide similar benefits from a biodegradable tube. The top of the pipe should have a cap or screen (1/8" mesh hardware cloth) cover to keep lizards, insects, and animals out of the pipe. Pipes can be filled with jerrycans with a nozzle or from a pulsed irrigation from a remote storage tank. One to two liters per month may be sufficient for small seedlings. Deep pipe irrigation is better than surface or buried drip systems in several respects. First, it can be used with low quality water and low technology. Second, the deep pipe provides the benefits of buried drip systems, greater water use efficiency (due to reduced evaporation) and reduced problems with weeds. Where the materials and technology for drip systems are available the deep pipe system with a drip emitter can be monitored and repaired much more readily than a buried drip system.

A system to provide the benefits of deep pipe irriation without a deep pipe is now being developed. A pressurized backpack sprayer is being modified to feed an injection needle that will place irrigation water in the deeper soil near seedlings. A larger volume injector is used in

Australia ( ). A water injector may also be suitable for inoculation with rhizobia and mycorrhizae. The Tree of Life Nursery used pressurized water jets to make holes for transplants and this may also work well in the desert.

Buried clay pot irrigation

Buried clay pot irrigation has been very effective in establishing and growing plants in arid environments (Gomez-Pompa, 1985; Kurian et al., 1983; Sheik & Shah, 1983; Bainbridge, 1986,1990; Bainbridge & Virginia, 1990). Buried clay pot irrigation uses an unglazed, low-fired clay pot filled with water to provide a steady supply of water to plants growing nearby. The water seeps out of the clay walls of the buried clay pot at a rate that is in part determined by the plant's water use.

Most standard red clay garden pots are suitable if the bottom hole is plugged with a rubber stopper or silicone caulk. A tight fitting lid with drain hole should be used or animals may knock loose lids off to drink the water. Buried clay pot systems may require water only every two weeks or perhaps just once a month.

Researchers in Pakistan used buried clay pot irrigation to establish acacia and eucalyptus trees in an area with 200 mm annual precipitation (Shiek'h & Shah, 1983). The buried clay pot irrigated trees grew 20% taller than hand watering at the same rate and survival increased from 62% to 96.5%.

Buried clay pots have worked well at the Ant Hill. Only a few have been used because of the cost but these have worked very well for both bur sage and ocotillo, with survivng plants on all pots. They were also most effective in triggering germination of existing seeds in the topsoil.

Drip/trickle

Several different systems for drip irrigation have been tried in the desert. The standard commercial systems are expensive and have proved troublesome in wildland use (Virginia & Bainbridge, 1986). Coyotes, rabbits, and other animals chew on the polyethylene tubing and emitters are easily clogged by debris in the lines and from salt accumulation at the emitter orifice. In a herbivory repellent study in the Coachella Valley, few plants were eaten but virtually every peicce of drip tubing was severed.

Cryptogamic crusts

Cryptogamic crusts can be very important in the desert but little evidence of these crusts was found at the Ant Hill. This may be a function of the soil type (they are more common on less sandy soils) and/or the extensive disturbance. Cryptogamic soil crusts of algae and lichens reduce erosion (Bailey et al, 1973; Bond &Harris, 1964; Fletcher & Martin, 1948; Marathe, 1972) and may provide improved conditions for plant establishment by increasing infiltration and soil nitrogen and by improving soil structure (Metting & Rayburn, 1983; St. Clair et al, 1984). Some efforts to encourage algal crust development have been successful (Ashley & Rushforth, 1984; Metting & Rayburn, 1983; St. Clair et al, 1986). The addition of a soil crust slurry may be very helpful. Studies have shown this type of treatment may reduce algal crust recovery times from 6-7 years to six months (Johansen et al, 1984). The recovery of these crusts can speed succession and revegetation.

Plant protection

Plant protection is one of the most important factors in plant establishment. Protection should provide shelter from microclimatic extremes (particularly sand blast) and herbivory.

A wide range of plant protection strategies can be considered ranging from expensive and very effective double-walled TUBEX™ treeshelters to plastic mesh, wire cages, rock mulch, fences, repellants, etc. The best choice for a given site will depend on primary protection goals, aesthetics, budget, and labor.

Herbivore pressure can be very high in the low desert. Newly established seedlings are often the most succulent plants available to herbivores. Rabbits, rodents and insects may prove fatal to new plants unless protection is provided (Clary, 1983; Kay & Graves, 1983; Bainbridge & Virginia, 1990). The size of the protection will depend on the predominant herbivores or threats.

Solid plastic shelters may be the most effective protection against herbivory. TUBEX tree shelters block side access to even the smallest rodents. The top of the shelter should be covered with a small mesh screen or the stretchable mesh net from TUBEX.

Wire or plastic screens have been more commonly used than TUBEX. A small mesh size, 1/2 x 1/2 inch [1.2 cm] or less, may be needed to keep mice and rodents out. Window screen may be more appropriate where insects are a problem. Heavy gauge wire screen may be essential in areas where grazing pressure is very high, because herbivores may chew through chicken wire. Metal screen can cause serious problems if the wire is not removed before the plant grows into it.

Commercial plastic mesh guards (e.g from International Reforestation Suppliers) are often preferred because they are inexpensive, easy to install and eventually degrade in sunlight with no further labor for removal. However, the breakdown fragments are ugly and protection may be inadequate.

In areas where screen is unacceptable for aesthetic or economic reasons brush or rocks can be used. Rock mulch is effective even in areas with very high winds and provides acceptable performance in many cases.

Protection from the wind may be very important (Kunkle, 1976; Schiechtl, 1980). High winds alone can damage plants, and if sand is carried by the wind it can mechanically damage living tissues (Downes et al., 1977; Lyles & Woodruff, 1960). Although the effects of sandblast on jojoba have been studied (Mosjidis, 1983) little research has been done on other native species. Wind speeds of 10 m/sec (approx. 30 mph) were sufficient to kill an annual crop in 20 minutes (Fryear & Downes, 1975). High winds are relatively common at the Ant Hill and have limited work on several days. Wind speed at the site probably exceeds 10 m/sec fairly often. Mosjidis (1983) found that wind speeds in eastern Riverside County were often above 12 m/sec and one wind storm maintained speeds over 14 m/sec for more than 8 hours.

Solid wall shelters are preferred for wind protection. TUBEX treeshelters have worked very well in high sand blast areas in the Coachella Valley (Bainbridge, 1990). Screen or plastic mesh can be upgraded with a wrapping of clear plastic film. IRS makes a plastic sleeve to fit over their mesh plant protector and these have worked in the Coachella Valley but they are awkward to put on. The top of tubes or protective devices should be rolled to reduce mechanical damage toi the plant stem from high winds.

Pressed peat collars (from IRS) also provide wind protection and will degrade naturally. Dead plants, shade screens, or stubble can all provide wind protection.

Reed fences (10 cm buried, 40 cm exposed) have been very effective wind fences in desert areas with shifting sands (Tag El Din, 1986). Straw bundles buried vertically can provide similar protection and will also improve infiltration. Straw, rye or other durable straws are preferred. Ground pitting also helps control wind erosion and reduces sand transport.

Rock mulches are economical (if stones are present), durable, and aesthetically pleasing. They have worked well at the Ant Hill. Large stones are placed around seedlings to provide protection from grazing and microclimate extremes (Goor & Barney, 1976; Bainbridge & Virginia, 1990). Rock planters are used in Red Rock Canyon State Park to provide protected sites for revegetation and to discourage ORV traffic (Faull, 1989).

Vandalism

The west fence has provided fairly good protection from vandalism, which can be a major problem in restoration efforts. Bare areas attract ORV operators who may disrupt or vandalize plantings (Faull, 1989: Bainbridge & Virginia, 1990). Mulch (esp. rock or brush), ground shaping, and signing can provide some protection from vandalism but fences (maintained regularly) are better. Wind and grazing guards and shading devices can provide additional protection if rebar is used instead of wood stakes.

Maintenance

Maintain fences, protection, erosion control structures and irrigation systems for a minimum of 3 years if possible. Maintenace of records, seed collections photos etc.

Monitor

The site should be monitored for 10-20 years if possible. Treatment and plant labeling should be clear and permanent to faciltiate follow-up studies by subsequent resource managers. This will provide more information on what really works.

Appendix 1. Restoration equipment and supplies

Plant protectors

Tree shelters have worked well in the desert but they are not a panacea for all situations and species. Plants with upright growth forms and rapid growth rates seem particularly well suited for tree shelters. The benefits in reducing transplant shock seem to extend to many other species as well and a 2-3 month starting shelter may be generally advised. The value of the tree shelter is also related to irrigation system, water schedule, and fertilizer and the interaction of these factors with the microclimate created by the shelter. There are also costs associated with the reduced light, as low as 30% of outside light with the tan TUBEX tree shelters tested in Southern California. The shelters may also trap birds, mammals and lizards and often require netting or cross-threaded fish line near the top to restrict access.

Tubex Treeshelters™

Double wall plastic shelters. Stable, easy to install. Flared top. Two colors.

TUBEX
75 Bidwell Street, Suite 105
St. Paul. MN 55107
(800) 328-4827 ext. 1906.

Tree Pro™

The Tree Pro shelters are made of polyethylene and are assembled on site. The top is flared to reduce damage.

Tree Pro Tree Protectors
445 Lourdes Lane
Lafayette, IN 47905
(317) 463-1011

Tree Sentry™

The Tree Sentry is an open rolled tube made of recycled polyethylene. This allows opening the shelter to look at the seedling.

Tree Sentry
PO Box 607
Perrysburg, OH 43552
(419) 872-6950

BLUE-X™

The Blue-X shelters are made of rolled recycled X ray film.

All Season Wholesale Nursery
10656 Sheldon Woods Way
Elk Grove, CA 95624
(916) 689-0902

Wire screen fences, tubes, and cages

Wire fences, cages and boxes can be made in any shape desired. Rabbits and rodents rarely crossed the 2 foot tall fences, which were staked with rebar. Cattle and burros can be controlled with six foot cages made with reinforcing wire mesh and t-posts. If cages are well built they can be repaired and reused. We have found that 1/2"-1" mesh tied to 1/4" reinforcing bar stakes ("pencil rod") works well. The tubes are rolled and fastened with aviary clips. Final cost may be from $2.00-5.00 each plus installation. Cage making is generally a good activity for volunteers.

Plastic mesh

International Reforestation Suppliers manufactures plastic mesh tubes for plant protection. The open mesh provides little protection from drying winds and blowing sand. The plastic mesh is photodegradable (different lifetimes are available) and if staked with bamboo can be left in place. IRS sells a 1 mil plastic bag which fits over the tube and provides some of the benefits of the rigid treeshelters. The advantage of these tubes is the cost.

International Reforestation Suppliers (IRS)
PO Box 5547
Eugene, Oregon 97405
(800) 321-1037

Supercells and plant containers

Stuewe and Sons
2290 SE Kieger Island Rd
Corvallis, Oregon 97333
(503) 553-5331

Silva Seed
PO Box 118
Roy, WA 98580

see also IRS

Plant bands

Pacific Western Containers\
1535 East Edinger
Santa Ana, CA 92705
(714) 547-9266

Monarch Manufacturing
13154 County Rd 140
Salida, CO 81201
(719) 539-3335

Augers

Cannon Tree Planter (IRS)
Little Beaver (BM)

Irrigation goodies

Water jugs (3 gal Igloo) BM
Battery irrigation valve (Galcon) GS
Watering cans (French) GS

Source:
Gardener's Supply
128 Intervale Road
Burlington, VT 05401

Garden fork

Bulldog tools (england)

Source:
Smith and Hawken
25 Corte Madera
Mill Valley, CA 94941

Screen cutters (for tall pot bottoms and deep pipe covers)

TWP Inc.
2133 Fourth St
Berkely, CA 94710
(800)-227-1570

Transplanters
Contour transplanter (Ben Meadow)

GENERAL SUPPLIERS:
Planting bars, flags, jugs, hoedads, etc.

IRS, PO Box 5547, Eugene, OR 97405
(800) 321-1037

Ben Meadows, 3589 Broad St., Atlanta, GA 30341
(800) 241-6401

General Supply, PO Box 9347, Jackson, MS 39286
(800) 647-6450

Appendix 2. Seed data

unique running #

BIOLOGY
SDSU
SEED COLLECTION REPORT

NO.

SPECIES____
Seed zone (if applicable, see Calif. Dept. Forestry map on reverse)____________
Elevation ______________ Aspect _________ Slope ____________
Vegetation type ____________________________________

SITE LOCATION
(Township) ______(Range) _______(Section) _____
Nearest town ______________
Road location ____________________________

sketch map

COLLECTED BY____
Address:
Phone
No. of plants collected from _________Distance between plants____________
Date collected ____
Site certification by (CT/Biology or ______) if reqd
______________________Certifier phone # ____________________

Remarks ____

SOIL TYPE: Description __________________________________
pH __________ EC _____________ Texture ________________
more soil info ____

NOTE: USE PENCIL OR PERMANENT INK TO FILL OUT FORMS

Seed collection site soil No. On soil bag Coll: Date:	**Seed collection** No. staple on seed bag Coll: Date:	**Seed collection** No. put in seed bag Coll: Date:
Seed collection site soil No. In soil bag Coll: Date:	**Seed collection** No. staple on seed bag Coll: Date:	**Seed collection** No. put in seed bag Coll: Date:
No.	No.	No.

BIOLOGY
SDSU LOT NO. (from collection tag)________________

SEED LOT HISTORY **STORAGE**

LOCATION(S) ______________________

storage conditions________________________________

SPECIES____________________________Quantity (lbs rough seed)______________

(lbs clean seed)________________

Date collected ____________No. of plants collected from __________Lbs clean /lbs rough seed _________ Purity ______

Bugs, mold, or fungi? ____Treatment for bugs _________________________

COLLECTOR (name/address/phone)______________________________________

Seed zone (if applicable see Calif. Dept. Forestry)________________

Elevation __________________ Aspect _______ Slope ___

Vegetation type ________________________

Site location (Township) _______ (Range) ________ (Section) _____

Nearest town ________________ Road location ________________

Moisture content: initial

	date	moisture
map		

SOIL TYPE: Description ____

pH ___________ EC _______________ Texture ________________

After-ripened (temperature) ____________

GERMINATION **INVENTORY**

DATE	PRETREAT	week 1	2	3	FINAL	Disposition	date	used	balance

Summary of perennial desert plant characteristics

Species	Common name	Seeds/lb	PLS	Seed treatment	Optimum Germ temp	Seed life	Cuttings	Symbionts	O2	pH	salinity
Acacia greggii	Catclaw	2,500	60-75	T12		years	y4	VAM	m	w	mod
Agave deserti	Desert agave			none			y	VAM		w	non
Ambrosia dumosa	Bur sage	70-170,000	5-60	cool/moist	15-25°C	decades	y	VAM	low	w	
Aristida purpurea v.glauc	Blue Three-Awn			none				VAM			
Astragalus crotalariae	Salton Sea Locowee			none			no	VAM			
Atriplex canescens	4 wing saltbush	10-25,000++	12	T2/AR1	2-40°C	years	y4	VAM	m	w	hi
Atriplex confertifolia	Spiny saltbush	65,000+	40	T2/AR2	6°C	years		VAM	m	b	non
Atriplex hymenelytra	Desert holly			AR		years		VAM	m	b	mod
Atriplex lentiformis	Quailbush	500,000+	63	none		years		VAM	m	w	low
Atriplex polycarpa	Cattle spinach	500,000+	28	none	20°C	years		VAM	m	n	
Baccharis glutinosa	Seep-willow	7,000,000	1	none	18-26°C	years		VAM	m-hi	n	low
Bouteloua curtipendula	Sideoats Grama	143-500,000	22	AR	16-32°C	years		VAM	m	n-b	non
Cassia armata	Armed senna	17,600	60-70	none	15-20°C	decades	?	VAM	m-hi	n	mod
Cercidium floridum	Palo verde	175	80+	scarify	20-30°C	years		VAM	hi	n-b	low
Chilopsis linearis	Desert willow	40-100,000	80	T1	21-26°C	6 mo.	y3-4	VAM	m-hi	n-b	mod
Coleogyne ramosissima	Blackbush			T2	28°C	years		VAM		b	low
Croton californicus	Mohave Croton			none				VAM			
Encelia farinosa	Brittlebush	350,000	24	none			y	VAM	m-hi	n	low
Ephedra nevadensis	Joint Fir	18-25,000		AR,T8	15-25°C	years			m-hi	n-b	non-low
Eriogonum inflatum	Desert Trumpet	240-450,000	30	T6		years	no	VAM	m		
Ferocactus	Barrel cactus			none	30°C		y	no	hi	b	non
Fouquieria splendens	Ocotillo			none	46°C		y		hi		non
Hilaria jamesii	Galleta	159,000	14-40	none			no	VAM	m	n-b	mod
Hymenoclea salsola	Cheese bush	37,000	40	none	20°C	years	y2	VAM	m	n-b	mod
Hyptis emoryi	Desert lavender			scarify	27°C	years	y	VAM	m-hi	n-b	mod
Isomeris arborea	Bladderpod	4,000	50-60	none	5-15°C	years	y3	VAM	l-m	n	mod
Justicia californica	Chuparosa			none				VAM	hi		
Krameria parvifolia	Pima Ratany						no	root parasite			
Larrea divaricata	Creosote bush	80,000	5-30	AR/T11	23°C			VAM	l-m	w	non
Lycium pallidum	Wolfberry			T2			y5	VAM			mod
Olneya tesota	Ironwood	2,000	80+	T9				R/VAM	hi		low
Opuntia bigelovii	Cholla			scarify	21°C		y	no	m-hi	w	
Oryzopsis hymenoides	Indian ricegrass	100-200,000	to 80	T9	15°C		y6	VAM	m-hi	n	low
Penstemon stephensii	Beard-Tongue	1,000,000	34	T2	24°C	years	y	VAM			
Populus fremontii	Cottonwood	1,000,000	79	T4	16-21°C	20 weeks	y	ECM	m	w	mod-hi
Prosopis glandulosa	Honey Mesquite	13,400	81	T12	10-30°C	decades	y1	R/VAM	m	w	mod
Prosopis pubescens	Screwbean	13,400	81	T12	27°C	decades	y1	R/VAM	l-m	w	hi
Psorothamnus emoryii	Dyeweed			none				VAM			
Psorothamnus schottii	Indigo bush			none				VAM			

Psorothamnus spinosus	Smoke tree		80+	none				VAM		n-b	low
Salix goodingii	Gooding willow	10,000	80	T1/T4	21-27°C	7 weeks	y	ECM	l-m	n	non
Sphaeralcea ambigua	Desert mallow	300,000	50	none	18-23°C		y4	VAM	m		
Sporobolus cryptandrus	Sand Dropseed	2-5,000,000	4	T2	20°C			no	m-hi	n-b	non
Stephanomeria exigua	Small Wreath-Plant			none				VAM			
Tiquilia plicata	Plicate Coldenia							VAM			
Tiquilia palmerii	Palmer's Coldenia							VAM			
Washingtonia filifera	California fan palm	6,000	80	T13	28°C	days		VAM	l-m	w	non
Yucca schidigera	Mojave Yucca	22,000	80	T11	27°C		y	VAM	hi	w	
Yucca whipplei	Our Lord's Candle	22,000	80	T11	27°C		y	VAM	hi	w	

KEY

+:no wings, ++:with wings(Atriplex)

PLS=pure live seed (purity x germination)   Unknown=?

Seed Treatment:

AR: after-ripening of seeds   AR1: for 10 months   AR2: for 6 months

Scarify: options include, boiling water, acid, chipping, sanding, soaking in running water, tumbling with sharp gravel

T1: soak and place in a can full of sand in the sun. Very susceptible to damping off and rots

T2: cold stratification at 6C for 60-120 days

T3: incubate w/light & KNO3 enrichment

T4: saturated seedbed

T5: store at 50C for 3 weeks

T6: leach in a stream of cold running water for 24 hours

T7: place moist seed in freezer

T8: soak in hot water and stratification for 3 weeks

T9: fresh seeds, no treatment; stored seeds, scarify and soak 24-36 hours

T10: store fresh seeds from 1-2 weeks at 51C

T11: soak for 24 hours

T12: pour boiling water on fresh seed, and allow to soak until cool, acid scarify if dried seed.

T13: scarify, then soak in 1000 ppm gibberellic acid for 72 hours

Cuttings: y=yes, n=no, y1: yes not easy, y2: indole 3 acetic acid(IAA), y3: Roottone, y4: IBA, y5: in sand

Symbionts:R=rhizobia   ECM=ectomycorrhizae   VAM=vesicular/arbuscular mycorrhizae

Oxygen demand: hi/moderate/low

pH: a=acid: n=neutral: b=basic: w=wide

salinity: hi/moderate/low

Summary of annual plant characteristics

Species	Common name	Seeds/lb	PLS	Seed treatment	Optimum Germ temp.	Seed life	Cuttings	Symbionts	O2	pH	Salinity
Abronia villosa var. villosa	Desert Sand-Verbena	68,000	24	none			no	no			
Brassica tournefortii	Wild Turnip						no	no			
Chorizanthe rigida	Rigid Spine-Flower						no	VAM			
Dicoria canescens	Desert Dicoria						no	VAM			
Eriogonum trichopes	Little Trumpet	500,000	30	none			no	no			
Fagonia laevis	Smooth Stem Fagonia						no	no			
Geraea canescens	Desert Sunflower			T10	20C	5 mo.	no	VAM			
Helianthus niveus ssp. canescens	Gray Sunflower				21-26C		no	VAM			
Hesperocallis undulata	Desert Lily			none			no	VAM			
Lepidium lasiocarpum var. lasiocarpum	Sand Peppergrass			T10			no	no			
Mentzelia affinis	Hydra Stick-Leaf							VAM			
Monoptilon bellioides	Mojave Desert Star							VAM			
Oenothera deltoides	Dune Evening Primrose	800,000	30	none	16-21C			ECM			
Palafoxia arida	Desert Spanish-Needles							VAM			
Plantago ovata	Woolly Plantain			T6				VAM			
Sisymbrium Irio	London Rocket			T5				no			

KEY:

T5: store at 50C for 3 weeks

T6: leach in a stream of running water for 24 hrs

T10: store fresh seeds from 1-2 weeks at 51C

ECM: ectomycorrhizae

VAM: vesicular/arbuscular mycorrhizae