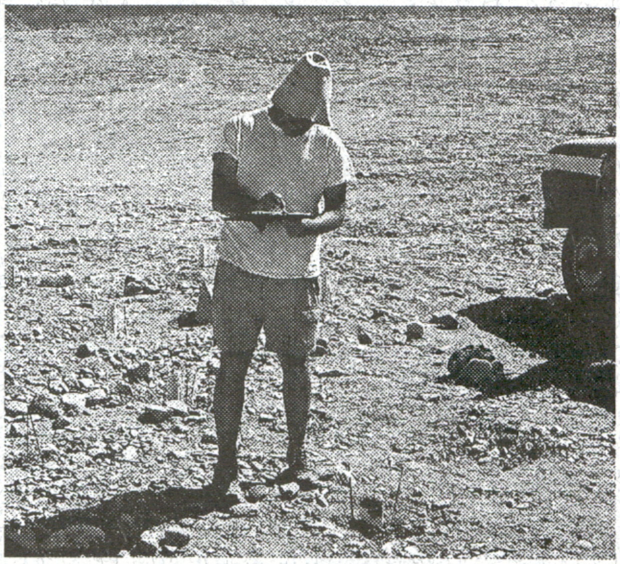

A Beginner's Guide to Desert Restoration

Based in large part on research reports from the Soil Ecology and Restoration Group, SDSU Biology. Some excerpts from a book on "Desert Restoration" being prepared by D.A. Bainbridge and R.A. Virginia, by permission of the authors. Photos by David Bainbridge.

Cover Photos:
Travertine Borrow Pit, 1989 (top)
Travertine Borrow Pit, 1993 (bottom)

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September 1995

A Beginner's Guide to Desert Restoration

United States Department of the Interior • National Park Service • Denver Service Center

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PURPOSE AND SCOPE

Desert restoration, like restoration in other areas, has suffered from a lack of communication among active and past restorationists. The Desert Restoration Task Force is working to improve communication by making this guide available in both print and electronic form. We expect this to be a working document that will be updated as information is shared and new lessons are learned. Our understanding of how desert ecosystems function and how to restore them is growing, but limited; but there are still many successes to report. By communicating both successes and failures, we can build on the knowledge base rather than repeating the same mistakes.

To many restorationists, the terms restoration, revegetation, rehabilitation, and related terms refer to the use of native flora to reestablish native communities. We hope this document will be useful to anyone planting desert flora. We are specifically targeting restoration practitioners, regulators, native plant growers, and native seed collectors. It should also prove useful for foresters and range managers on seasonally dry sites in the Southwest.

Desert areas may take centuries to recover from human disturbance without active intervention and restoration work. This is not surprising as establishment in this severe environment is naturally slow and disturbance can make conditions for plant establishment many times more difficult.

The function and structure of desert ecosystems has been the subject of research for almost 80 years; but much remains to be learned about virtually every aspect of these fragile lands. This is particularly true for the complex interactions involved in soil restoration and plant establishment. Restoration practices can be improved by testing a range of options that previous research suggests are "best bets" and reporting the results — even when they are disappointing. Reporting all projects can help fine-tune treatments and improve recovery rates on future restoration sites. Accurate descriptions of projects can also make future follow-up possible for long-term evaluation of survival and success in restoring structure and function to damaged desert ecosystems.

This report describes promising restoration methods and approaches. The paper is organized into sections which describe key issues: restoration planning, soil management, water management, seed management, strategies for plant establishment, and follow-up and monitoring.

Effective planning can maximize the benefits achieved with limited money and time. The planning process should consider: site evaluation, project timing, determining restoration goals, determining the best course of action, implementing the restoration project, and follow-up monitoring and reporting.

These steps are considered separately and in order.

TIMING

DO plan at least one year (two years is better, six months is minimal) in advance of the ground work of the project. You must determine the following needs right away:

- seed required or desired (species and amount)
- plants (species — size, container, and number)
- any specialized equipment and labor that must be contracted

IF YOU NEED SEED AND/OR PLANTS

DO plan to collect seed at full maturity or hire an experienced and respected seed collector to collect local seed for you.

DO NOT expect seed companies to have locally collected seed from species you desire.

DO NOT assume seed set will be plentiful or viable for all species you are interested in every year (see "Seed Management" for details).

South Flat, Red Rock Canyon State Park, was studied before planting began. Survival and growth have been good.

DO expect to give nurseries locally collected seed to grow seedlings for you.

DO NOT expect nurseries to be able to deliver appropriately grown seedlings in less than four to six months, some species have a four- to six-month stratification for seed alone.

DO as soon as you can, if you can, restrict use and protect the area from further damage or disturbance.

SITE DESCRIPTION AND EVALUATION

DO take the time to develop an accurate evaluation and description of the site. On a regional scale, characteristics of interest include land uses, land units, soil type, historical review, vegetation hydrology, distribution of wildlife, existence of wildlife corridors, and rare and endangered species. On a site-specific scale, characteristics of interest include regulations pertaining to the site, other interested parties (collaborators, etc.), severity of problem(s), agent(s) of disturbance, and nature of structural and functional problems. A careful description of the project site can make future follow-up possible for long-term evaluation of the restoration project by others. (Site evaluation forms are available from the Soil Ecology and Restoration Group, San Diego State University, San Diego, CA 92182. Please send a large self-addressed and stamped envelope.)

RESTORATION PROJECT GOALS

DO determine reasonable and meaningful goals for the restoration project. Find a site comparable to the disturbed site that is relatively "pristine." Take measurements of plant community composition, vegetation density and cover, soil strength, infiltration, soil organic matter and nutrients, and/or other measurements of interest. Compare the two sites. The "pristine" site is your ultimate goal, but you may not have the time or money to achieve that. You must determine what meaningful progress toward these goals is for your project.

DO NOT assume an area is pristine because it has a higher density or cover of plants. Look at sites carefully and consult with others until you are convinced you have a reasonable comparison to your disturbed site. Develop site histories if you can.

BEST COURSE OF ACTION

DO determine a "best bet" course of action. It is a good idea to try a variety of methods since in the long-run you will be able to weed out the less effective methods and get better results. A range of treatments also makes it more likely one will be well suited for the conditions of the year. Review all the site specific information you can find and evaluate success on other sites in comparable ecosystems. Develop contingency plans in case the unthinkable happens: you do not get any seed set, none of your seeds were viable, it does not rain, it rains too much, etc.

DO NOT put all your eggs in one basket. Tackle the problem in a variety of ways to avoid a complete project failure.

IMPLEMENT THE RESTORATION PROJECT

DO the ground work for the project in a time of year that works with you not against your efforts. For example, plant seedlings or direct seed in the growing season when they will naturally receive some water or they are most active. Try to not let bureaucratic time drive biological considerations.

FOLLOW-UP

DO monitor the project over time and compare its progress with your set goal, and communicate your results with other restorationists. If your goals are not being met, then redesign your methodologies to see if the results improve.

DO NOT keep "mistakes" to yourself, even the best cannot always hit the right note. Others can greatly benefit by knowing what has already been tried with and without success. The following outline provides a more detailed program for planning and implementing a restoration project.

A SITE PLANNING OUTLINE

Planning the Study

- Identify objectives.
- Specify area to be covered.
- Identify collaborating institutions and staff (including volunteers).

Regional Reconnaissance

- Identify, map, and describe major land units, soils, vegetation, hydrology, distribution of wildlife, wildlife and human corridors, and rare and threatened species.
- Do a library and literature review of similar sites.

Preliminary Description of Land Use

- Differentiate and describe important land uses affecting the site.
- Identify regulations and rules that may be in force and plan compliance (rare and endangered, etc.).
- Make a preliminary assessment of constraints & problems.
- Do an eco-historical review of the area and its archeological, anthropological, and historical uses and abuses (estimate character in 1600, 1800, 1900, 1930, 1970, and today).

Site Selection

- Select areas for priority attention based on severity of problems, restoration potential (and or demand), long-term stability and protection, and regional importance. Provide information of use to others working on the same system.

Diagnostic Survey

- Conduct a field survey to identity land problems.
- Troubleshoot the historic and current use patterns to identify causal factors and constraints (compaction, fire management, overgrazing, etc.).
- Investigate interactions between and within the restoration site and adjacent areas and the processes in the general landscape and watershed (peak flood intensity, for example).

Analysis

- Analyze field data to identify key constraints and intervention points for restoration.
- Begin seed collection of key species as soon as possible.
- Assess sustainability problems.
- Specify appropriate interventions.
- List goals and specifications: functional and structural specifications, design constraints, equipment availability, irrigation, money, time, plant materials, desirable attributes of restored system — including target specifications — cover, diversity, etc.
- Finalize seed collection and banking program and develop cutting beds or start grow-out if appropriate.

Identify Candidate Treatments

- List feasible technologies for restoration (soil treatment, water retention, direct seeding, transplants, etc.).
- Do a library and literature review of similar activities (especially within the region).
- Select and prioritize the most promising technologies and combinations.

Treatment Specifications

- Make a detailed list of desirable attributes of each of the selected treatments (characteristics, management. considerations, etc.).
- Prioritize the attributes on this list in the light of the total knowledge of the system.

Design

- For each specific treatment or intervention, give detailed answers to each of the following questions:

What functions should it address? (safe sites for seeds, stabilize hydrology, critical habitat, etc.)

Where-how-what arrangement (the landscape plan and specifications). What management practices are required to achieve the desired performance?

- Develop contingency plans (late delivery of plants, lack of seeds, drought, fire, freeze, etc.)
- Take note of all design questions to which the restoration team is presently unable to give satisfactory answers (topics for further consultation or research)
- Develop an integrated restoration program.

Evaluation and Redesign

- Check land users response to the design proposal (optional resurvey).
- Conduct a preliminary evaluation of the restoration design, compare with present land use in terms of productivity and sustainability (ecosystem structure and function, environmental. impact, recreation, etc.).
- Return to design stage activities to make modifications suggested by the preliminary evaluation.
- Develop an accounting system that tracks installation and maintenance cost.

Monitoring

- Develop and implement a long-term monitoring and maintenance plan.

Damage to the soil structure and function is a common and serious problem in most desert disturbance. The most effective soil management strategy is to minimize access or intensity of impact to minimize damage. For construction activities this may mean back-blading temporary roads and access areas rather than traditional scraping. In areas where soil physical properties have been adversely affected, action must be taken to restore "native" soil characteristics. Several soil properties should be examined, including soil compaction, infiltration, soil moisture, soil fertility, and susceptibility to erosion. If adverse properties are observed these may require alteration.

TOPSOIL STORAGE AND REPLACEMENT

DO take the time to salvage topsoil, respread immediately if possible. Some advantages to using topsoil are returning native seeds, organic matter and nutrients, and native microbiota to the site. It is also easier to get a good color match for soil, minimizing visibility of disturbance.

DO NOT store the soil for over more than a few months if possible. If piles must be maintained for longer periods, keep the piles small, shallow, and dry.

Topsoil should be removed before extensive mechanical disturbance if possible. Make sure the equipment operators are clear about what is being done and why. The soil can be stored and respread over the disturbed area to facilitate revegetation. This practice is most effective if storage length is limited. Ideally the topsoil should be stripped and replaced in the same day, but if the piles are kept small, shallow, dry, and not severely disturbed, the seeds, propagules, and microbiota may survive for several months in good condition and up to several years for many species.

TREATING COMPACTED SOILS

DO rip compacted soils, if possible, without inverting the soil layers. Compacted soils recover slowly in the desert. Treating soil compaction should accelerate plant establishment. Respreading and shaping with rakes after ripping can eliminate the "tilled" appearance of ripping. If ripping is not possible other methods are available (see below).

DO NOT use small hand powered augers or small tractors on severe compaction (heavily used roads, mining areas, and construction sites). Breaking up severe soil compaction requires strong tools on heavy machinery (often a D-8 or 9 tractor) — nothing less will do the job.

Compacted soils reduce water infiltration and soil moisture, limit plant establishment, and encourage rapid run-off and accelerated erosion. Recovery of compacted soils in the desert occurs very slowly (if at all) and intervention and alteration is required to facilitate plant establishment. Compacted soils may be aided by breaking up the soil as deep as possible with a ripper, subsoiler, or spading machine such as the Celli™ spader. This should be done without inverting the soil layers to maintain a natural fertility gradient.

If equipment operation is possible (cost and access often limit potential use) deep ripping is desirable because compaction of roads, mining areas, and construction sites can reach several feet below the surface thick and a 24- to 36-inch ripping shank may be needed. Deep ripping facilitates infiltration and rapid root growth. Deep ripping on mine spoils has been found to reduce soil bulk density, to nearly double rooting depth, and to increase survival. Penetrometer resistance was decreased for more than 30 months after deep ripping.

Unfortunately, ripping is difficult to do safely on roads, trails, and hill climbs that ignore contours. Equipment operation is also likely to do collateral damage and to emphasize linear patterns. A power auger, power shovel, or garden fork can be used on sites where ripping is impractical. A tractor mounted posthole digger can also be used to auger holes. A hydraulic chisel on a Bobcat or walking tractor can be used to treat slopes without creating linear features. Drilling holes up to 3 meters deep has improved establishment and survival of plants in the low desert.

The European soil spaders are mechanized equivalents of shoveling or forking. They appear to be one of the best choices for soil treatment. The Celli™ spader is available in a range of sizes, and the bigger machines can reach 8 inches or deeper.

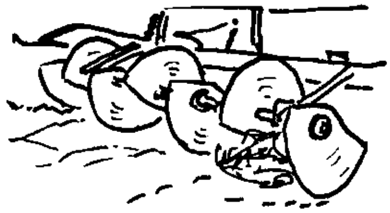
INCREASING SOIL MOISTURE

DO consider improving soil moisture of the disturbed site to improve seed germination and plant establishment. Methods to consider: pitting, imprinting, and/or adding mulch.

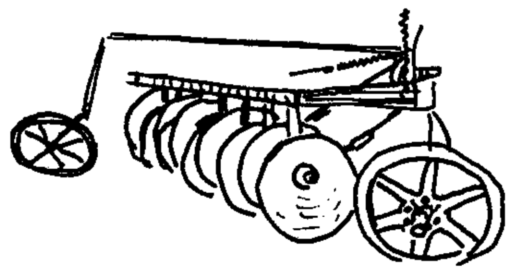
DO NOT necessarily consider watering or irrigating your project site. Desert plants are, in general, adapted to dry conditions and by adding too much water (relatively), you may encourage exotic plant (weed) invasion.

Improving moisture retention is critical for seed germination and plant establishment. It has the added benefit of reducing erosion and the potential for gullying. Soil strength is related to soil moisture, so adding moisture enables roots to extend more easily into the soil

Cut-out disk pitter



Eccentric disk pitter



Kimseed Camel Pitter
Australian Revegetation Corporation

Pitters

and makes it easier for insects and animals to burrow.

Pitting

DO create pits in the treatment area to capture water, organic debris, and seeds. When working in loose, sandy soils, exaggerate the dimensions of pits since these will be filled in over time.

DO add locally collected seed to the pits before the rainy season.

DO NOT create pits in areas which will puddle and hold water for weeks.

DO NOT add too much mulch to pits. This can impair seed germination if mulch chunks are large or the mulch layer is too thick.

Soil pitting (depressions 1-2 m long x 1-4 m wide x 10-20 cm deep) can improve water retention and infiltration and reduce evaporation. The resultant pits serve as rain catchment areas and increase soil moisture (particularly on fine textured soils). The increased availability of water in and around the pits encourages plant establishment and growth. Overland flow and soil erosion on bare areas are minimized. Seed catchments and safe sites for windblown seeds are created as well as seedling protection from wind and sand blast. Mulching the pits can increase soil moisture. However, seed germination and plant establishment at the bottom of the pit can be impaired if mulch chunks are too large, mulch is too thick, or if standing water remains for more than a week.

Pitting is a simple process but like most arid land treatments it encompasses a complex set of relationships and many uncertainties. The goal is to create pits that will last and trap blowing silt, seed, and soil microflora. The size of the pit will depend on the soil type, rainfall amount and variation, selected species, seeding methods, and equipment availability. One of the benefits of large shallow sloped pits is the range of conditions they provide for seeds to germinate.

Pitting implements commonly use either disks or tines. Disk pitters are best suited for light textured soils. In areas with heavier soils they can be used after ripping. Tine pitters are more suitable on a wide range of soils.

Imprinting

DO imprint areas that are sealed with crusts that need to be broken up to reestablish vegetation.

DO NOT spend much time imprinting very loose and sandy soils since wind and water will quickly "erase" your efforts.

Land imprinting can convert smooth-sealed soil surfaces into a rough-open surfaces with rapid infiltration and excellent rainwater retention. Imprinters commonly consist of a simple rolling cylinder attached to a towing frame, with the cylinder being the only moving part. Iron or steel teeth are welded to the cylinder to force imprints into the soil surface. These teeth marks form the fluid exchange funnels that are needed for rainwater retention and infiltration. The imprinter establishes interconnected water shedding and water absorbing imprints.

Imprinting is most effective for soils where infiltration is limited by soil crusts. Sandy soils are less likely to benefit from imprinting. The compaction created by an imprinter may benefit grasses more than shrubs. The imprinter marks are relatively small and less apparent in the landscape than contour terraces, contour furrowing, and pitting. An imprinter can be run up and down steep slopes on a cable from a winch. Imprinting has been most effective in areas with summer and winter rains.

SOIL AMENDMENTS AND MULCHES

DO consider whether mulches are necessary, often they are not.

DO add mulches that have a high carbon to nitrogen (C:N) ratio to pits and around planted seedlings and imprinted areas to increase soil moisture and enhance seed germination and plant establishment. Potential mulches include bark, rice hulls, almond shells, straw, and wood chunks.

Vertical Mulch, Red Rock Canyon State Park

DO use mulches that are wind resistant or place mulch in pits or protected areas where it cannot be blown away. Large pieces or heavy materials work better since they will deteriorate more slowly and do not blow away as easily as lighter materials. Crimping or punching in straw can make it more wind resistant.

DO NOT add mulches that have a low C:N ratio since desert plants are not adapted to high nutrient input and invasive species are more likely to invade.

DO NOT add mulch that may have weed seeds in areas where invasive species are likely to flourish once established.

Soil amendments and mulches are often unnecessary in the desert, although adding organic matter may increase germination and establishment. Mulch can provide wind protection, reduce evaporation, increase infiltration and rainwater retention, reduce erosion, and improve plant microclimate. Materials with lots of lignin and a high C:N ratios appear to be desirable in most desert soils, providing a long-term food source for fungi and subsequent grazing by microarthropods. This grazing makes mineral nitrogen available to plants.

Mulches can also be used to tie up available nutrients as a "anti-fertilizer" (St. John 1987) so that the site is less suitable for invasive exotics. Native plants are, in general, adapted to relatively low nutrient sites and do not respond strongly to fertilization. Invasive exotics in contrast, are often from areas of high disturbance and/or high fertility and will respond very strongly to fertilization.

Bark, almond shells, rice hulls and rice straw, and chunks of wood have worked better than more decomposable materials. These large chunks deteriorate more slowly and do not blow away as easily as lighter materials. If straw is vertically placed in slots or holes it can provide increased infiltration and serve as a wind break.

Although desert soils are often infertile and a standard soil test laboratory will recommend fertilizer application, the addition of nutrients can reduce long-term native plant survival and promote invasive exotic plants that respond well to fertilizers. Nitrogen and phosphorus in fertilizer can also depress important microbial activity and prevent root inoculation by soil symbionts. High nutrient levels can also decrease the root-to-shoot ratio and limit root spread. These many factors may interact to increase moisture stress on plants and reduce survival. Herbivores also tend to prefer plants with more nitrogen!

Super-absorbent polymers that store many times their own weight in water are often touted for desert planting. While these amendments have proved useful in some cases (primarily where water is available at regular intervals), the polymer chunks may limit root growth and do not reduce plant water use.

GULLY CONTROL

DO control soil erosion due to disturbance at your site. Symptoms can be treated with check dams, bypass drops, and shrubs — but treat the watershed to cure problems.

DO set up trails and fences to reduce concentration of flows.

DO NOT underestimate the power of flowing water; improperly designed or installed check dams can increase erosion.

Gully control is difficult in any environment and particularly hard in the desert. High intensity rains, rapid runoff from denuded areas, and steep slopes contribute to the difficulty of controlling erosion in the desert. Gullies, which often follow old offroad-vehicle (ORV) roads and trails, may increase several feet in depth after a single storm. Hundreds, if not thousands, of tons of soil may be lost in one storm and cannot be replaced without expensive tractor and truck work.

Check dams (T-post and wire, rock, coir netting and bamboo, straw bale, gabion, and brush) and bypass drops to move water off the steep slopes and gradient changes can help. Rehabilitating the watershed and increasing surface storage throughout the watershed is most effective. Reestablishing shrubs in the gullies will also help reduce erosion.

Water is one of the most important factors limiting growth and establishment in the desert. Many seeds are available in the soil, but they cannot grow without water. Changes in surface soils and the removal of vegetation limit water retention and infiltration. The following strategies have been used to increase soil moisture.

WATER COLLECTION AND RETENTION

Degraded desert soils may capture only 10 to 20% of the water that an undisturbed site retains. Shaping the ground to capture and concentrate available rainfall has been very effective for vegetation establishment in deserts. When budgets are limited simply roughening the soil surface is worthwhile to increase surface storage and increased infiltration. Deep ripping can further improve infiltration.

Larger pits can be made with mechanical implements or by hand using a shovel, hoe, or McLeod (a large fire fighting hoe). Pitting machines leave a number of discontinuous pits in the soil which concentrate water and improve infiltration. Bigger pits may also discourage ORV traffic.

Disks (3-foot diameter) with an offset mounting hole or 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 effective pits. Similar results can be achieved with a dish-shaped blade on a hydraulic mount.

Even larger collection areas or microcatchments have been used in North Africa since Roman times and are now being used in many arid regions. These basins can be irregularly shaped to appear more natural. A typical microcatchment might concentrate water from an area of 30 square meters. These can provide effective rainfall several times higher than the actual rate. Microcatchments can also reduce salt concentrations at the planting spot.

Brush or rock dams across washes are widely used to spread flood water on adjacent lands and control gullying. Typically, these are permeable to allow some of the water and suspended soil through the structure.

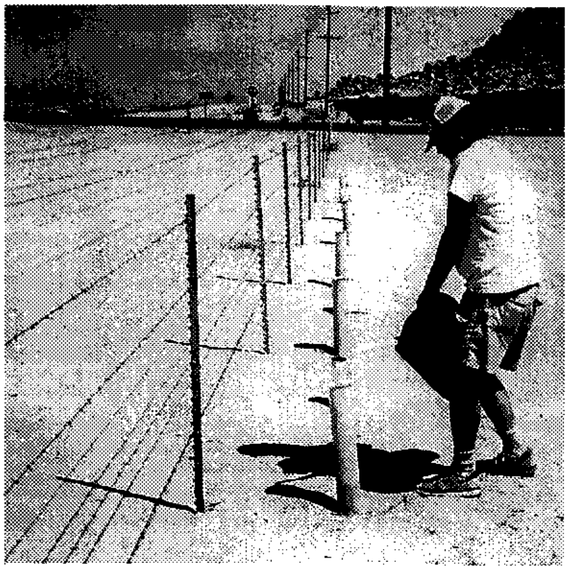
IRRIGATION

DO water seedlings immediately after transplanting.

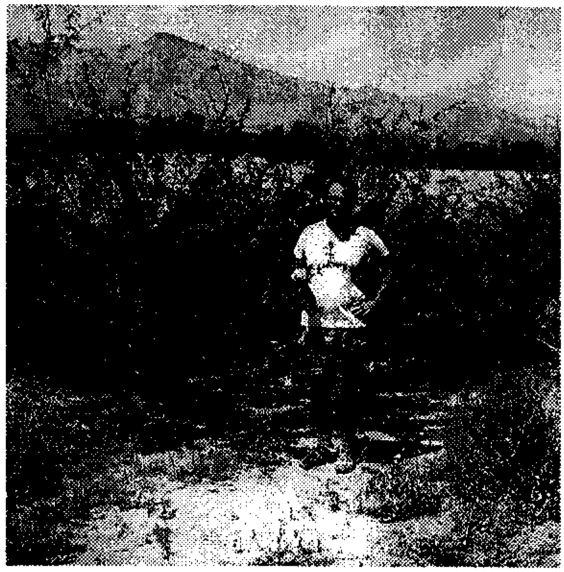
DO set up irrigation on the scale of individual plants if you are considering watering seedlings to enhance survival. Hand watering into plant collars or tree shelters can improve watering efficiency. Deep pipe irrigation, sprinkling, drip/trickle systems, and buried, clay-pot irrigation may also be considered.

DO NOT set up large scale irrigation systems. The high evaporation pressure in desert systems can leave salts at the surface that kill the plants. Added water also benefits invasive weeds more than perennial shrubs and grasses.

Many desert plants respond well to limited irrigation. When planting seedlings, thorough watering at the time of planting is essential. If long-term irrigation is feasible, survival and growth can often be enhanced. Once the plant is established the irrigation can be tapered off and terminated. Pulsed irrigation may be more desirable than continuous irrigation as many desert species are very sensitive to overwatering. A side-spray water truck can sometimes be used to provide needed watering.



Mesquite Planting, Highway 86, 1990



Mesquite Planting, Highway 86, 1993

Hauling water to remote sites can be expensive. It can be trucked to remote sites in a tanker, collapse-a-tank, or drums and jerricans. French-style watering cans with a long, rounded handle are much more comfortable to use than conventional patterns. The watering rose should be removed when watering into deep pipes, tree shelters, or clay pots. Catchment basins can also be installed; our catchment in Anza-Borrego collected water with rainfall of only 0.03 cm.

Drums or tanks used to store water onsite 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. Sand tanks, where water is stored in the pore space of sand, can be built and are more durable.

Battery powered timers have been very helpful for remote site irrigation systems, but check pressure head requirements. Several battery powered valves are available to fit hose fittings or PVC pipe.

Plant Collars and Tree Shelters

DO consider watering into the tree shelter as a first, best option. Set the collar or shelter tightly into the ground

DO NOT overwater and drown plants.

Impenetrable barriers around the seed or seedling have been effective for improving irrigation efficiency, and they also reduce plant water demand by reducing transpiration and evaporation. Tree shelters can be very effectively used in this manner. Two or three additions of one liter of water may be sufficient.

Deep Pipe Irrigation

DO consider deep pipe for remote sites and seedlings from deep containers

DO NOT install deep pipes without covers.

DO NOT set pipes below the deepest seedling roots without drilling some drain holes in the pipe on the side closest to the plant.

Deep-pipe irrigation uses an open vertical pipe to direct irrigation water to the deep root zone. For hand watering 5-cm

(2-inch) diameter vertical pipe is used, for drip systems 1.2 cm (1/2 inch). The base is buried 30-45 cm or deeper near the seedling. The top of the pipe should have a cap or screen (1/8-inch mesh hardware cloth glued on with silicone caulk) to keep lizards, insects, and animals out of the pipe. Using caps makes watering slower and adds the risk of having the cap left off or blown away by the wind, creating a hazard to wildlife.

Pipes can be easily filled with a watering can, with one or two liters a month. Water delivery takes less time than for surface basins, less water is evaporated at the soil surface, and no water is lost to runoff. Deep pipes can be used with low-quality water and low technology. 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.

Buried, Clay-Pot Irrigation

DO consider clay-pot irrigation for plants with high water demand or for cuttings.

DO NOT underestimate how much time it will take to fill pots.

Buried, clay-pot irrigation uses unglazed, low-fired clay pots 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 pot at a rate that is in part determined by the plant's water use and leads to very high efficiency. Most standard red-clay garden pots are suitable if the bottom hole is plugged with a rubber stopper or silicone caulk. The pot can be partially painted with a plastic paint to reduce water loss. Aluminum pie tins work well for lids on 8-inch (20-cm) pots. Two holes are punched in the lid to allow precipitation to drain into the buried clay pot. Rocks are glued to the lids used to hold them in place. A tight fitting lid will prevent animals from removing the lid and drinking the water.

Buried clay pots are not as sensitive to clogging as drip emitters, although they may clog over time (three to four seasons) and require renewal by reheating the pots. Buried clay pots can be used without pressurized water systems, which can be difficult to establish and maintain at remote sites. They are less likely to be damaged by animals or clogged by insects than drip systems. They can collect any precipitation that does fall. And finally, the buried, clay-pot systems may require water only every two weeks or perhaps just once a month. Even a brief interruption of water supply to a drip irrigation system due to a pump or filter failure or pipe break can lead to serious problems and plant diebacks. Buried, clay-pot irrigation provides young seedlings with a steady water supply even during periods with very high temperatures, low humidity, and desiccating winds. This controlled water delivery is of special value in porous sand or gravel soils. Buried, clay-pot irrigation has also been very effective in areas affected by salinity or where only saline water is available for irrigation. A side benefit of using buried clay pots is often the germination of existing seeds in the soil seed bank.

Sprinkler

DO consider sprinkle irrigation for raising annuals, but use good quality water.

DO NOT sprinkle irrigate if weed seeds are common is site soils.

A side-spray water truck can be a useful irrigation tool. For larger sites a water truck with a pump may be used to water with a large impact jet sprinkler. Pulsed irrigation is fine.

Drip/Trickle

DO expect regular maintenance and install multiple holddowns to prevent wind damage.

DO NOT ignore signs of belowground breakage or leaks.

Many different systems for drip irrigation have been tried in the desert. The standard commercial systems can be expensive and have proved troublesome in wildland use. Coyotes, rabbits, and other animals will chew on the polyethylene tubing even with open water nearby. Lines are more easily repaired if they are run aboveground with PVC main lines. Emitters are easily clogged by debris in the lines, salt accumulation at the emitter orifice, and insects.

PLANT GENETIC CONSIDERATIONS

DO think about plant genetics before ordering plants or seeds. Consider the sections below carefully.

Most restoration practitioners have little or no background in plant population genetics. Although plant population genetics can be very technical, restorationists can still use common sense when selecting plant materials for restoration projects.

Two opposing mistakes are commonly made when selecting plant material for restoration work. First, restorationists assume that if the plant is the right species, its origin does not matter. The range of a native plant may extend for hundreds of miles, and the plant may be highly adapted to various rainfall, altitude, temperature, and day-length regimes across its range. Seed from the same species collected in Texas may be very poorly suited to growth in the Mojave desert, despite being a "native." Plant shape and color may also be different from different locations, and a nonlocal source may stand out very clearly.

Unfortunately, in reaction to the first mistake, project managers may decree that only exactly "local" seed can be used in restoration projects. In extreme cases, project managers have left ground unrestored rather than allow native seed from outside the immediate area to be used, even if it is from similar aspect, elevation, soil, and slope.

THE CONCEPT OF ECOTYPE

An ecotype is a plant population that is genetically adapted to the specific environmental conditions in the habitat in which it grows (see Turesson 1922, Clausen, Keck and Heisey 1939, and Gregor 1942 for the original references on the concept). Ecotypic differentiation has only been demonstrated for a few plant species. In the work of Clausen, Keck and Hiesey (1939), ecotypes were measured on a scale much larger than the scale of a plant population. For example their demonstration of an alpine ecotype referred to all of the populations of plants of the given species growing in an alpine zone.

Meanwhile, the term has moved into common usage in the restoration field. It is commonly and incorrectly used in place of the word genotype. Any plant population studied closely will yield multiple genotypes. Whether any of those genotypes are adaptations to the local environment (ecotypic) is a very different question. Ecotype in the restoration field has come to be an assumption rather than something that is measured.

The average restoration practitioner has little or no training in plant population genetics and little or no time or inclination to get that training. Yet, the average restoration practitioner must make decisions on how to collect the best plant material within the constraints of the project. The following dichotomous key gives a restorationist a commonsense framework from which to make decisions on genetic considerations in plant selection for each plant species used in a restoration project.

Dichotomous Key for Selection of Plant Material for Restoration Projects.

1a. All of the plant material for the species in question can be collected very locally (example: rooted cuttings). If so, stop here and do it.

1b. All of the plant material for the species in question cannot be collected on a very local scale. Go to 2.

2a. The population of the plant species in question on the restoration site is a population of the species known to be a rare genotype. Collect seed and/or cuttings from this population only.

2b. The populations of the plant species in question on the restoration site are not known to contain any rare genotypes. Go to 3.

3a. The populations of the plant species in question on the restoration site have visible morhologic characteristics that may be genetically based. Collect seed and/or cuttings only from plant material with similar morhologic characteristics See section titled "General Constraints for Selection of Plant Material."

3b. The populations of the plant species in question on the restoration site have no obvious morhologic differences from populations of the species outside of the restorations site. Go to 4.

4a. The restoration site is similar physically to the site before disturbance. See the section titled: "General Constraints for Selection of Plant Material.

4b. The restoration site's physical characteristics have been changed drastically (examples: soil, altitude, water table, topography). The plant species in question may no longer be suited to the site. See the section titled "Selection of Plant Material on Drastically Disturbed Sites."

General Constraints for Selection of Plant Material

1. If all of the plant material you need can be collected on a very local scale do it. Since this will seldom be the case, read on.

2. Distance: Whenever possible, collect plant material from within 100 miles of the restoration site.

3. Altitude: Whenever possible, collect plant material from within 500 feet of the altitude of the restoration site.

4. Rainfall: Whenever possible, collect plant material from areas where the average rainfall is within 2 inches per year of the annual rainfall for the restoration site.

5. Soil: Whenever possible, collect plant materials with the same general soil type. For examplexample, avoid collecting plant material from a sandy soil if your restoration site has a clay soil.

6. If the only plant material available will violate one or more of these contraints, consider whether the available plant material is preferable to no plant material.

Selection of Plant Material on Drastically Disturbed Sites.

A restorationist may be asked to restore a community on a site where the disturbance is so drastic that the predisturbance community cannot be reestablished. If the water table, altitude, or soil composition of the site has been permanently altered, many of the native species may no longer be suited to the site. One example would be a riparian community where the water table has been permanently lowered. Growing plants on the site will require local species that previously could not grow on the site, or non-native species.

In cases where the disturbance is less severe, there still will be no reason to assume that local populations of the plant species in question will be well suited to growth in the disturbed area. In such cases, limiting the genetic variability of the plant material to very local genotypes is not necessarily advantageous. A variety of plant material collected within the general constraints will provide much more genetic diversity from which to find genotypes well suited for growing on the restoration site. An example of this situation is overburden piles at mine sites. The overburden is made up of crushed rock that bears no resemblance to the pre-mining soils and the piles may be 200 feet deep.

SEED MANAGEMENT

DO pay for seed PER POUND LIVE SEED, if possible, when hiring a seed collector to collect seed for you in your local or appropriate area. The amount of live (or pure) seed in a pound is going to be less than a pound of seed collected. Although the company will no doubt want to charge extra for the seed testing and price per pound, this ASSURES you of getting live seed. Otherwise you could be paying a lot of money for dead, nonviable seed and plant debris.

DO consider how you will store the seed and for how long you will need to store it.

The foundation of a successful revegetation or restoration program is quality seed. This requires careful collection, processing, and storage. Seed production in desert species is erratic and seeds of a desired species are rarely available from wild stocks for collection when needed. The establishment of a native seed collection is desirable for assured availability. The California Department of Transportation allows advance collection for this reason. If very large quantities are needed a grow-out phase of two to 10 years may be required. Before a useful seed collection can be established, proper collection, storage and germination techniques for each species must be determined. A desert seed storage facility would be useful for the large scale of work anticipated in the desert preserve and related lands.

Seed Collection

Seed quality is highly variable from year to year and should be evaluated before collecting large quantities of seed. If the seed quality is very low it may not be worthwhile collecting seed. If the seed quality is very high in a given year it may be worth setting up a large-scale collection program. Seed quality can be assessed by nondestructive x-ray analysis, dissection, and germination tests. Contact the Seed Lab at the L.A. Moran Reforestation Center in Davis (916) 753-2441 for a price and services list for evaluating and upgrading seed.

At least 50 plants should be utilized as seed sources for most restoration projects, if possible. Seeds from different maternal plants may have significantly different germination rates. Plants should be selected from different stands in a range of comparable sites, as provenance may affect germination and growth characteristics. Stands are considered different if plants are separated by enough distance to prevent cross fertilization between populations.

Revegetation efforts should use seed from local stands because local genotypes are most likely to succeed and successfully reseed. Seed should generally be collected and planted within the same seed zone and within approximately 150 m (500 feet) of its original elevation. The importance of local collection can only be determined by a careful examination of the genetics of the species, but is generally most important at the edges of a plant range and in unique ecosystems, such as unusual soils. Allowable seed collection areas for many revegetation projects will be limited by regulations that are very conservative (i.e., very local collection only) and these may demand a much longer collection period or stimulation of seeding by supplemental watering of wild stands.

Once a stand has been selected, collection timing can be critical. For some species, ripe seed is available for several weeks or months, in others it may be for only a few days or hours. Collection of immature seed results in low seed viability or dormancy. If seed collection is delayed the seeds may disperse or be consumed by various seed predators.

It is usually best to harvest seed directly from the plant. Bush collected seed will often have twice the viability of ground collected seed. Seeds that ripen and fall quickly can be collected by placing the seed head in a section of nylon stocking or netting. This has worked very well for collecting ocotillo seeds.

Seed harvesting usually requires manual labor since the desired species rarely grow in pure stands, and the topography often limits use of mechanical equipment. Collection often involves holding a tray, bucket, or box under the outstretched branches of a shrub while flailing the branches with a stick or paddle or by sweeping the hands and arms across the upper branches to loosen the seeds, which fall into the receptacle. For heavier seeds canvas or plastic sheeting can be spread on the ground to collect seeds as they are beaten off with a paddle, piece of bamboo, or by hand.

Seed collection is commonly contracted out; however, staff and volunteers can be useful seed collectors with minimal training. The most important requirements when harvesting seeds are assuring seed maturity, correct plant identification, clearly identified seed collection sources, and proper seed handling and storage. Commercial seed collectors are crucial to most restoration programs. If the places they normally collect happen to be close to your restoration site they can provide you locally collected seed cheaply. If you have to pay them to be near your site when seed is ripe, costs will go way up. Most commercial seed collectors have excellent reputations. However, with pressures mounting to produce local seed at low cost, unscrupulous seed collectors may appear. If you are forced to obtain seed on short notice and do not know the reputations of the seed companies you contact, ask them where they have collected the seed you need rather than telling them where you need seed from.

Processing

Seeds commonly require cleaning and upgrading. Improving seed purity can reduce the storage space needed for seeds, improve the quality during storage, and allows more accurate seeding, which then reduces seed use and plant production cost. Seeds can often be pre-cleaned in the field by hand screening. The collected material is shaken or rubbed through a screen with large enough openings to allow the seeds or fruit to pass through, leaving coarse trash and waste on top of the screen to be discarded. A second sieving is made with a smaller screen which prevents the desired seed from passing through. Weed seeds, the seeds of other plants, and empty seed must be removed to improve seed purity and decrease the percentage of empty or less viable seed. Seeds are most easily sorted and cleaned using an air separator, which utilizes the movement of air to divide materials according to their terminal velocities. When fed into a rising airstream, seeds and debris of different terminal velocities will separate from each other. Commercial seed companies and public facilities such as the Seed Lab at the

L.A. Moran Reforestation Center will do this for a modest fee. Some types of fluffy seed can be placed in a mesh bag and blasted with a jet of compressed air to clean off the fuzz.

Disease Control

Insects and fungi on seeds are usually controlled by storage in dry, near freezing, or subfreezing environments. At one time, seed collectors routinely treated seeds with fungicides before storage or prior to sowing, but because of possible toxicity to the seeds and potential risk to human health and the environment, less drastic measures to control seed pests are becoming more popular. A 48-hour running water rinse has been found to reduce levels of pathogenic fungi as well as chemical controls without affecting seed viability. For the running water rinse, seeds in a mesh bag are placed in a bucket with a shower head on a running hose, and an aquarium bubbler is used to increase the concentration of dissolved oxygen and promote water circulation. Drain water can be run to the garden. This washes off germination inhibiting chemical compounds as well.

Seeds may be surface sterilized by soaking them in a 40% solution of household bleach in tap water (2 parts bleach in 3 parts tap water) for 10 minutes, then thoroughly rinsed. A similar procedure can be followed using a 3% hydrogen peroxide solution. Unfortunately, both the bleach and hydrogen peroxide treatments are phytotoxic to some species.

Storage

Although desert seeds are often long-lived and exhibit multiple dormancy, many seeds have their best germination potential at the moment they reach maturity on the plant. Proper storage conditions are critical in order to maintain seed viability over an extended period of time. The two most important factors affecting seed longevity are seed moisture content and seed temperature. As a general rule, each 1% reduction in seed moisture doubles the life of the seeds, and each 10°F (4°C) reduction in seed temperature, respectively, doubles the life of the seeds.

Temperatures can be controlled by storage location, refrigeration, or freezing. Refrigeration, though usually beneficial to seed life, is expensive and may not be cost-effective for large quantities of seed. Seed moisture content is controlled by storing properly dried seed in tightly closed containers (or doubled 4-mil plastic bags sealed with barlok ties) or by regulating humidity in the storage area.

Studies have found that many desert seeds showed unchanged or increased germination rates after nine years of storage in hermetically sealed glass containers. Seeds must be stored in conditions that will protect them from rodents, birds, and insects. Many seed collections have been destroyed by seed predators. Metal tins or glass bottles are often best. Seed collections have also been destroyed by fire in seed facilities and splitting up larger collections between sites is recommended.

Bad bookkeeping has also destroyed many seed collections. Stored seeds need to be identified with detailed label information about the seed (see figure 1).

Breaking Seed Dormancy

Seed dormancy is an ecologically important device to optimize the survival of desert plant species, but it is an obstacle to revegetation efforts where prompt, uniform, and complete germination is desirable. Nondormant seeds readily pass through three germination stages: 1) imbibition of water, 2) activation of metabolic processes, and 3) growth of the embryo. If

SEED LOT HISTORY

STORAGE LOCATION(S)________ LOT NO. (from collection tag)___________

storage conditions________________________________

Species__________________________ common name(s) _________________________

Collector (name/address/phone) ____

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 __________________________

SITE CHARACTERISTICS

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

Elevation __________________ Aspect _______ Slope ___

Vegetation type _______________________

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

Nearest town ________________ Road location ________________

Moisture content:	date	moisture
Initial		
After treatment		

site locator map

SOIL TYPE: Description ____

pH ___________ EC _______________ Texture _______________

After-ripened (temperature) _____________

GERMINATION (by week)							INVENTORY			
DATE	TRTMNT	1st	2nd	3rd	4th	FINAL	Disposition	date	amount	balance

Figure 1: Seed Lot History

any of these stages are blocked, the seed remains in a state of dormancy.

Impermeability of the seed coat to water or gases (hard seeded) is the most common form of seed dormancy and is characteristic of certain families, including the legumes. If the seed imbibes moisture, but does not germinate, moist stratification (storage under cold or in some cases warm, moist conditions) may be needed.

If the seed does not imbibe moisture, scarification is needed. Scarification involves the physical abrasion or removal of the seed coat to allow entry of water. This can be accomplished by soaking the seeds in hot water or acid, mechanical abrasion, or rinsing with repeated changes of water. Small batches of seeds can be scarified by hand, using a file or knife to make a nick or slice in the seed coat, but care must be taken to avoid injuring the radicle. The hot or boiling water dip is safer than acid scarification.

If seeds still fail to germinate following scarification, stratification can be used to overcome dormancy. Many seeds with physiological/physical dormancy require exposure to either high or low temperatures before being placed in conditions favorable for germination.

Cold, moist stratification is most commonly used. The seed must generally be fully imbibed before temperature can be effective in breaking dormancy. The embryo of many seeds fails to germinate because oxygen does not diffuse through the seed coat. Oxygen is more soluble in cold water, so the oxygen requirements of the embryo can be better satisfied during cold, moist stratification. The correct temperature and duration for stratification varies according to the species and must be determined. Temperatures generally range from 34°-40°F (1-4°C); with duration varying from weeks to months. Any seed lot to be stratified for more than 30 days should be surface dried after imbibition or periodically surface dried to reduce or prevent mold development.

Plastic bags are good containers for stratification. The seeds can be placed in bags with a variety of substrates, or without substrate (a "naked" strat). Common stratification substrates include moist sand, activated charcoal, vermiculite, or calcined clay (kitty litter).

Some desert seeds require high temperature stratification (120°F/50°C) rather than low temperature/moist stratification. High temperature stratification appears to promote seed maturation in desert species. Seeds show vastly improved germination percentages during the first five weeks of high temperature storage (compared to seed stored at room temperature), but continued storage at high temperature results in a loss in viability. Thus, if a seed lot is to be planted during the same season that it is collected, it may be beneficial to try high temperature stratification. If the seed needs to be stored for longer periods of time, lower temperatures may be desirable. For other desert plants, such as creosote, dormancy can be broken by rinsing off chemicals that inhibit seed germination (48-hour rinse).

Seed Testing

To determine the value of a seed lot or the rate of seeding needed for a successful planting, every seed batch should be evaluated for purity and percentage of sound seed. Percentage of sound seeds can be determined by different methods depending upon the species. X-ray evaluation is a nondestructive method of assessing seed fill and potential viability. Alternatively, a cutting test can be a quick and easy way of determining the number of full seeds but requires some experience with the species being tested. By combining x-rays with cutting tests it is possible to relatively quickly determine seed quality. The time required for germination tests varies among species.

ESTABLISHING PLANTS ON RESTORATION SITES

DO consider methods of improving and enhancing plant establishment on disturbed or barren areas. Methods to consider are direct seeding, transplanting plants grown from seed, and transplanting plants grown in the wild. Other considerations include plant protection, microbial inoculation of plants, etc.

Direct seeding rarely works in the desert, but when it does it can be less costly than container planting. Container planting is reliable if it is done well.

Direct Seeding

DO use high seeding rates — from 100 to 500 live seeds per square meter. Seeds can be broadcast or drilled by hand or machine. Direct seeding should be done just before or after heavy rains or flood events.

DO consider spreading cracked wheat to reduce granivory.

DO NOT hydroseed. This method is effective in moister parts of the country and is often recommended because it is relatively inexpensive with cited costs as low as $50 to $100 per acre. However, an adequate seed mix may cost more than $1,000 per acre and hydroseeding is likely to work only one year in 10 in the wetter parts of the southwest desert.

Pitting and Seeding, Anza Borrego Desert State Park

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). 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. Ripping, digging, or forking the soil 25 to 50 cm deep to loosen the soil and back-filling to leave a small depression will often increase the likelihood of success. Planting seeds in pits or imprinted areas can improve germination and survival. Tree shelters can help seeds germinate and grow.

High seeding rates should be used for most species, with 100 to 500 live seeds per square meter. Timing can be critical, but the occurrence of good conditions can be very difficult to predict. Direct seeding too early in the summer in Arizona can lead to seed germination with early light rains, then die-off before more effective rains fall later in the season. Most years may never have appropriate rainfall for germination and establishment of key species.

Seeds can be blown away or lost to predation by insects and rodents and seed quality declines if rain does not fall within a few months or years of planting. Harvester ants may be partially neutralized by using cracked wheat to satiate the colony before seeding. The addition of organic mulch can improve survival by providing improved microsites.

A few species such as *Atriplex, Croton, Oryzopsis, Sphaeralcea*, and *Haplopappus* grow from seed in most years. However, for the majority of desert species, reproduction from seed is a rare event. The more you know about seed germination in a site and the fewer species that need to be included in seed mixes, the less seed will be wasted.

Transplanting

DO use local or appropriate seed and plant sources.

DO use containers and soil mixes that will develop a very vigorous root system.

DO train planting crews carefully, institute root checks on large commercial projects.

DO consider using a range of container sizes to maximize the chances for survival and to develop a varied plant architecture.

DO NOT let containers sit in the sun on the site too long. Keep them shaded and sprinkled if possible.

DO NOT drag out planting over many days, unless plants are delivered on a daily basis.

DO be careful if cuttings are used, making sure that root development is good.

Vegetation restoration will usually require transplanting. Restorations must determine (at a minimum) the most appropriate container types, best transplanting times, planting patterns, and required aftercare. Local seed sources are desirable since genotypic variation can be high and adaptation to local climatic conditions is essential. Inoculation with proper mycorrhizal fungi may improve survival and growth of transplants.

A full appreciation of the ecological setting and adaptation of desert plants can make establishment less costly and more successful. Multistemmed shrubs and trees such as creosote bush and mesquite appear to be 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; increasing infiltration and water storage in the soil; and providing protection from the sun and wind.

Develop a planting goal based on local plant communities and soils. The planting pattern for a site will be determined by a wide range of factors including species density goals, seed availability, container type (and expected survival), and access. If planting must be minimal to reduce the cost, the effectiveness of planting can be enhanced by shifting plants toward the windward side of the site to improve seed distribution once the plants mature. Seed set occurs on many shrubs in the first season.

Concentrating transplants to create resource islands may provide greater benefits than less intensive treatments over a larger area. These islands can provide seed and inoculum for surrounding areas. Transplanting clumps of shrubs into the center of barren areas is a low cost method of promoting resource island formation.

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. Pruning some species (given some time for healing and hardening off) can provide desirable large root-to-shoot ratio.

Fast deep rooting may be achieved by early out-planting or using deep containers for nursery stock to protect and encourage tap root development. The meter tall, 15-cm diameter plastic "tall pot" containers (made from PVC pipe) developed by the Center for Arid Lands Restoration at Joshua Tree National Park work well but are expensive.

Generally money spent on better and deeper plant roots will pay off with improved survival and faster growth. The benefits of longer taproots have been documented in reclamation after mining. Survival with longer taproots increased in relation to root length, 29 cm 15% survival, 48 cm 75% survival, 68 cm 92.5% survival. Longer roots also increased growth of plants over several years. Larger container plants are more costly to grow

Tall Pots at Joshua Tree National Monument

Transporting Tall Pots, Jurrassic Park Movie Mitigation Site

and to buy and planting from small containers works well if the tap root has not been damaged. This can mean planting within three to four weeks of germination. In sites where the soil is very rocky it can be difficult to dig holes for planting tall pots.

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 multistem shrub canopy, improves soil moisture holding capacity, and supplies added nutrients.

A wide variety of containers have been used for transplants for desert revegetation, ranging from the small conetainers up to meter tall 15-cm-diameter tall pots. Costs range from 25¢ to 75¢ up to more than $15 per plant at the nursery.

The following containers are typically used for restoration projects.

- Supercells, conetainers, leach tubes — 3.5 cm x 20 cm. Easy to handle and work with, light to carry, cheap, and reusable. Require frequent water and temperature fluctuates more than in bigger containers. Roots may be damaged when they are removed from the conetainer. These work well if plants will be outplanted while still small. They are more restrictive to root growth than other containers and transplanting is slightly more difficult.

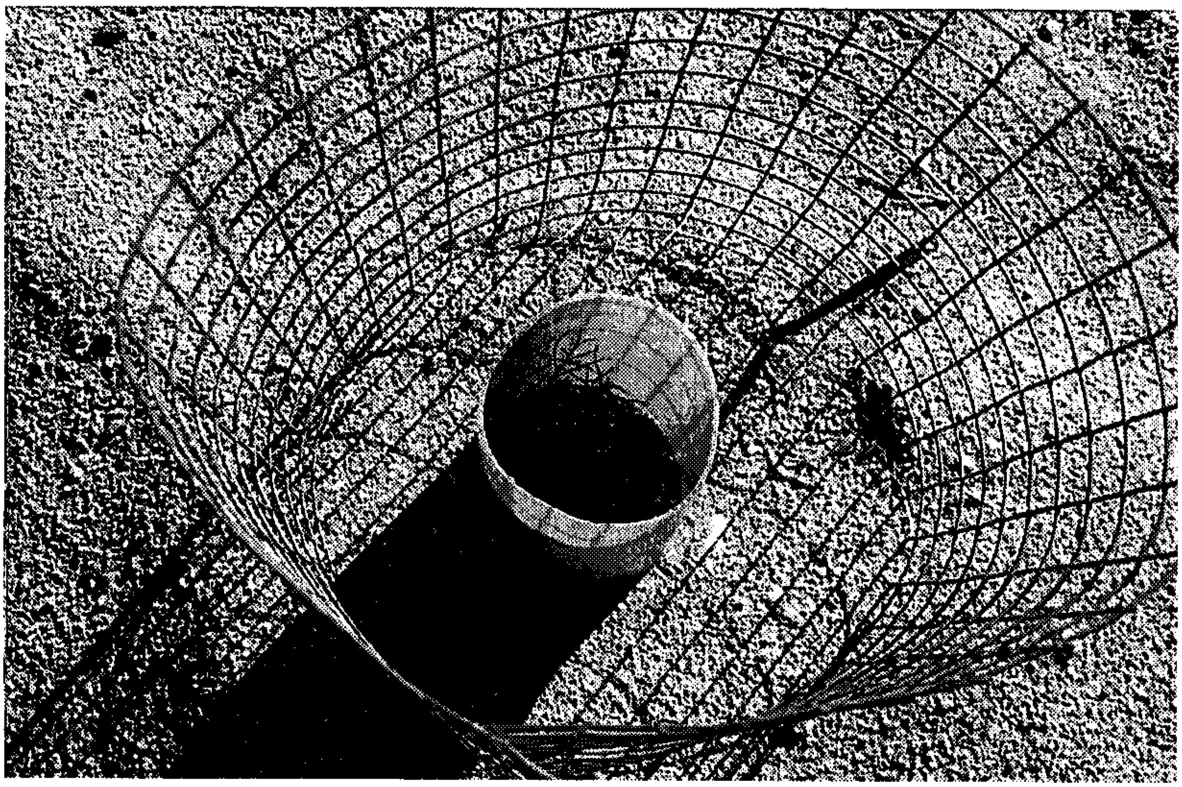
- Plant bands. Many sizes are available from Pacific Western Container and Monarch Manufacturing. They are made from plastic or foil coated cardstock square tubes. Plant bands are readily available and inexpensive but they can be awkward to fill, move, and hold unless a rack system is developed. With sandy mixes the plant band can be pulled up from around the seedling as the hole is back-filled, minimizing root disturbance. For more cohesive soil mixes the band is cut or torn. These create a good root-to-shoot ratio and are easy to plant.

- 7.5- to 10-cm pipe x 50-100 cm. These pipes are relatively easy to work with. They provide a stable environment for the plants and are easy to remove with a sand mix and acceptable with most other soil mixes. They also create a good root-to-shoot ratio, but are more costly and more difficult to transport than plant bands.
- 15-cm pipe x 100 cm. These pipes are large, heavy, and awkward to move. They provide a very stable environment for plant root development and are excellent for long-term grow out. They are more difficult to transplant but the plastic tube can be pulled out after backfilling, leaving roots undisturbed. Deep planting holes must be augured, so tall pots are not feasible in rocky soils.

The plant bands (5 cm x 5 cm x 40 cm is a good size) often offer the best compromise between ease of handling, price, and economy. A mix of container sizes is most appropriate, perhaps 40% supercells, 40% plant bands, and 20% tall pots. More accessible sites may benefit from use of more of the larger containers.

Many desert species are very sensitive to reduced oxygen levels, mold, and fungi and require well aerated, rapid draining soil mixes. Sand is usually the major component of soil mixes, with a coarser grain size preferred. Many species will grow well in pure sand or in sand with a modest amount of vermiculite, pumice, or calcined clay.

Many desert plants depend on mycorrhizal fungi for successful establishment. Lack of needed symbionts is often revealed by plant failure after initial growth following germination.



Short Treeshelter in Wire Cage

Inoculation can be done with native soil taken from under healthy plants of the same or closely related species or with commercial inoculum. Native inoculum is preferred for restoration work and can be produced relatively inexpensively (contact Ted St. John or Ray Franson). The most important symbiotic partners are rhizobia which enable many leguminous plants to fix nitrogen, and mycorrhizal fungi which improve soil structure, plant nutrient uptake, and plant growth.

Inoculating legumes with Rhizobium is rarely required as bacteria are abundant in air and soil. However, roots can be visually checked for nodules in the field and commercial inoculum is available if needed.

Mycorrhizal inoculum is less well distributed and inoculating plants in the nursery or onsite can be beneficial, particularly for highly disturbed sites like borrow pits, mine spoils, and areas where top-soil has been removed. Improving the conditions for the fungi is also 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.

Mycorrhizal fungi can only be identified in plant roots using a microscope. Unscrupulous contractors may try to take advantage of this "invisible" fungus by saying the transplants they are providing are mycorrhizal when they are not. If you order mycorrhizal transplants, you might wish to arrange for an independent assessment.

Plant adaptation to high temperatures may make summer planting acceptable or desirable for many species, contrary to normal expectations and recommendations to plant only 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). The best season for transplanting is species specific. Information for various species is available (see "Further Reading") or can be estimated by reviewing ecological literature.

Problems with container planting include the timing of producing larger plants, the cost per plant, and the labor and equipment requirements for planting. Establishing plants in the field can be expensive, and losses will occur.

Contacts:

- Jane Rodgers at the Center for Arid System Restoration, 74485 National Park Drive, 29 Palms, CA 92277 (619) 367-4528.
- Raymond Franson, Viceroy Gold Corporation, P.O. Box 68, Searchlight, NV 89046.
- Laurie Lippitt, L.A. Moran Reforestation Center, California Department of Forestry and Fire Protection, P.O. Box 1590, Davis, CA 95617.
- Ted St. John, Tree of Life Nursery, PO Box 736, San Juan Capistano, CA 92693 (714) 728-0685.
- Scott Messersmith, Borrego Valley Growers, PO Box 37, Borrego Springs, CA 92004 (619) 767-4476.

Transplants from the Wild

DO salvage plant materials from construction projects. Concentrate on species that are known to tolerate replanting.

DO be gentle and minimize root damage.

Transplanting from the wild can be relatively easy from deeper soils in a maintained setting, using a tree spade.

Many species have been successfully transplanted including large mesquite trees. Remove the plants with as much of the root system and as little disturbance to the roots as possible. This can be done with a backhoe, tree spade, or by hand. Damaged roots should be clipped and cleaned up. Dusting with sulfur may reduce disease problems. With most species (notably NOT Yucca or Ferocactus species), tops should be trimmed back as far as possible to eliminate transpiration pressure until roots can adjust to replanting. Results have been good with aftercare — especially irrigation. Transplanting can be expensive, up to $100 per inch of trunk diameter.

Contacts:

- Viceroy Gold
- American Girl Mine
- Joshua Tree National Park

Most mines are required to do plant salvage and will therefore have some experience with the species they encounter. Plant salvage has also been required on many projects in Tucson, AZ; check the phone directory.

Plant Protection

DO consider plant protection for transplants, volunteer seedlings, and direct-seeded areas. Protection is almost essential in most locations and most seasons.

Plant protection is often the most important factor in plant establishment after water. Protection should provide shelter from microclimatic extremes (particularly sand blast and drying winds) and herbivority, as herbivore pressure can be very high. Newly established seedlings are often the most succulent plants around. Protecting seedlings that germinate naturally on the site may be one of the most cost effective methods of improving site recovery.

Place plant protectors around seedlings after planting or sowing. A wide range of plant protection strategies can be considered ranging from expensive (but very effective) tree shelters to more affordable (and less effective) wire cages, plastic mesh, and rock mulch.

We have found that solid plastic shelters such as TreePee or Tubex offer the most effective protection against herbivority. These also provide many physiological benefits for the plants. The top of the shelter should be covered with a small mesh screen or stretchable mesh or a stick should be placed inside the shelter to allow lizards to climb out.

Wire screen cages have been more commonly used than tree shelters. A small mesh size, 1/2 inch x 1/2 inch (1.2 cm) may be needed to keep mice and rodents out, but stucco wire laced over a 1/4-inch rebar pin makes a good cage for rabbit protection. These have been found to be effective in preventing herbivory, but provide little physiological protection and are difficult to transport, install, and remove.

Commercial plastic mesh guards are often used 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 against hungry jack rabbits.

Brush or rocks can be used in areas where screen is unacceptable for aesthetic or economic reasons; several large rocks are placed closely around the seedling. Rock mulch is effective even in areas with very high winds and often provides acceptable performance.

DO consider the possible human impacts on your site.

DO budget for maintenance and replacement if possible.

DO mark plants with permanent labels and monitor the survival and growth.

DO write-up the project, even a short description in *Restoration and Management Notes* will help.

Fences provide fairly good protection from vandalism, which can be a problem in restoration efforts. Bare areas attract ORV operators who may disrupt or vandalize plantings. Mulch (especially rock or brush), ground shaping, and signing can provide some protection from vandalism but regularly maintained fences are better. Wind and grazing guards can provide additional protection if rebar is used instead of wood stakes. Installing large plants and berms at trail ends can disguise trails and discourage users.

Restoration has occasionally been treated as a known process with increasingly rigid requirements and specifications. This is rarely the case and research-based restoration programs are much more likely to pay dividends over the long haul. Although revegetation and restoration experiments have been undertaken for many decades, poor monitoring, evaluation, and dissemination of data on these projects has greatly limited their value. By providing more data about the site before restoration, more complete descriptions of what has been done and better mapping and identification of sites, much more information could have been collected by subsequent investigators revisiting these sites.

We would suggest that these studies be indexed by the Desert Restoration Task Force. Indexing should include descriptors, key words, and addresses of contact people and should be available in a data base available through the internet or world wide web.

A second problem with much restoration work has been the lack of interest in publishing data on complete failures — a not uncommon outcome in previous revegetation and restoration projects. This null data is important and needs to be reported. If it is not, the same treatment may be tried repeatedly at a 15- to 20-year generation interval in the same lab, or more frequently by institutions and groups in other areas.

Poor experimental design and limited publication and description have also made it difficult to improve the art and science of restoration. The key failings are lack of clear hypotheses, poor design, limited replication, incorrect analysis, and insufficient time. Experiments must provide sufficient rigor and detail to yield statistically sound information on treatment effects to justify costly monitoring. It is worthwhile, although this is often difficult with highly variable short-term funding and/or no funding allowed for monitoring.

Several years of repeated treatments are desirable to provide improved confidence in the understanding of the effect of the treatment under varied environmental conditions. It can be very helpful to provide a consistent control treatment (a commonly accepted treatment) to contrast new or unusual treatments. This can provide more valuable information than simply using a treatment versus no treatment combination.

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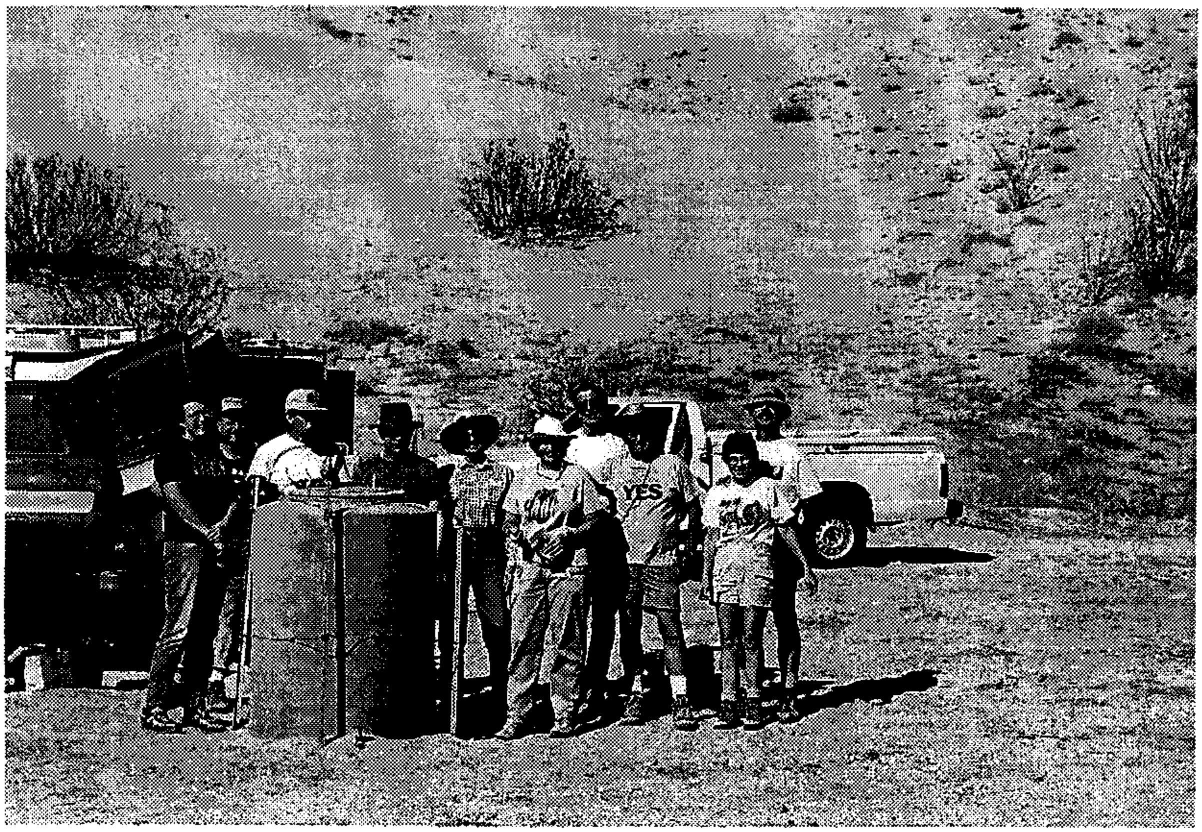

Volunteers at Anza-Borrego Desert State Park

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SUPPLIERS

Ben Meadows (BM) (800) 241-6401

Gardener's Supply (GS) (800) 444-6417

International Reforestation Supply (IRS)
(800) 321-1037

Forestry Suppliers (FS) (800) 647-5368

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Bailey's
PO 550
Laytonville, CA 95454
(707) 984-6133

Treessential Supertube™
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WIRE SCREEN FENCES, TUBES, AND CAGES

Rabbits and rodents rarely cross 3-foot-tall fences. Cattle and burros can be controlled with six-foot cages made with T-posts and welded wire mesh or tall tree shelters. Short tree shelters in cages can improve survival.

REPELLENTS

Many commercial and homemade solutions have been tried to no avail. Systemic repellents included in container mix appear most likely to help.

ASG Consultants
7868 11th Avenue, Burnaby, BC
V3N-2N3
(604) 521-0864

PLASTIC MESH

Several companies manufacture 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. Plastic tubes to go over mesh are available to improve shelter effect.

Tubex Tree Shelter, Near Salton Sea

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OTHER CONTAINERS

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Silvaseed (foam blocks)
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Roy, WA 98580
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Little Beaver (BM, FS)

AMS - hand auger (IRS, BM, FS)

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IRRIGATION SUPPLIES

Water jugs, 3-gallon Igloo (BM)

Battery irrigation valve, Galcon (GS)

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