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Restoration of Damaged Lands at the National Training Center

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The National Training Center at Fort Irwin is a military base located north of Barstow (San Bernardino County, California) in the Mojave Desert. The base encompasses nearly 260,000 hectares and is used as the United States Army's center for desert training. Training operations at the base include large-scale ground maneuvers with tanks and wheeled vehicles, as well as live-fire and military training activities.

As a result of the military training operations, the shrub cover has been severely diminished and in some areas eliminated. The desert soil structure has also been severely disturbed and compacted. The damaged lands have increased erosion from wind and rain resulting in gully formation, and the loss of the native environment for military training. With the natural soil stabilizers removed, wind and water remove the fragile, nutrient rich top layer of soil. The dust released from the barren soils has caused a secondary health hazard to humans. The soil compaction also slows natural plant recolonization rates due to slow water infiltration. Restoring vegetative cover is the best solution for erosion control and the reclamation of the military base.

To assist in restoring the disturbed lands at the United States Army's National Training Center (NTC), the Integrated Training Area Management (ITAM) program whom are army affiliated, and the Soil Ecology Restoration Group (SERG), which is a program from San Diego State University, developed a comprehensive restoration plan identifying damaged areas. A list of sites in need of erosion control, revegetation, and a management plan was devised from the studies. Along with numerous restoration projects, a variety of revegetation, erosion control, and windbreak sites to reduce airborne dust particles have been installed throughout the NTC.

Based on the results of the studies and surveys of the damaged sites, several large-scale restoration projects were initiated to prevent further damage as well as to repair and improve existing conditions at the base. The projects are up to 20 hectares in size. The projects include large-scale soil modification such as ripping and/or pitting to improve water infiltration, seeding and planting trials, irrigation methods, and several, large-scale erosion control methods. Goals for these projects include immediate restoration results, visual blocking of excess trails to prevent further destruction and the establishment of windbreaks to aid in the elimination of harmful dust particles. Data and information collected from these projects will be used to develop the most cost effective methods for future restoration projects not only at the National Training Center but other ecosystems throughout the Mojave Desert.

Ecology of Target Ecosystem

To the southwest of the NTC lie the San Gabriel-San Bernardino Mountains and to the northwest lies the Sierra Nevada Mountain range. The Mojave climate is cooler than the neighboring Sonoran Desert because it is a higher great basin. The Mojave Desert's climate is characterized by extreme variable temperature, and an average annual precipitation of less than 13 centimeters, most of which falls during the winter months. Summer months are hot, dry and windy, while freezing temperatures commonly occur during the winter.

The Mojave has a typical mountain and basin topography with sparse vegetation. Though some do not consider the Mojave a desert in its own right, it provides a habitat for nearly two hundred endemic plant species found in neither of the neighboring deserts. The vegetation at the National Training Center consists of "Creosote bush scrub (*Larrea tridentata, Ambrosia dumosa, Encelia frutescens, Encelia farinosa, Senna armata, Psorathamnus arborescens, Hymenoclea salsola,* and others), salt bush scrub (*Atriplex polycarpa, Atriplex confertifolia, Atriplex canescens,* and others), at higher elevations black

bush scrub (*Coleogyne ramossissima, Yucca bacata, Lycium* sp. and others), and Mojave Desert wash (*Senna armata, Hymenoclea salsola, Larrea tridentata,* and *Ambrosia dumosa*). Unique plant assemblages also occur (*Prosopis gladulosa* var. *torreyana, Prosopis pubescens, Atriplex hymenolytra, Allenrolfea occidentalis, Sueda moquinii* and others) at the various springs throughout the base (SERG, 2000)". Unlike the Neighboring Sonoran Desert, trees are few, with the exception of the Joshua tree at higher elevations, only found in the Mojave Desert. The NTC though, remains at a lower elevation than the Joshua trees.

Restoration Techniques and Management

Desert ecosystems have evolved to withstand severe conditions. Plant species regeneration occurs predominantly in years that are above average in rainfall. In the Mojave Desert, freezing temperatures during the winter months further inhibits regeneration. For the Mojave Desert, sufficient moisture for regeneration is only available during the months of December and January. However, nighttime temperatures often dip below freezing during these months, damaging or killing new growth. Therefore, desert ecosystems may take centuries to recover without active intervention. Disturbances can further slow this process. The uncertainty, and harshness of the Mojave Desert climate and conditions make restoration difficult. Thus, a variety of restoration, revegetation, and management practices were required to assist in the restoration and reclamation of the National Training Center. SERG and ITAM on a base-wide scope used a wide variety of restoration methods to accomplish their goals. They included: **Protecting sites from further disturbance**. This was accomplished by limiting access to the damaged areas so that seed or vegetation had time to establish. **Seed Collection**was a priority at the sites to increase the likelihood of survival rates and site adaptation. **Decompaction** techniques were widely used throughout the base. Tanks and other heavy equipment were the cause of soil compaction to considerable depths, which has increased sheetflow and eliminated seed germination sites. Deep ripping using one-meter ripper bars was the preferred technique for decompaction. **Micro catchments** were created at numerous sites in order to concentrate available rainfall by shaping the ground. **Soil Amendments, i**ncluding bark chips, local plant litter, straw, and large wood chunks aided in the reduction of dust particles, and improved plant establishment and survival. Though difficult, **gully control** through stabilization methods using riprap, sandbags, or check darns was practiced. **Direct Seeding** within the modified microsites was practiced to increase germination and reduce costs. Along with direct seeding, **container shrubs and trees** were used for revegetation and restoration efforts for immediate dust trapping results, as well as improving site conditions by trapping organic matter, symbiont propagules and increasing water infiltration. **Protecting natural volunteer plants** was an inexpensive method for vegetation recovery and was used whenever possible at the National Training Center. **Vegetation islands** were used to concentrate resources and create islands that provide seed and innoculum for surrounding areas. **Tree and shrub windbreaks**were established to help control the air pollution caused by dust. **Pitting** techniques aided in erosion control. Slopes were pitted with tools in order to create pits that would help reduce erosion and increase the soil moisture level.

Specific Sites, Materials, and Methods
The data and information from the studies of the disturbed sites was used as the basis for the long-term restoration and maintenance projects. SERG and ITAM along with the National Training Center's environmental division conducted five main, large-scale restoration projects throughout the base. These projects Include:

The Langford Lake Windbreak Site
This site consists of a 5-hectare plot at an elevation of 623 meters. Due to vehicular traffic, the sandy soil has become highly compacted. The site slopes slightly to the southeast and sheet flow and small wash runoffs have occurred after moderate rainfalls. There were no plants established on this site. The surrounding vegetation though, consists of Creosote bush scrub, mainly *Larrea tridentata*, *Ambrosia dumosa*, and *Encelia frutescens*.
The soil surface was ripped to a depth of three feet, and fifty parallel, one hundred foot long berms were installed. The berms pointed toward the east and were spaced about one hundred feet apart. The purpose of the berms was to provide a screening/barrier to prevent vehicles from entering the site, and also to aid in dust and erosion control.
A total of eight hundred plants of species including *Isomeris arborea, Prosopis glandulosa, Atriplex canescens, Atriplex polycarpa*, and *Larrea tridentata* were planted on the berms in which an irrigation system existed. To assist with the windbreak effect, the tallest species (*Prosopis*) and the larger evergreen species (*Larrea* and *Isomeris*) were evenly planted throughout the site to create a consistent windbreak.

Bunker Revegetation Site
The Bunker revegetation site is a quadrangle of about 9 hectares, at an elevation of 645 meters. This site is generally flat but drains from west to east. The soil is sandy and was moderately compacted except where trails pass through, creating areas of severe compaction. The Bunker site vegetation mainly consisted of *Larrea tridentata, Ambrosia dumosa, Ephedra nevadensis,* and *Hymenoclea salsola*
The trails were ripped to a depth of 1 foot, and the trails at the perimeter of the worksite had been improved to keep the traffic at the perimeter. The north side of the site contained the most vegetative cover while the rest of the site was more or less "spotty". A series 165 mounds were constructed around the perimeter of the site to discourage traffic. The mounds were installed about 5 meters apart from one another. Each mound was two to three meters long, one meter wide, and almost one meter high. An average of five plants were planted on each of the 165 mounds. Roughly one thousand plants were planted, including: *Ambrosia dumosa*, *Larrea tridentata*, *Encelia frutescens*, *Hymenoclea salsola, Ephedra nevadensis*, *Senna armata*, and eight minor species. Irrigation techniques were used to establish the plants.

The Southern Sites
The southern sites consist of two projects identified as the bivouac site and as Hill 526. These sites were heavily denuded sites and the restoration focused on revegetation and decompaction.
The bivouac site, used in training exercises, encompasses about 5 acres and is surrounded by vehicle trails. The bivouac site is in a creosote bush scrub vegetation zone with the dominant plants being *Larrea tridentata* and *Ambrosia dumosa,* and contains a sandy soil that has suffered low to moderate compaction. Due to training and encampment activities, the bivouac site had a general loss of vegetation in the middle area and left the perimeter partially void of vegetation.
All tank trails were closed and there was no access into the worksite. Trails running through the bivouac site were closed off to discourage any more damage. These trails were closed by the construction of 2 mounds, 5 meters apart at the entrance of each trail. A total of eight mounds were created to close off the trails. Each mound was planted with 10 nursery grown shrubs. Forty plants were planted at the base of the mounds and 43 were planted at the top of the mounds. In the mounds, 8 by 61 cm deep pipes were placed for irrigation. The closed trails behind the mounds were pitted and a native seed mix consisting of *Ambrosia dumosa, Brickellia incana, and Encelia sp.* was used to revegetate disturbed trails.

The Hill 526 worksite lies at an elevation of 450 meters at the northern end of the base of a hill that has an elevation of 466 meters. Hill 526 is 28 acres large and lies within a rectangle of vehicular trails. Soil compaction is a moderate problem and the mild slope makes erosion control a low priority. The soil was sandy and the area was a creosote bush scrub vegetation zone.
Revegetation was the main concern at Hill 526. This site was sectioned off into three areas based on the amount of existing vegetation found on the site. The northeast area of Hill 526 is where most dense vegetation exists. In this area sixty, 1-meter basins were constructed and planted with 2 nursery grown shrubs. The northwest area of the site where less existing vegetation was, one hundred-forty two, 1-meter basins were constructed and planted with two nursery grown shrubs. The species planted in the basins include: *Ambrosia dumosa, Encelia farinosa, Encelia frutescens, Hymenoclea salsola, and Isomeris arborea*. Direct seeding occurred in this northwest section as well as the unplanted southern section.

Hill 760

This worksite is approximately 700 meters in elevation and is located in the foothills of the Tie Fort Mountains. The soil is a sandy texture with a moderately compacted soil structure. Hill 760 is in a creosote bush scrub vegetation zone with the main vegetation consisting of *Larrea tridentata* and*Ambrosia dumosa*. Hill 760 is approximately 6 acres large and is predominately affected by sheet erosion. A management plant was needed to prevent any further erosion from happening by shaping the land and creating water catchments. Revegetation was also used for restoration purposes and erosion control.
Four water catchments were constructed in the washes of the hill, four meters in diameter with a depth of one meter. Each catch contained different water control treatments including: rocks with punched broom corm; coir netting; jute netting; and curlex netting. Six hundred plants were planted including: *Ambrosia dumosa, Atriplex canescens, Atriplex polycarpa, Hymenoclea salsola, Isomeris arborea* and *Larrea tridentata*. In order for improved plant survival and to improve revegetation from the seed bank the surface topography was modified, and small contour swales and micro catchments were installed. In each of the three corners of the triangular site a large berm was constructed and planted with shrubs. Drip irrigation was installed in each of these berms. Protective zones were built around the ten largest *Larrea tridentata* shrubs by building small berms one meter long and one half meter high. The berms were placed fifteen feet away from the shrubs in a triangular pattern. In each of the revegetation berms constructed in the corners of the site, one hundred-five plants were installed. A drip irrigation system was also installed in these berms. At the edges of the main vehicular trails that pass through Hill 760, twenty smaller two-armed berms were constructed. The crotch of the two-armed berms faced uphill to catch any sheet flow from heavy rains. Each of these catchments was planted with five nursery grown shrubs on the uphill side of the berm. Drainage pipes were installed in each berm for irrigation. All work for Hill 760 was completed by December 1998.

Windbreak Site

The fifth restoration site at the NTC is the windbreak site. This site has two seasonal streams running through it and its topography consists of “rolling alluvial hills”. The tank trail passing through this site was highly compacted and has rocky soil. Soil organic matter on the windbreak site was extremely low along with nitrogen levels. A three quarter mile long native plant windbreak was installed to help reduce airborne dust.
The tank trails were ripped to a depth of 30 to 45 cm and then graded in order to construct a water catchment area. After the irrigation pipes were installed the windbreak was planted with four different native species: *Prosopis glandulosa, Isomeris arborea, Chilopsis linearis,* and *Atriplex polycarpa*.

Results and Discussion

Work at the National Training Center was finished between 1997 and 1998, and necessary watering and site maintenance took place regularly after installation. Due to the scant amount of rainfall in the ensuing years, watering was conducted at a regular basis at the main sites. The shaping of the soil by pitting and

micro-catchments proved effective for concentrating available rainfall and aided in the high plant survival rates, which overall, averaged about seventy-five percent.
Direct seeding was proven ineffective under the desert conditions. The southern sites showed no signs of seed germination. This may have been due to the scant amount of rainfall, though the direct seeding approach is very vulnerable to the severe desert conditions and is often unsuccessful.
Along with the severe conditions, herbivory, and vehicular damage were also concerns at the NTC. At Hill 760 all of the large unprotected shrubs (roughly 63) were reduced to stubs by rabbits or damaged by vehicles shortly after planting. Plant protectors were soon installed in order to prevent further damage. The continual use at the base compacted the soil at the site once again and would hinder the roots from spreading out of the loose soil, decreasing the chances for plant survival.
Data that was collected at the windbreak site gave an indication of which species may be more resistant to the harsh desert conditions. The mesquite (*Prosopis*), bladderpod (*Isomeris*), and desert willow (*Chilopsis*) had grown out of the tree shelters they were planted in, and some of the *Isomeris* had set fruit two months after planting. After two months the allscale (*Atriplex*) had the highest survival rate at 98%, then the mesquite at 91%, then the bladderpod at 85%, and the desert willow at 84%. The mesquite appeared to be the most successful species for a windbreak installation. The overall survivorship of the 824 plants was 729 (84%) as of June 1997.

Conclusion

Desert areas disturbed by human activities may take many decades to recover without intervention. Recovery from human disturbance is very slow in the harsh conditions of the Mohave desert. The severe compaction that has taken place over the years at the NTC has reduced soil moisture and the native soil conditions have been severely affected. The disturbances at the NTC have reduced the concentrations of available nitrogen as well as organic matter and soil fungi. Though too early to tell, the measures taken at Fort Irwin that include the ripping of the soil and water catchments may prove efficient in restoring the "native" soil.
Due to the low levels of rainfall and rapid evaporation in desert conditions, water is most frequently the factor limiting the establishments of plants. The irrigation techniques and water have allowed for the high success rates at Fort Irwin. Because of the extremely low germination results more attention ought to have been paid to the areas where direct seeding had taken place. A successful direct seeding method would greatly improve revegetation efforts at the NTC. Though still not considered a long-term project, an establishment of an effective restoration procedure has been made and continues to be managed and monitored.
An issue that needs to be raised will be the effectiveness of this restoration project. Due to the continual use of the base, plant survivorship will eventually decline in the ensuing years. The proper steps, though, have been taken to encourage revegetation, and limiting the number of trails that provide access to the sites, which, in turn, increases soil compaction. These steps will aid in water infiltration and the rise in organic matter.
A natural desert ecosystem will not arise with continual training activities. Restoration will be most effective when focused on the fringe areas where damage has not been as severe. This will provide a buffer zone for less-used areas. Finally, a long term monitoring program can help the National Training Center provide significant data to ensure establishment at the sites in future projects.

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