Revegetation of Degraded Lands at U.S. Department of Energy and U.S. Department of Defense Installations: Strategies and Successes

D. C. ANDERSON

W. K. OSTLER

Ecological Services

Bechtel Nevada

Las Vegas, U.S.A.

This work was supported by the U.S. Department of Energy, National Nuclear Security Administration, Nevada Operations Office under Contract No. DE-AC08-96NV11718.

Address Correspondence to D. C. Anderson, Bechtel Nevada, P.O. Box 98521, MS NLV-081, Las Vegas, Nevada 89193-8521.

Running Title: Revegetation of Degraded Lands

Abstract

Recent research has provided important principles to follow in successfully revegetating disturbed lands in arid climates. Sustainable revegetation needs to be accomplished within the confines of the existing ecosystem of the area. Revegetation planning, revegetation implementation, and evaluation and monitoring should be considered for each revegetation project. Planning includes conducting a site assessment, establishing goals and standards, determining site preparation requirements, selecting species, selecting revegetation techniques, selecting conservation and water management treatments, determining timing and evaluating costs. Revegetation implementation begins with the selection of an on-site manager who will monitor adherence to the revegetation plan, conduct pre-job meetings and endure revegetation is implemented as planned. Project evaluation and long-term management includes conducting on-site inspections, evaluating success and implementing modification where necessary. Successful revegetation projects completed within the Great Basin and Mojave Desert ecoregions are presented. Seeding and transplanting prove to be successful in Great Basin ecoregion. Irrigation was used with highly predictable success in transition zone between Great Basin and Mojave Desert ecoregions. Seed pretreatment, irrigation, and various mulches show promise for successful revegetation in drier Mojave Desert ecoregion.

Keywords

arid land, desert, land reclamation, land rehabilitation, seeding, western U.S.

Introduction

The U.S. Department of Energy (DOE) and the U.S. Department of Defense (DoD) administer large areas in the western United States. Military bases alone occupy more than 4.4 million ha in the southwestern region (Briuer & Hebler, 1992). It is important that this land be available for training of military personnel, testing of weapons, and homeland security on a sustainable basis. Many of the activities on these lands involve disturbance of the environment with subsequent loss of vegetation. Sustainable use of these areas will require revegetation of the disturbances.

It has been stated that revegetation in areas where precipitation is less than 230 mm per year is a difficult if not impossible task (Plummer et al., 1968). Wallace et al. (1980) claim that only two years in six have suitable precipitation for revegetation to be successful in the northern regions of the Mojave Desert. Despite these gloomy predictions, long-range plans of both DOE and DoD include the revegetation of large tracts of land. Research sponsored by these and other federal agencies over the past 10 years has focused on developing effective revegetation strategies for arid lands of the desert southwest (Winkel et al., 1999; Bainbridge et al., 1998; Roundy et al., 1995; Hall & Anderson, 1999). Improvements in technology, species selection, and planning have increased the likelihood of success and yet there is much we do not understand.

Any long-term strategy to achieve success in arid land revegetation must work within the ecological constraints of the area. This means attempting to restore a vegetation association that is successional or climax within the existing ecosystem. Although the soil may be severely disturbed and native vegetation lost or replaced by nonnative weeds, the general climatic conditions, including precipitation patterns, remain constant. While it is true that grass and trees can be established on a golf course anywhere in the desert with enough input of resources, this is not the objective of arid land revegetation on federal lands. Revegetation of these areas must be sustainable after the first or second growing season with no additional inputs. To reach this goal, not only do species need to be adapted to site conditions, but erosion must be under control and natural nutrient cycles reinitiated. Each site and vegetation type present different challenges and, thus, different revegetation strategies must be employed if success is to be attained.

Revegetation Planning

Several major phases need to be considered in developing a revegetation strategy. The first phase is planning which includes several components that are discussed in the following sections. Many issues can be resolved and savings gained by careful planning prior to any activity on the site. During this phase stakeholders or land managers have the opportunity to identify concerns and priorities. As a result many misconceptions and misunderstandings can be resolved.

Conducting Site Assessments. An assessment of the biological resources required for revegetation may include a characterization of the vegetation, evaluation of the soils, history of disturbance, or identification of possible “troubled areas”. Climatic data should be obtained to assess the need for erosion protection and irrigation, or other site enhancement treatments. An assessment of adjacent undisturbed areas can provide valuable information (i.e., site potential, vegetation associations, drainage patterns, plant spacing) to be used to define goals or standards for revegetation success, and to develop a specific reclamation strategy.

Establishing Goals and Standards. Goals may focus on erosion control, restoring or creating wildlife habitat, or aesthetics. Regulatory requirements and future use of the site my also define revegetation goals. Some agencies and states have standards that must be met for revegetation of land, which are often tied to a performance bond. While neither DOE nor DoD has such standards, they do have internal regulations and executive orders that serve as drivers for revegetation of disturbances.

Project goals and standards are usually measured in terms of vegetative cover, density (number of plants established per unit area), species diversity, or all of the above. These characteristics of the vegetation are used to measure success and determine costs and, therefore, must be realistic; otherwise, success may be unattainable. Interim goals and standards are often desirable to ensure that the process is on track and will eventually reach the long-term goal.

Determining Site Preparation Requirements. The effort expended and the equipment required for site preparation varies depending on the nature of the project, remoteness of the site, slope, and soil texture. Site preparation may occur prior to any land disturbance, as a project is completed, or when the site is abandoned or decommissioned and the land is to be returned to its original use. Prior to a disturbance, site preparation may consist of vegetation salvaging or removal, and topsoil salvaging and storage. Salvage of topsoil takes advantage of the existing seedbank and microbiotic activity of the recovered soil and has been used effectively to jump start revegetation (Winkel et al., 1999). Post-disturbance site preparation may include reestablishing natural drainage patterns, alleviating soil compaction, replacing salvaged topsoil, preparing the seedbed and constructing erosion control structures (see Schaller & Sutton, 1978, and Brown et al., 1986 for comprehensive reviews of site preparation practices).

Selecting Species. One of the most important aspects of the revegetation effort is species selection. Native species are often required because they are either adapted to the conditions that will exists at the site after revegetation, or they are disturbance adapted and perform well during the first few years (Wallace et al. 1980; Bainbridge et al., 1998). Past performance of particular plant species in similar conditions and availability of seed or plant material should be considered in the species selection process. The source of the seed or plant materials should be as close as possible geographically to the area being revegetated or originate from similar environmental conditions (e.g., soils, elevation, slope climate). National and local databases with characteristics of species performance (i.e. transplant mortality, ease of germination, availability of seed) can be a valuable resource to identify species adapted to a particular site. Information from these databases and from the site assessment, help determine the species to use and quantity of seed or transplants of each species.

Selecting Techniques. Many factors determine which revegetation technique will be the most cost-effective (i.e., lowest cost for each established plant). Two broad approaches to revegetation in arid environments are seeding and transplanting. Seeding has a much lower initial expense and, where it can provide reliable results, is the preferred approach. Seeding is less reliable when climatic conditions, particularly rainfall, are variable. An alternative to seeding is use of transplants. Transplanting avoids the initial seed germination and seedling survival periods, which often prove to be fatal, however, up-front (i.e., growing and planting) costs are higher. Transplants may require supplemental irrigation particularly in areas with less than 200 mm of rainfall and/or high temperatures. New in-use and under development irrigation techniques (i.e., catchments, pitting, berms, deep watering) direct water to individual plants greatly decreasing the amount of supplemental water needed to establish transplants. At a minimum, transplants need to be watered as they are planted to ensure that the soil is settled around their roots and no air pockets occur near the roots that will cause the plants to dry out. Whether to seed or use transplants is determined by the amount of natural precipitation, its reliability, the harshness of the site, the need to establish a quick cover, the need to establish woody species, the steepness of the side slopes, its priority, and the visibility of the site.

Selecting Conservation and Water Management Treatments. The selection of appropriate conservation and water management treatments often will determine whether project goals are achieved. If it is imperative that a vegetative cover be established on the site as quickly as possible, supplemental irrigation may be appropriate. Irrigating to supplement natural precipitation should be limited both in time and volume to (1) avoid major diebacks when the irrigation is stopped, (2) minimize the potential for increased salts at soil surface, and (3) keep costs low. Costs for irrigation are particularly high when there is not a nearby water source. Fertilization also may be necessary if soils are impoverished and plant responses to fertilizer are favorable. Care must be taken because fertilization may encourage weedy invasive species that compete with desirable species. In the western U. S. protection from wind and water erosion to protect fragile soils and young seedlings is a necessity. It is commonly accomplished with organic mulches (i.e., straw) that add organic matter to the soil, lowers surface temperatures, retains moisture, and shields young seedlings from the effects of wind and water erosion. Compacted soils may retain too much water at the surface and ripping is required to allow water infiltration. Other soils may allow water to move too quickly through the soil profile and soil amendments are needed to increase water-holding capacity. The presence or absence of herbivores may dictate whether the site should be protected. The herbivore species will determine what kind of protection is required. If large grazing animals (i.e. horses, cattle) are the concern, a three-strand barbed-wire fence would be appropriate. On the other hand, a wire mesh buried 25 cm may be necessary to impede rabbit or small mammal access.

Determining Timing. Timing is critical whether transplanting or seeding. Transplanting should take place when plant metabolism is low. For the Great Basin, that may be in the fall before the winter snows or in the spring after the snows have melted and plants are still somewhat dormant. For the Mojave Desert, it could be from late fall to early spring. Seeding must precede the period of reliable moisture so that there will be adequate water available for germination and early plant growth. Seeding also must coincide with a period of suitable growing temperatures. Summer precipitation may be adequate for growth, but temperatures are high and soils dry out quickly making seedling germination and establishment improbable. In the Great Basin and Mojave Desert regions the best period for seeding native plant species is in the late winter or early spring (December – March). In the Sonoran and Chihuahuan deserts where late summer rains are more consistent, late summer and early fall are suitable times for seeding. The schedule for revegetation should be closely coordinated with other entities so biological timelines are not compromised in favor of fiscal timelines.

Evaluating Costs. The cost of revegetation is dependent upon key factors such as types of equipment, techniques employed, size of disturbance, continuous nature of disturbance, remoteness, slope, timing, weather, and experience of the operator or contractor. For some projects, a pre-established budget dictates the level of effort. In all cases it is important to know where to cut, or not cut, costs. Buying seed of unknown quality or not putting up a fence may appear to be a logical place to cut costs but may ultimately doom the success of the revegetation effort. Monetary costs to establish an individual plant or a certain amount of cover should be calculated to obtain the true cost of revegetation. The data should be recorded in some form of database, which can then be used to develop and assess revegetation costs for future projects.

Plan Implementation

The second phase of the reclamation process is plan implementation. This phase requires the selection of an on-site manager to monitor adherence to the revegetation plan, conduct pre-job coordination meetings and oversee revegetation fieldwork.

Monitoring Adherence to Plan. The on-site monitor should know the specifics of the entire revegetation process, know where compromises can and cannot be made, and have a good working relationship with the field supervisor and crew. The purpose of the on-site manager is to insure that the site is prepared and revegetated as planned.

Conducting Pre-Job Implementation Meeting. To ensure a good working relationship with the construction supervisor an implementation meeting should be held well in advance of revegetation work. At this meeting the revegetation plan should be reviewed to ensure clarification of the scope of work. Equipment needs and schedule of use should be detailed, as well as, contingency actions in the event equipment fails. Equipment calibration requirements and other specifications in the revegetation plan should be reviewed in detail. Checklists for equipment maintenance may be valuable. Maps, aerial photos, and diagrams may help the supervisor visualize the area and identify where work is to be done.

Completing Revegetation. Whether working with subcontractor or an in-house revegetation crew, the critical nature of work cannot be over emphasized. If specifications are not followed goals and standards may be compromised. The on-site monitor should ensure revegetation processes are followed, which may include ripping depth, number of disk passes for a good seedbed, mulch thickness and distribution, stem length of straw, application rate for soil amendments (i.e., fertilizer, polyacrylamide gel), and calibration of the seeding rate. In addition the revegetation equipment should be inspected frequently for performance, as well as, safety. Equipment maintenance should occur daily to minimize the potential for equipment breakdown or malfunction. The on-site monitor should not be a member of the revegetation crew but should be free to observe the ongoing work and make recommendations for improvement, as necessary.

Project Evaluation and Long-term Management

When fieldwork is completed evaluation and long-term management begins. The major components of this phase are on-site inspections, success evaluations and implementing mitigation measures. This phase may afford the greatest potential for savings on current and future revegetation projects.

On-site Inspections. On-site inspections are particularly critical in erosion protection projects. Visiting a site after the first major rainstorm helps determine if erosion control treatments (i.e., water bars, contour ditches) function as designed. The objectives are to evaluate the success of the project early on, correct minor deficiencies in order to avoid major problems later, and gather information to generate management practice guidelines for specific site conditions.

Evaluating Success. Species performance during the first six months and periodically over the next five years will indicate whether remedial measures are needed to achieve the goals established for the site. Once plants mature and become established, plant cover and density should be compared with adjacent undisturbed areas or standards previously established. If success criteria are met, monitoring may be suspended or scheduled at longer intervals. Monitoring of restoration projects identifies those treatments or techniques that contribute to the long-term success of the revegetation effort. Once identified, these treatments and techniques can be refined and incorporated into future revegetation plans, leading to greater success and lower costs.

Implementing Modifications. If plant densities are low after the first six months re-seeding or planting may be appropriate. If plant densities decline or plant cover is low after three to five years, other remedial actions (i.e., supplemental water, fertilization) may be employed to increase plant growth, plant vigor or seed set. Usually within five years natural drainage patterns are evident and some recontouring may be necessary.

Project Examples

Reclamation scientists at Bechtel Nevada (BN) have completed a number of revegetation projects over the past several years in the Great Basin and the Mojave Desert. Several of these projects are highlighted in the following sections.

Great Basin. In the semiarid climate of the Great Basin, annual precipitation averages between 180 and 300 mm and generally comes during the winter and spring months. Droughts are common and unpredictable. Seeding is a common revegetation practice in this region. During the last five years, BN reclamation scientists completed revegetation of several sites on lands administered by the Bureau of Land Management at the Central Nevada Test Area (CNTA), DoD-managed lands at the Tonopah Test Range (TTR), and DOE-managed lands on the Nevada Test Site (NTS).

CNTA is located in the Hot Creek Valley of central Nevada (Figure 1) and is dominated by *Artemisia tridentata* Nutt. Elevation at the site is approximately 1860 m, and average annual precipitation during the last 20 years has been 135 mm. During the late 1960s, DOE conducted isolated testing activities in the area. Closure of one of the sites was completed in fall 2000, and included construction of a cover cap over a previous landfill area. The total disturbed area was about 3.24 ha. Seeding was completed in November 2000 and transplanting in April 2001 at the time of several late spring snowstorms. Plant density and cover were estimated in October 2001.

The goal for this revegetation project was to establish a viable vegetative cover as quickly as possible to keep water from infiltrating and compromising the integrity of the cover cap. The strategy was to seed the area in the fall before winter storms and, to ensure an immediate vegetative cover, followed with transplants the next spring. Transplanting was selected because it provided mature plants quickly, and there were concerns that irrigation may affect the integrity of the cover cap. The goal was 7.5% vegetative cover after the first growing season and near 25 percent vegetative cover by the fifth year. The seed mix included five native shrub species and three native grasses. Transplants were custom grown by the Nevada Division of Forestry and included four of the five shrub species included in the seed mix. A total of 4300 transplants were planted on the cover cap. In October 2001 density averaged 46 plants m^{-2} and plant cover was nearly 23%, three times the goal of 7.5% (Figure 2). All eight species included in the seed mix were found on the site, five of them over 90% of the time. Shrubs, established from seeding and transplanting, set seed during the first year and, at some locations on the cover cap, approached 1 m in height.

At TTR a landfill and bomblet pit, previously used by DOE for testing activities, were prepared for closure and the establishment of vegetative. Both sites are located along the edges of Cactus flat at an elevation of 1650 m (Figure 1). Site-specific reclamation plans were developed taking into consideration the unpredictability of the 130-150 mm of annual precipitation and the potential effect of an increasingly large herd of wild horses (Anderson & Hall, 1997). Revegetation was completed in November of 1997. Monitoring was conducted in the spring of 1998 and again in 2000 to verify that a viable vegetative cover was reestablishing and to document any concerns or issues that may have developed (i.e., severe erosion, subsequent use or disturbance of the site).

At the landfill site dominant shrubs are *Atriplex canescens* (Pursh) Nutt., *Chrysothamnus greenei* (A. Gray) Greene, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, and *Artemisia spinescens* D.C. Eat.; and the dominant grasses are *Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth and *Elymus elymoides* (Raf.) Swezey. The alluvial soils are deep and sandy, with little profile development. Closure activities left a pit 6 m deep in places and steep side slopes. The pit and slopes comprised about 60% of the total disturbed area (0.93 ha); staging areas and access roads made up the balance. Challenges with this particular site were (1) stabilization of the loose sandy soils, especially on the side slopes, and (2) protection of the site from herbivores, primarily wild horses and rabbits. Irrigation was not justified because the landfill is not highly visible nor is it a priority area. Seed germination and plant establishment would rely on natural precipitation.

During site preparation, the ridge of the slope was pushed into the pit, thus reducing the angle of the side slopes and creating a depression rather than a pit. All work (i.e., disking, seeding, crimping) along the slope was perpendicular to the slope, thus creating mini-terraces and reducing the potential for downhill runoff and gullying. Once completed, the site was fenced to prevent intrusion by wild horses and rabbits. Seeding of native plant species was completed prior to fall/winter precipitation. The site was mulched at 5600 kg ha^{-1}, about 1000 kg ha^{-1} more than usual, to provide additional organic matter and structure to the sandy soils.

The goal of revegetation was to reestablish a cover of native plants on the closure site similar in density and cover to an adjacent undisturbed reference area. After the first growing season, shrub density was 2.8 seedlings m^{-2} and grass density was 7.4 seedlings m^{-2}. By the end of the third growing season, the number of shrubs declined to 0.7 m^{-2} and grasses declined to 7.0 m^{-2}, which is not unexpected. Plant densities are from 10 to 25 plants m^{-2} after the first year but gradually decline until densities are comparable to the adjacent undisturbed area, which for this site is 3.1 plants m^{-2} (1.6 shrubs m^{-2} and 1.5 grasses m^{-2}). The percent vegetative cover on the revegetated site was almost the same as on the adjacent reference area, 15.8% compared to 16.7%, after just three growing seasons. There are no signs of soil erosion on the site. The high plant densities, plant cover, and diversity suggest that this site is “on track” for meeting revegetation goals.

Atriplex confertifolia (Torr. & Frem.) S. Wats, *K. lanata* and *A. spinescens* are the common species found at the bomblet pit site. The total area of the site is a little more than 0.5 ha. The challenge at this site was to reestablish native plant species on a site completely dominated by weedy species, primarily *Halogeton glomeratus* (Bieb.) C.A. Mey. During site preparation, the surface soils laden with *H. glomeratus* seed were scraped into small pits that had been dug during closure activities. The goal was to bury the *H. glomeratus* seed at a depth detrimental to germination. Areas compacted during closure activities were then ripped, and the site was seeded and mulched. Again, quality seed of native species was used, including *A. spinescens* that had been collected just a few kilometers to the south of the site. This site, like other closure sites, was fenced to deter rabbit and horse entry. Plant density increased from 13.6 plants m^{-2} in 1998 to 16.9 plants m^{-2} two growing seasons later. Most encouraging was the trend in the density of *H. glomeratus*. The first year after revegetation 5.1 *H. glomeratus* plants m^{-2} were found, more than on the adjacent reference area (4.0 plants m^{-2}). By the spring of 2000, however, the density of *H. glomeratus* had declined to 2.1 plants m^{-2}. Plant cover in 2000 on the revegetated site was 22.5%, almost double that found on the adjacent reference area. About 30% of the total cover was grass, which is encouraging because grasses were absent in the reference area in spring 2000.

The Double Tracks remediation site is located on the western slope of the Cactus Range and the northwestern edge of Stonewall Flat at an elevation of about 1525 m (Figure 1). This site is in a transition zone between the Great Basin and Mojave Desert. *K. lanata*, *Sarcobatus vermiculatus* (Hook.) Torr., *A. spinescens*, and *A. confertifolia* are the common shrubs; and *A. hymenoides* and *E. elymoides* are the most common grasses. Native soils are a gravelly sandy loam. Average annual precipitation is 13.2 cm. Remediation at the site was completed during the fall of 1996 and included removal of the surface 50 to 150 mm of contaminated soil from approximately 1.21 ha (Figure 3). Supporting operations disturbed an additional 2.43 ha for a total of 3.64 ha disturbed (Anderson & Hall, 1996). Reestablishment of a vegetative cover on the exposed subsurface soils was a high priority. Major challenges for this site were low and very unpredictable annual precipitation, as well as, the complete loss of topsoil and, with it, the seed pool, organic matter, and soil nutrients. The approach addressed precipitation and soil loss problems. A portable irrigation system was designed and constructed to supplement the meager annual precipitation. The objectives were to provide water at a level similar to a good growing season (i.e., where precipitation is greater than average) and at the time when most needed, mainly late winter and spring. The seed mix used included 11 different species of shrubs, three grasses, and one forb. All species are native to the area. A polyacrylamide gel was used to increase the water holding capacity of the soil. The gel was applied at a rate of about 1.12 kg ha^{-1}. No fertilizers were used because experiments conducted previously at this site and other sites in the region suggested that fertilizers favored annual grass vigor and had little effect on native species. Revegetation was completed in November 1996. Irrigation began in December 1996 and continued at monthly intervals until June 1997. The equivalent of 112 mm of precipitation was applied to the site.

Revegetation success was evaluated in the spring of 1997 and 1998. In 1997, there were 5.3 shrubs m^{-2} and 3.4 grasses and forbs m^{-2}. By June 1998, shrub density had decreased to 3.1 plants m^{-2}. The density of grasses and forbs increased slightly to 3.8 plants m^{-2} (Figure 3). The average plant density was about three times the average of 2.1 plants m^{-2} estimated for the adjacent native plant community that same year.

Mojave Desert. The Mojave Desert is one of the driest deserts in North America with average annual rainfall under 100 mm. Variability of this rainfall also makes the Mojave one of the most difficult places to revegetate. There are more than 0.8 million ha of DoD-managed lands in the Mojave Desert (Briuer & Hebler, 1992) that are often heavily impacted by military training and other activities. Seeding has not proved to be an effective strategy for revegetating the disturbed areas. Much better success has been achieved using transplants, but this has been very costly and results are still often disappointing.

BN scientists have worked on two Mojave Desert sites with the objective of making seeding a more viable alternative to planting. Most of the work has been on small sites where reclamation trials or experiments were implemented as part of interim or final reclamation plans. One of the sites is Yucca Mountain, located in the southwestern corner of the NTS approximately 145 km northwest of Las Vegas, Nevada (Figure 1). Yucca Mountain ranges in elevation from 915 to 1524 m at the summit. Rainfall varies with elevation and has ranged from 0 to 300 mm annually during the last 10 years.

Reclamation studies at Yucca Mountain have been varied and extensive (Winkel et al., 1999). Two of those studies are noteworthy and provide data on techniques that have been successful in the Mojave Desert.

The first study demonstrated a variety of reclamation techniques at a site where the existing vegetation was a mix of C*oleogyne ramosissima* Torr., *Larrea tridentata* (Seese & Moc. Ex DC.) Coville, and *Ambrosia dumosa* (Gray) Payne. The reclamation techniques included 33 different treatments in five categories: water conservation, amendments, seeding techniques and rates, mulching, and irrigation. Germination during the first year was excellent for many treatments because of adequate precipitation (165 mm) from December

1991 to March 1992. Seedling density on seeded plots averaged nearly 29 plants m^{-2} compared with the unseeded control of <2 plants m^{-2}. The treatment showing the highest density (64.2 plants m^{-2}) was drill-seeded, mulched and a water-absorbing polyacrylamide gel mixed into the soil. In the spring of 1993, average seedling densities for all treatments had dropped from 29 plants m^{-2} to 5.7 plants m^{-2}, which is above the average density in the adjacent undisturbed vegetation (1.1 plants m^{-2}). The treatment with the highest density (13 plants m^{-2}) in 1993 was broadcast-seeded at double the normal rate and mulched with straw. Treatments that did poorly were those with compacted soils or where fertilizer had been applied. The unseeded control treatment had <1 perennial species m^{-2} in 1993, but there was an abundance of weeds.

A second follow-up study at Yucca Mountain focused on the more promising techniques in the demonstration plot and applied a more rigorous statistical analysis. The study design was a completely randomized 2 x 2 factorial with four replicates and analyzed with analysis of variance techniques. The study site was a disturbance several km to the south of the demonstration site. It was extremely sandy (more than 93% sand in the textural analysis), and susceptible to wind erosion. The objective at this site was to control erosion and improve the water-holding capacity of the soil. The treatments included two different types of mulch, crimped straw, and gravel, and with and without an application of polyacrylamide gel. The plots were seeded in late fall 1992. Spring precipitation in 1993 was approximately 77 mm from February to May, which was adequate for germination. Seedling densities were recorded in June 1993 and were excellent with an overall average of 37.7 plants m^{-2}. No difference in species density was found between the mulch treatments. Seedling density was significantly higher, however, on the plots where the polyacrylamide gel was used (41.6 plants m^{-2}) than where it was not (33.3 plants m^{-2}). These plots also were sampled again in 1995. Total densities decreased to 7.1 plants m^{-2} for gel treatments and 5.3 plants m^{-2} for no gel treatments. The mulch treatments were not significantly different in spring 1993 but were significantly different by 1995. The straw mulch averaged 7.8 plants m^{-2} while the gravel mulch averaged only 5.0 plants m^{-2}. These densities are still well above the average density in the adjacent undisturbed vegetation (1.1 plants m^{-2}).

The other site is at Fort Irwin, California, an active U.S. Army training center, located about 60 km northeast of Barstow, California in the center of the Mojave Desert (Figure 1). The dominant vegetation of the area is *L tridentata* and *A. dumosa*. Elevations of the study sites ranged from 600 to 1100 m. Precipitation averages about 100 mm per year. Soils are very sandy and highly disturbed by training activities. Revegetation trials were initiated in 1999. The revegetation trials were stratified based on soils and degree of disturbance. The revegetation strategy included soil stabilization (crimped straw mulch and chemical stabilizer), micronutrient additions, and irrigation. The heavily disturbed sites were all treated with straw mulch. Soil stabilization, fertilizer addition, and irrigation were the major treatments tested. The sites were seeded in December 1999 and irrigated monthly (1-2 days as access permitted) during January-March 2000 to supplement natural precipitation so that monthly levels would be equivalent to the top five high precipitation years during the past 20-year period. Sites were sampled in May 2000, and densities were low (average 0.2 plants m^{-2}) on all but one site (6.3 plants m^{-2}) (Figure 4). This site had soils with more silt and clay-sized particles that retained moisture, and also was at a higher elevation (1100 m), which may have decreased evapotranspiration. At the other sites soil moisture was not adequate for seed germination because of the poor water-holding capacity of the soil and additional water could not be applied more frequently because access to the sites was limited (water could only be applied 1-2 days per month). These results led to a series of experiments focusing on pretreatment of *L. tridenata* and *A. dumosa* seeds. The goal was to achieve germination within a few days of seeding. Field experiments were conducted in spring 2001 at two Fort Irwin sites. Seeds were rinsed in water for approximately 36 hours immediately prior to seeding. Different mulches (i.e., plastic, rock, straw and chemical) were evaluated for their effectiveness in conserving moisture at the soil surface. Within two-three days after planting, densities of *A. dumosa* seedlings were 40-140 m^{-2} and *L. tridentata* seedling density was 10-160 m^{-2}. A plastic mulch provided maximum germination (total seedling densities often exceeding 200 m^{-2}). The lowest densities (38 plants m^{-2}) occurred when a straw mulch was used. This revegetation strategy will be expanded and further tested in spring 2002. It appears that pretreatment of seed, combined with mulching and irrigation at the time of seeding, is a superior technique for the establishment of these two species in the Mojave Desert.

Conclusions

Revegetation of disturbed areas in arid regions of the southwestern U. S. has proven successful when projects have been carefully planned and responsive strategies developed and implemented. In the Great Basin, seeding prior to winter precipitation accompanied by mulching appears to be adequate for seed germination and plant establishment. In the drier transition zone between the Great Basin and Mojave Desert, supplemental irrigation results in highly predictable success. In the Mojave Desert, seed pretreatment accompanied by supplemental irrigation and mulching appears to be a successful combination (Table 1). Future research efforts should focus on the seed-soil moisture interface to understand the soil moisture level required for seed germination and, equally important, define the length of time those levels must be maintained. This information is critical for determining irrigation strategies, amounts of water necessary and, eventually, revegetation costs. Another issue typically overlooked is herbivory. A “rabbit” fence may be the obvious solution, but based on observations in the Mojave, ants may be very important in the loss of seed prior to germination. Various species of small mammals and birds also can be detrimental to revegetation efforts. Quantification of the number of seeds being removed will help determine the impact on revegetation. Successful revegetation in arid regions of the world continues to be challenging, but contrary to the opinions revegetation specialists in the 1970s (Plummer et al., 1968; Wallace et al., 1980), it is far from impossible.

References

Anderson, D. C., and D. B. Hall. 1996. *Double tracks revegetation and monitoring plan*. DOE/NV 11718-104, UC-708. U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada.

Anderson, D. C., and D. B. Hall. 1997. *Tonopah Test Range closure sites reclamation plan*. DOE/NV 11718-115, UC-702. U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada.

Bainbridge, D., R. MacAller, M. Fidelibus, A. C. Newton, A. C. Williams, L. Lippitt, and R. Franson. 1998. *A beginner’s guide to desert restoration*. U.S. Department of Interior, National Park Service, Lake Mead National Recreation Area, Nevada.

Briuer, F. L., and G. A. Hebler. 1992. *Military installations for the southwest region*. (www.wes.army.mil/el/ccspt/dodmap/milca.html). Legacy Resource Management Program, Department of Defense, Vicksburg, Mississippi.

Brown, D., R. G. Hallman, C. R. Lee, J. G. Skogerboe, K. Eskew, R. A. Price, N. R. Page, M. Clar, R. Kort, and H. Hopkins. 1986. *Reclamation and vegetative restoration of problem soils and disturbed lands.* Noyes Data Corp., Park Ridge, New Jersey.

Hall, D. B., and D. C. Anderson. 1999. Reclaiming disturbed land using supplemental irrigation in the Great Basin/Mojave Desert transition region after contaminated soil remediation: Double Tracks. Pp 260-265. in *Shrubland ecotones. Proc. RMRS-P-11*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah.

Plummer, A. P., D. R. Christensen, and S. B. Monsen. 1968. *Restoring big game range in Utah*. Publication No. 68-3. Utah Division of Fish and Game, Ephraim, Utah.

Roundy, B. A., E. D. McArthur, J. S. Haley, and D. K. Mann. 1995. Wildland shrub and arid land restoration symposium. *General Technical Report INT-GTR-315*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah.

Schaller, F. W., and P. Sutton, eds. 1978. *Reclamation of drastically disturbed lands.* American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin.

Wallace, A., E. M. Romney, and R. B. Hunter. 1980. The challenge of a desert:

Revegetation of disturbed desert lands. pp 216-225 in S. L. Wood Ed., Great Basin naturalist memoirs: *Soil-Plant-Animal Relationships Bearing on Revegetation and Land Reclamation in Nevada Deserts*. Brigham Young University, Provo, Utah.

Winkel, V. J., K. W. Blomquist, J. P. Angerer, M. W. Farris, and W. K. Ostler. 1999. Reclamation feasibility studies at Yucca Mountain, Nevada: 1992-1995. *Civilian Radioactive Waste Management System Report B00000000-01717-5700-00003 Rev 00*. U. S. Department of Energy, Yucca Mountain Site Characterization Project, Las Vegas, Nevada.

Table and Figures

Table 1. Summary by ecoregion of revegetation projects completed during the last 10 years.

Figure 1. Location of reclamation project sites in the Great Basin and Mojave Desert. Key to sites is as follows: GB1 = Central Nevada Test Area; GB2 = Tonopah Test Range, Landfill and Bomblet Pit; GB3 = Tonopah Test Range, Double Tracks; MD1 = Yucca Mountain; and MD2 = Fort Irwin.

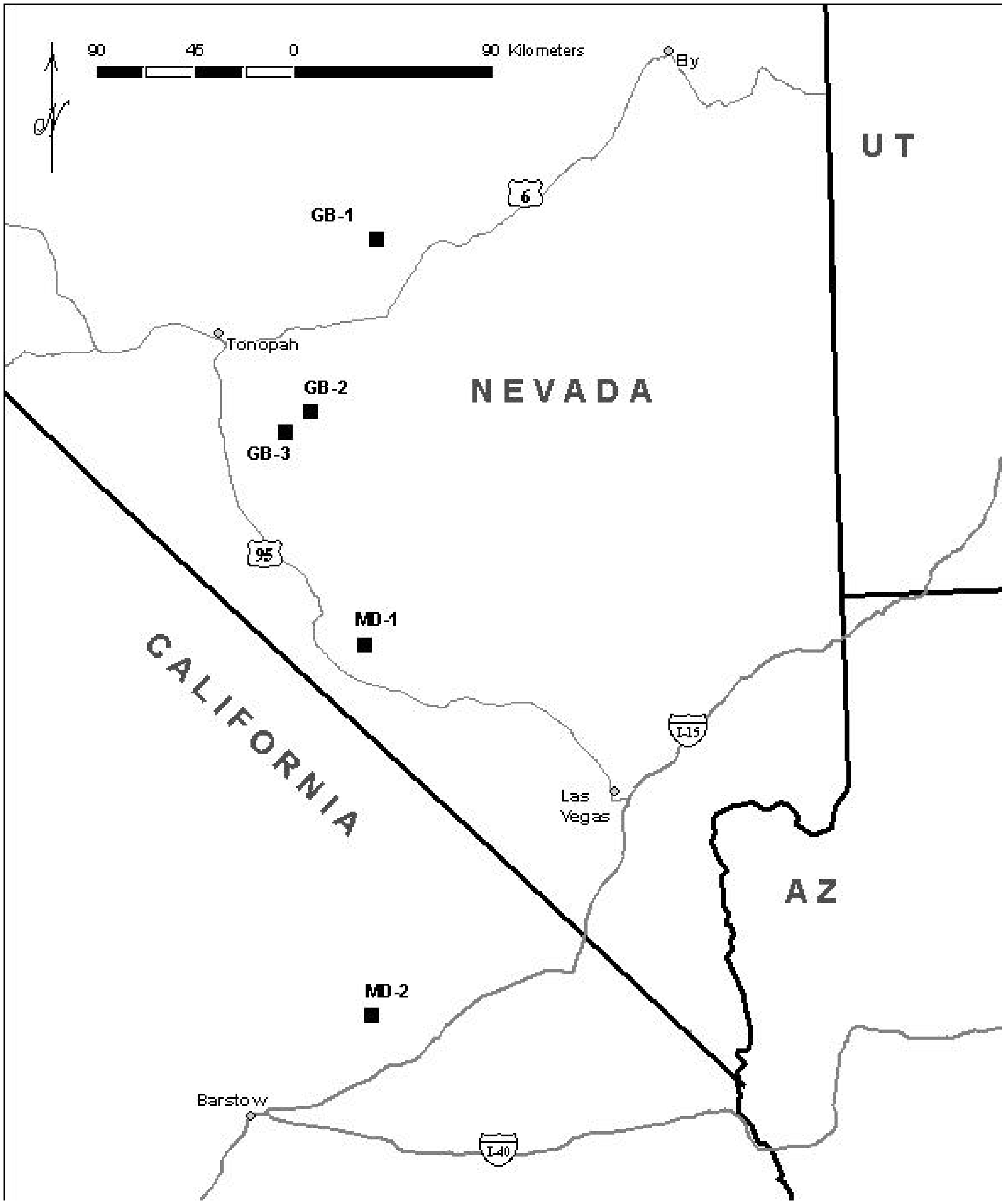
Figure 2. Top: Site preparation at Central Nevada Test Area was completed in October 2000 followed by revegetation in early November. Bottom: One growing season after revegetation, October 2001.

Figure 3. Top: Ground zero and plume area after site preparation at the Double Tracks site, October 1996. Bottom: Double Tracks site two growing seasons later, June 1998.

Figure 4. Top: Drinkwater site after seeding, December 1999. Bottom: Drinkwater site, May 2001, two years after revegetation.

Ecoregion	Location	Soils	Treatments	Plant Density # m^{-2} (Reference)	Plant Cover % (Reference)	Time[1]
Great Basin	CNTA	Fill material	Ripping Seed/Transplants Mulch Fence	46 (goal 9.0)	23.0 (goal 7.5)	3
	TTR landfill	Fill material	Recontouring Seed Mulch Fence	10.2 7.7 (3.1)	Not collected 15.8 (16.7)	1 3
	TTR bomblet pit	Fill material, surface disturbance	Bury surface soils Seed Mulch Fence	13.6 16.9 (8.0)	Not collected 22.5 (18.5)	1 3
	TTR Double Tracks	Subsurface soils	Disk Seed Mulch Fence Irrigate	8.7 6.9 (2.1)	Data not collected	1 2
Mojave Desert	Yucca Mountain	Disturbed (1992)	Seed-2 x rate Straw Mulch	13.0 (1.1)	Data not collected	2
		Disturbed (1993) Sandy soils	Gel Seed Straw Gravel	7.1 (1.1)	8.3-10.6 (8 – 16)	2
	Fort Irwin	Disturbed	Disk Fertilize Seed Mulch Irrigate Fence	6.3 (data not collected)	Data not collected	1

1 - Number of growing seasons between sampling and revegetation.


90
45
0
90 Kilometers
N
Ely
UT
6
GB-1
Tonopah
GB-2
NEVADA
GB-3
95
MD-1
CALIFORNIA
I-15
Las
Vegas
AZ
MD-2
Barstow
I-40