Central Valley Project Improvement Act
Land Retirement Demonstration Project
A Synthesis of Restoration Research Conducted near Tranquillity, California

U.S. Department of the Interior
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Cover Photos:

Upper left: Experimental herbicide treatments at North Avenue Parcel

Upper right: Gumplant (*Grindelia camporum*) response to herbicide and charcoal treatments at the Manning Avenue Parcel

Lower left: Harlequin lupine (*Lupinus stiversii*)

Lower right: Mechanical harvesting of common spikeweed (*Hemizonia pungens*) at the native plant seed production facility

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Acronyms and Abbreviations

ac	acres
BLM	Bureau of Land Management
cm	centimeters
CSU	California State University
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
ESRP	Endangered Species Recovery Program
FWS	U.S. Fish and Wildlife Service
ha	hectares
HRS	Habitat Restoration Study
in	inches
km	kilometers
LRDP	Land Retirement Demonstration Project
LRP	Land Retirement Program
LRT	Land Retirement Team
Lockeford	Lockeford Plant Materials Center
mi	miles
NRCS	Natural Resources Conservation Service
MAP	mean annual precipitation
NPSPF	Native Plant Seed Production Facility
Reclamation	Bureau of Reclamation
TSC	Technical Service Center
UCD	University of California at Davis
USDA	U.S. Department of Agriculture
WWD	Westlands Water District

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Summary of Conclusions and Recommendations

Drainage in the San Joaquin Valley is rendering land unsuitable for irrigated agriculture. The Central Valley Project Improvement Act (CVPIA) of 1992 authorized the Federal government to purchase land from willing sellers, retire the land, and restore the land with native plant communities. The Land Retirement Demonstration Project (LRDP) evaluated re-seeding strategies to determine effective methods for restoring retired agricultural land.

Significant challenges to successful restoration include:

- The paucity of remnant native flora (i.e., potential seed sources).
- Problematic site conditions (e.g., high soil salinity; heavy, highly motile clay soils; and low topographic variability).
- Limitations associated with rainfall (e.g., low mean annual precipitation and extremely variable precipitation patterns).
- Weed pressure from non-native species and enhanced nitrogen deposition from airborne pollution.

Numerous experimental trials evaluated a variety of restoration strategies. This research included evaluations of irrigation, seeding techniques, seedbed conditions (e.g., seeded furrow depth, row and plant spacing, topographic modification), non-chemical and chemical weed control, seed mixtures, soil rhizosphere augmentation, and nurse and cover crops.

Based on this research, some general patterns and constraints are evident:

1. Results vary significantly among locations and years, precluding the development of a single "silver bullet" restoration strategy. Rather, restoration approaches will need to be carefully designed for conditions at the particular site and, to the extent possible, weather conditions during the period of vegetation establishment.

2. Competition from weeds will generally be the most significant impediment to successful restoration. Integrated weed control strategies, embracing an array of techniques, will need to be incorporated into re-seeding strategies. Weed control strategies using pre-emergent herbicides and activated charcoal "safening" are particularly promising.

3. Moisture conservation will also be of primary importance. Restoration strategies will need to consider a variety of moisture-conservation methods.

4. On some sites, suppression of insect damage will be a key component of restoration strategies.

5. Due to the extensive development of the San Joaquin Valley, little native upland habitat and historical flora appear to remain. Generally, the existing native seed bank on the retired agricultural lands will contribute little to restoration efforts.

6. Review of literature makes it very clear that restoring lands in the arid and semi-arid areas of the southwestern United States is difficult. Conditions that characterize the lands that have been targeted for land retirement (i.e., high selenium levels, low productivity, poor drainage, and shallow water tables) will present a significant challenge to these restoration efforts.

We offer the following recommendations, based on our results and observations:

1. Species selection will need to be site-specific (i.e., formulated to address the particular conditions at the restoration site), with species' considerations based primarily on soil texture and salinity, moisture regime, compatibility with weed control measures (particularly herbicidal), and availability and cost of seed. General suites of species have been formulated as generic mixtures that can be further tailored to address site-specific requirements and constraints.

2. Standard soil preparation practices (i.e., tillage and other measures common in local agronomic applications) appear adequate for proper seed bed preparation on soils characteristic of retired lands.

3. Commercial grass drills offered the greatest success of the seeding methods that were evaluated. Additionally, drilling is particularly well-suited to some of the recommended weed-control methods.

4. Due to the relative paucity of local native seed sources, efforts should focus on increasing (i.e., through active field propagation) local native seed stocks. These efforts should focus on the highest priority species that are not commercially available as local or regional ecotypes.

5. Agency, industry, and landowner collaboration and infrastructure development is needed to assure efficient technology transfer and timely seeding materials supply and delivery.

6. The objectives of large-scale restoration efforts should be refined. Considerations should include identifying target species, habitat goals, and target plant community composition.

7. "Core areas" and "linkage corridors" should be defined and delineated, and their relationships, priorities, and juxtaposition to LRDP habitat restoration efforts should be identified.

8. Research on chemical weed-control methods should continue, refining herbicide selection, and herbicide and charcoal rates. This research would be conducted in the laboratory, greenhouse, and in the field.

9. Additional chemical weed-control research should be initiated to evaluate effects of follow-up (secondary) applications on existing native vegetation.

10. Research should be initiated to evaluate the effects of grazing (herbivory) on native plants and understory weed composition. This research should also incorporate other weed-control approaches (e.g., chemical control, mechanical measures, etc.) in an integrated strategy.

Introduction

In this introduction, we present an overview of the issues associated with ecological restoration in the San Joaquin Valley. Site restoration is herein defined as establishing a self-sustaining, native plant community with desirable values for wildlife habitat, site stabilization and erosion control, and weed suppression. The conditions that characterize the lands that have been targeted for land retirement will present a significant challenge for restoration. This assessment is consistent with what has been noted for restoration in other arid and semi-arid regions[4,19,34,39].

Research Overview and Objectives

Our research addresses establishing native plant communities on retired (dewatered) cropland, and includes investigations of species selection and mixture formulation, species propagation and seed increase, seed conditioning, seed harvest and planting methods, soil amendments, and weed management. Data from the LRDP will be used to inform decisions regarding the broader-scale implementation of land retirement as a means to address agricultural drainage problems in the San Joaquin Valley. ***This document provides a non-technical synthesis of research findings and recommendations that will be supplemented at a later date with more comprehensive, technical supporting documentation.***

Other integrated strategies for weed suppression and native species establishment (e.g., grazing, mowing, fire and/or mechanical tillage measures) are also being evaluated. Study objectives also emphasize the development of revegetation prescriptions for land owners throughout the impacted land retirement area, with emphasis on restoration of native, salt-tolerant shrub/forb plant communities. It is intended that these restored communities will:

- Promote site stabilization and weed suppression
- Enhance habitat values for wildlife, including endangered species (e.g., San Joaquin kit fox [*Vulpes macrotis mutic*] and kangaroo rat [*Dipodomys spp*])
- Facilitate the recovery of the area's native flora
- Provide grazing resources compatible with habitat goals

In this document, we will:

- Summarize the challenges associated with the restoration of native plant communities in the San Joaquin Valley
- Describe the various experimental and applied restoration activities that we have undertaken
- Present synthesized results from this work
- Offer preliminary recommendations regarding the application of this work in a broader-scale setting
- Offer suggestions regarding the direction of future research

Program Background

The San Joaquin Valley Drainage Program, established in 1984, combined federal and state efforts to investigate drainage issues in the Valley, and to identify possible strategies for addressing these issues[40]. The program estimated that by 2040 approximately 160,000 to 225,000 hectares (ha) (400,000 to 554,000 acres [ac]) would become unsuitable for irrigated agriculture if no actions were taken to remedy drainage problems.

Land retirement (i.e., the removal of lands from irrigated agriculture) was proposed as one strategy to reduce drainage-related problems. Lands characterized by low productivity, poor drainage, shallow water tables, and high groundwater selenium concentrations would be retired from irrigated agriculture through a willing seller program. The CVPIA, enacted in 1992 as Public Law 102-575 Title 34, Section 3408(h), authorized the purchase of land, water rights, and other property interests from willing sellers who received Central Valley Project (CVP) water. Cessation of irrigated agriculture on these lands would facilitate the program goals to reduce drainage, enhance fish and wildlife resources, and make water available for other CVPIA purposes.

The Land Retirement Program (LRP) was developed cooperatively by an interagency Department of the Interior team with representatives from the Bureau of Reclamation (Reclamation), the U.S. Fish and Wildlife Service (FWS), and the Bureau of Land Management (BLM). The Land Retirement Team (LRT) was charged with the task of implementing the Land Retirement Program.

To study the environmental impacts of land retirement, the Land Retirement Demonstration Program (LRDP) was implemented at two sites: one in the western San Joaquin Valley (Tranquillity site; Figure 1), and one in the Tulare Lake Basin (Atwell Island site; Figure 1). Research at the Tranquillity project site started in

1999, and research at the Atwell project site in 2001. These two sites represent a range of conditions in the San Joaquin Valley for soil, climate, and adaptive plant communities. Recommendations within this document apply only to lands with site and environmental conditions similar to the Tranquillity site.

The California State University (CSU) Stanislaus Foundation, Endangered Species Recovery Program (ESRP) has served as a major research partner with the Land Retirement Team in developing effective means for restoring retired farmlands. Reclamation's Technical Service Center (TSC) in Denver has been a major research partner since 2003. Additional collaborators include the University of California, Davis (UCD) Weed Science Center, and the U.S. Department of Agriculture, Natural Resources Conservation Service, Lockeford Plant Materials Center (USDA-NRCS; Lockeford, California).

Environmental/Anthropogenic Issues

The San Joaquin Valley has already undergone extensive land conversion from native plant communities to agricultural or urban uses, and all indications suggest that land conversion will continue apace. Additional pressures are being brought to bear on the remaining habitat 'fragments' from a variety of forces, including population growth, air pollution, etc.

As of 2000, it was estimated that 3,320,096 people were living in the Central Valley[21] (i.e., the Sacramento and San Joaquin Valleys); it is anticipated that by the year 2040, the population will more than double[20]. The San Joaquin Valley possesses the state's highest population growth rate[5], with the San Joaquin Valley population expected to grow by 39 percent from 2003 to 2020, and with growth in some counties predicted to approach 55 percent[12]. Over a slightly longer term, the population is estimated to be at approximately 240 percent of the 2000 level by the year 2050[21]. A significant portion of the historical flora has vanished from the western San Joaquin Valley[37,38]. As the Valley's population continues to grow and additional habitat is converted, the status of local populations of native species—the potential source of seed for proposed restoration efforts—will undoubtedly worsen.

Air quality in the San Joaquin Valley, along with the Los Angeles region, is now considered to be the worst in the United States[5]. Although there have been reductions in some emissions in the San Joaquin Valley and Sacramento Valley Air Basins, the number of days in which the air quality did not meet federal standards has risen since 2000[22]. The effects of poor air quality on human health are well known. It is becoming increasingly evident that air pollution can also harm native ecosystems and, by extension, restoration. For example, air pollution is said to promote weed growth in southern California shrublands[1] and grasslands[54]. Similarly, nitrogen oxide (NOx) emissions frequently result in high concentrations of ozone[03], which are linked to severe injury in various plant species[17].

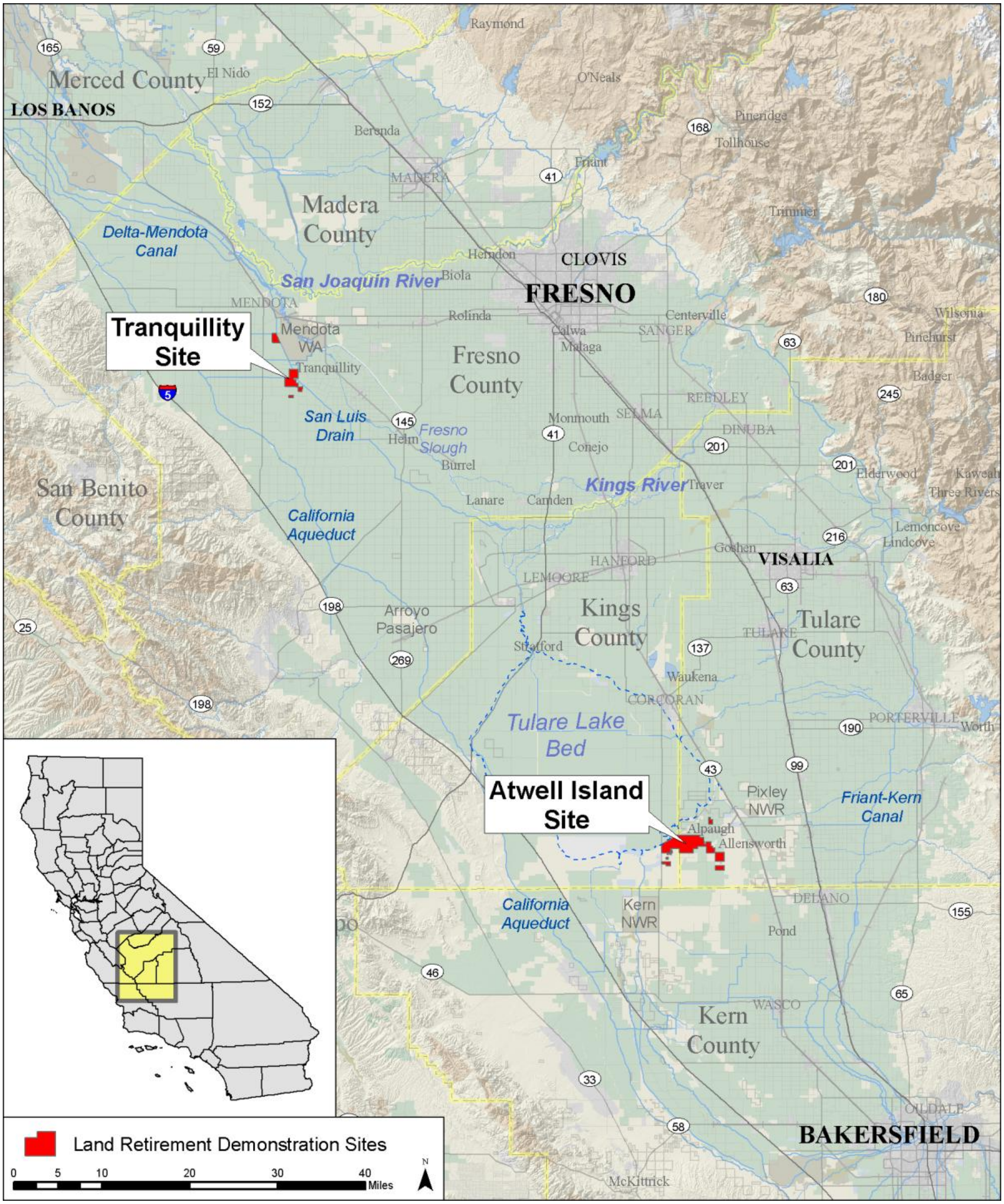

Figure 1. Location of the two Land Retirement Demonstration Project sites.

The buildup of nitrogen is occurring to such a degree that the biosphere has been likened to "a saturated gourmand … glutted with nitrogen compounds."[32, p. 988]. The Los Angeles air basin is said to possess the nation's highest known rates of nitrogen deposition, with rates estimated at 25 to 54 kilograms per hectare per year (kg ha^{-1} yr^{-1}) (22.5 to 45 pounds per acre per year [lb ac^{-1} yr^{-1}]) [10]. The rate of nitrogen deposition could double during years with high fog deposition[17].

Nitrogen deposition is an important consideration for restoration because elevated soil nitrogen levels can have fairly far-reaching affects on the biota. Nitrogen enrichment has been linked to community changes in plants and mycorrhizae, even at relatively low levels (e.g. 3 to 8 kg ha^{-1} yr^{-1}; 2.7 to 7.1 lb ac^{-1} yr^{-1})[17]. Nitrogen deposition is known to facilitate the spread of invasive species[7,10,16,54]. Additionally, increases in available nitrogen (which can translate to improved plant nutrition) may lead to increased insect fitness[30] and to increased herbivore consumption rates[47]. Many invasive plant species are adapted to soils with higher nitrogen levels. As a result, some restoration strategies employ "nitrate immobilization;" i.e., using microbes to remove soluble nitrogen from the soil[10,13,36,44]. It seems likely that the high nitrogen inputs associated with air pollution would nullify this strategy.

Revegetation Site Characteristics and Constraints

Soil Summary

All the factors described below combine to yield a harsh soil (i.e., growth medium) environment that inherently limits revegetation success, reduces native species adaptation and availability, and requires alterations to traditional revegetation strategies, management inputs, and techniques. This is particularly true in the absence of irrigation.

Soil Description

The general area, including the specific study sites, is characterized by surface and subsurface textures of sandy clay loam to clay. Other pertinent soil characteristics (mean topsoil values [0-15 centimeters (cm); 0-6 inches (in) depth]) include slopes generally less than 0.5 percent; 1.3 percent organic matter; pH 7.7; ECe 8.4 mmhos $centimeters^{-1}$; and SAR 8.5 meq L^{-1}. Extremely fine soil textures (primarily clays) are predominant throughout the upper portion of the soil profile. These clays severely limit the moisture available for root uptake, particularly under arid to xeric soil moisture conditions.

These clay soils shrink and swell with changing soil moisture to create substantial cracking in the soil during the dry season. We have observed that a large crack intercepting a shrub's rooting zone can frequently introduce enough stress to severely damage or kill the shrub (Figure 2). The adverse effects of this soil feature under limited moisture availability is compounded by the predominance of shrubs and forbs among the species with which we have had the most success, or which we consider to be priority species for the restoration of native plant communities (Appendix A, tables 2 and 3). Many of these species have predominantly vertically-oriented taproots with less fibrous (net-like), fine root filaments. Thus, germinating seeds and young seedlings are only able to capture limited soil moisture during early phases of establishment, particularly in the upper soil where evaporative losses are greater. Levels of soil salinity are moderate to moderately high, further restricting seeded species adaptation and resulting in the selection of salt-tolerant species.

Figure 2. Severe cracking in the shrink-swell clay soils at the Tranquillity site. White plastic tubes were used in watering the plants with DriWater™ (water bound in a gel matrix). The dead shrub at the end of the crack is a 3-year old *Atriplex polycarpa*.

Climate Summary

Native species that are extremely tolerant of variable, low-moisture conditions are needed to handle the San Joaquin Valley's "feast or famine" rain cycle. The San Joaquin Valley receives relatively small amounts of rainfall, falling mostly between November and March. Combined with the variability in precipitation patterns, timing and duration, this overall variability severely constrains revegetation efforts[1].

[1] For example, Bowers et al. (2004) reported that in their study in the Sonoran desert, only 2 of the 2,008 seedlings that were tagged between 1987 and 1989 survived for as long as four years.

It has often been an intuitively obvious recommendation (as a general guideline) that restoration will be more successful if undertaken in years of favorable weather conditions. It is unlikely, however, that restoration practitioners will be able to confidently predict rainfall during most years, given the extreme variability of precipitation in the San Joaquin Valley.

Climate

The San Joaquin Valley is characterized by a semi-arid, winter-monsoonal (Mediterranean) climate regime. Long-term mean annual precipitation (MAP) for the Tranquillity site is 24.1 cm (9.5 in), of which approximately 80 percent (19.3 cm) is received during the winter monsoonal period of November through March. Precipitation is highly variable spatially and temporally, with pronounced differences year-to-year (Figure 3) and within-year (Figure 4). In these figures, the bars represent monthly totals; the solid line represents the 30-year mean annual precipitation (1976-2006). Values above the bars in Figure 3 indicate the percentage of MAP represented by that particular year's precipitation.

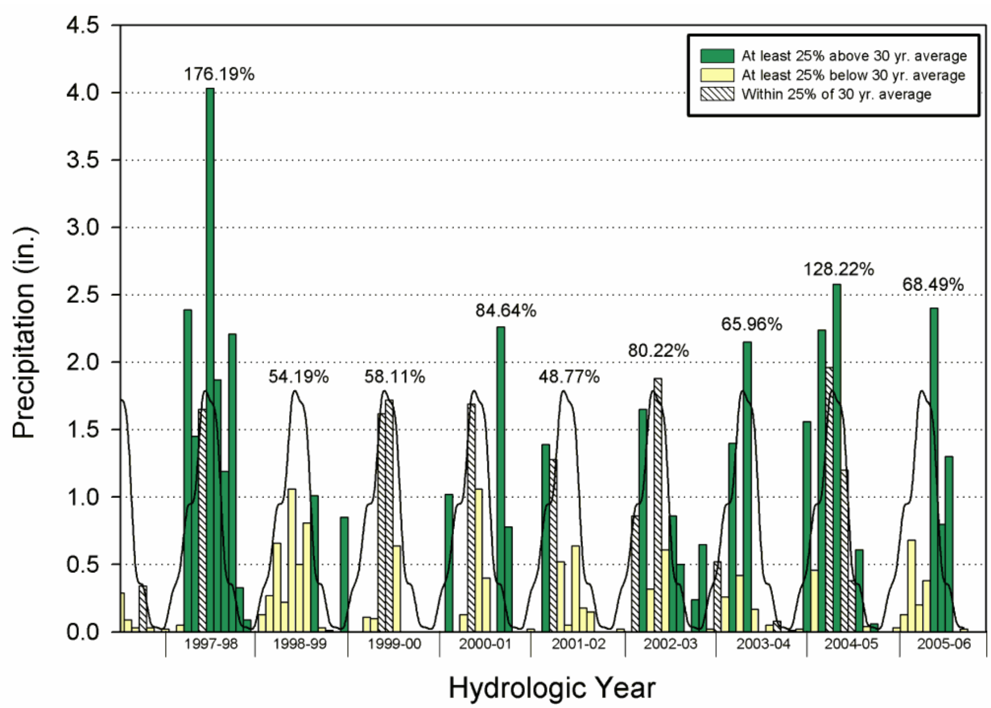

Figure 3. Precipitation during the course of the Land Retirement Demonstration Project (1997-present) at Tranquillity, California. Data are from CIMIS Station #105 <http://esrp.csustan.edu/projects/lrdp/restdata/precip>

As will be discussed more fully below, one effect of this climatic variability is that restoration in the San Joaquin Valley, as in other semi-arid regions, is a very "uncertain" undertaking. Major[29, p. 491] points to the constraints that the climate might impose upon restoration efforts: "California's Mediterranean climate combines the worst features of several other climates. Excess precipitation in winter leaches and impoverishes the soils, and summer drought of desert intensity prohibits growth of most plants at that time."

The “feast or famine” nature of precipitation at the Tranquillity site is well-evidenced in the graph of precipitation for the 2005-06 hydrologic year (Figure 4). In this example, not a single monthly total was within 25 percent of MAP, with precipitation in nine of the months well below MAP, and precipitation in the remaining three months well above MAP.

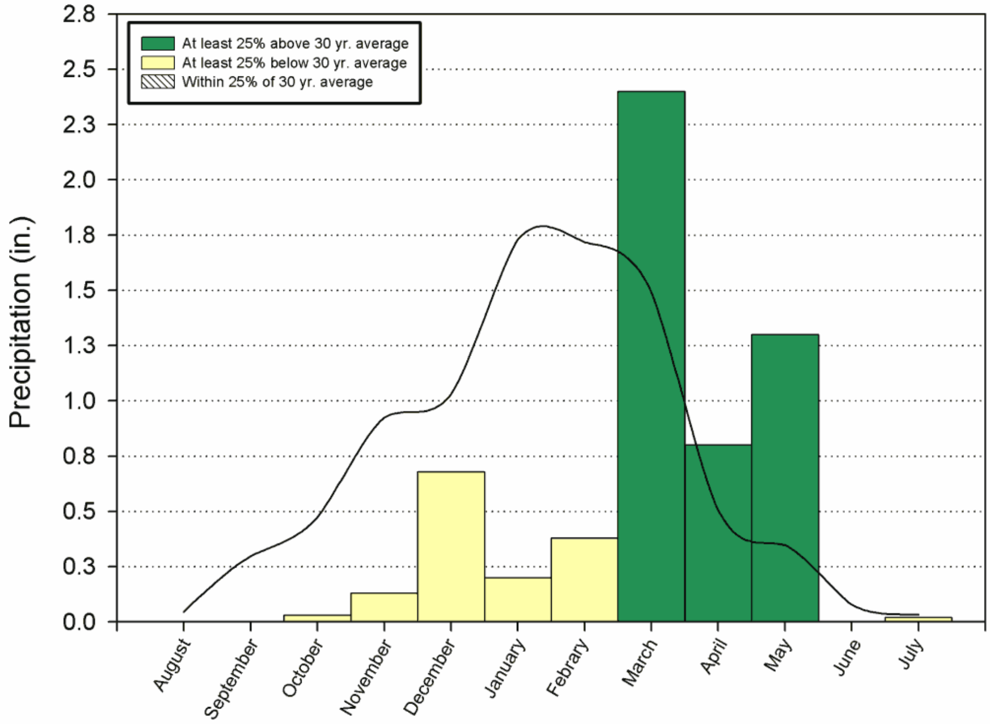

Figure 4. Precipitation at Tranquillity, California, during the 2005-06 hydrologic year (August, 2005 through July, 2006).

Weed Pressure Summary

Invasive species can quickly dominate a field that was used for crops when tillage and irrigation stops, requiring rapidly deployed integrated weed control measures.

Weed Pressure

Retired agricultural lands in the western San Joaquin Valley are typified by (former cropland) fields that have been continuously disturbed by tillage for crop production and weed suppression. As soon as these practices cease, encroachment of annual and perennial weeds onto these highly-disturbed, often bare surfaces is immediate. These conditions are particularly evident at the Tranquillity site, for which some general observations can be made about the vegetational colonization and development of the retired and fallowed lands in the Tranquillity area. However, it should be emphasized that these observations have been made over a relatively limited time period (five years).

At the onset of the first rains following the cessation of agricultural activities, various early winter weeds germinate and quickly become predominant. Most of the recently fallowed lands are colonized by non-native forbs (broadleaf herbs). London rocket (*Sisymbrium irio*) is most commonly the dominant species, with the wetter portions frequently dominated by black mustard (*Brassica nigra*; Figure 5). Other common representatives of the early-season, non-native forbs are filaree (*Erodium cicutarium*) and old man in the spring (*Senecio vulgaris*). However, these latter species are generally found in much lower abundance than are the two mustards.

A variety of non-native grasses can also be present during the early stages of vegetational development, and over time these grasses become predominant. Red brome (*Bromus madritensis*) is a common dominant of these "later successional" lands. Foxtail barley (*Hordeum murinum*) may also become a co- or sub-dominant species on many retired areas. Other typical non-native annual grasses are ripgut brome (*Bromus diandrus*), various species of oats (*Avena sp*.), and to a lesser degree, small fescue (*Vulpia microstachys*) and soft chess (*Bromus hordeaceus*). On one quarter-section on the Tranquillity project site, littleseed canary grass (*Phalaris minor*) is present as a co-dominant with black mustard (*Brassica nigra*) (apparently because grass was grown commercially here in past years).

Figure 5. ESRP biologist, Adrian Howard, in a stand of black mustard (*Brassica nigra*) during the extremely wet 2004-05 hydrologic year.

After the onset of the dry season—during which time the early-season species senesce—a second "wave" of weeds can become established. This portion of the flora is also characterized by an annual species component, but the predominant growth form is herbaceous broadleaf. Typical species in this category are the "tumbling saltweeds" (*Atriplex rosea* and *A. argentea*), Russian thistle (*Salsola tragus*), lambsquarters (*Chenopodium album*), and five-hook Bassia (*Bassia hyssopifolia*). The tumbling saltweeds have been particularly problematic and can form a dense cover over large areas (see the discussion of irrigation in the Research Section).

Many of the broadleaf annuals are "tumbleweeds" that break off from their base as they begin to senesce, and distribute their seeds as they are blown across the landscape. Additionally, although the tumbling saltweeds generally have declined in abundance in the years after the period when they were extremely abundant, the repercussions from their dominance can be severe. Principally, as their biomass resists degradation, the saltweeds' "skeletons" (i.e., the stems of the previous year's plants) remain on site and limit other species' germination. Establishment of the tumbling saltweeds, themselves, appears to be similarly limited by their skeletons. London rocket and black mustard, however, can become established under these conditions. London rocket also appears to be well suited for establishment under its own standing dead biomass (Figure 6).

Figure 6. ESRP biologist Justine Kokx in a dense stand of London rocket (*Sisymbrium irio*). The gray stems are standing dead stems from the previous year's growing season. The flush of green vegetation at the base of the stem is from the new year's growth.

It is important to recognize that this prevalence of weeds is not a situation that has developed merely with the cessation of agricultural activities. Rather, much of lowland California has long been plagued with invasive plants. California's grasslands have been used for grazing domestic animals since the arrival of the initial Spanish colonists in 1769[8], and the seeds of introduced plants have been found in adobe bricks dating back more than 200 years[41].

A striking example of the abundance of invasive plants in the 1850's can be found in Cleland[(11)] who described the measures by which ranchers in southern California attempted to control black mustard (*Brassica nigra*)[2]. As is clearly illustrated in Figure 5, similar conditions can be readily found in California 150 years later.

Considerations for Types of Species for Restoration

Recreating historically accurate and complete plant communities is beyond the scope of a large-scale restoration project such as envisioned under the LRP. Nevertheless, restoration should be directed towards establishing a plant community of more than just a few, "generalist" native species.

Assure Ecological Compatibility

One species of a particular genus may not be a reasonable "substitute" for another species of the same genus. At times, such a substitution may even have negative effects on the local fauna. For example, in one restoration project the endangered El Segundo blue butterfly (*Euphilotes battoides allyni*), which depends on coastal buckwheat (*Eriogonum parvifolium*), was harmed by planting California buckwheat (*Eriogonum fasciculatum*)[(27)].

Use Local Source Plant Materials

The "source" of the seeds (i.e., the area from which the seeds were originally collected) needs to be considered. The availability of suitable supplies of native seed represents one more limitation that must be addressed in any large-scale restoration strategy for San Joaquin Valley's retired agricultural lands.

Local populations of plants are generally considered to be better adapted to local conditions than non-local populations of the same species[(9,24,25,52)]. Additionally, the use of seed from distant or dissimilar locations may have undesirable effects on local population genetics. The problems associated with "non-local" introductions are of considerable concern[(31)].

Although it is desirable that species used in restoration are grown from seed taken from local populations, it has become increasingly apparent that the status of the San Joaquin Valley's native vegetation is such that it will be insufficiently cost-

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[2] Cleland (1941, p. 57) in his discussion of 'wild mustard' in southern California (subsequently identified by Burcham [1957] as black mustard, *Brassica nigra*) noted that: "In addition to the customary rodeos and the usual routine of ranch activities, some landowners found it necessary, at certain seasons of the year, to hold a special drive or roundup, probably unknown in any other part of the world. In southern California the growth of wild mustard was even more remarkable than that mentioned in Christ's striking parable. During the late spring, a sea of yellow bloom flowed over valleys, plains, and foothills; and the thickset stalks, higher than a man's head, made an ideal hiding place for cattle. Even when the bloom and the leaves died, a forest of dry, rustling stalks furnished ample covert (*sic.*) for livestock. In badly infested districts, neighboring ranchers and their vaqueros consequently united for a few days to carry on what was colloquially known as a 'run through the mustard'."

effective or logistically practical to provide the needed amounts of seed for all but the most common species.

Local ecotype plant materials may be available "for only a handful of common plant species that are easy to propagate"[(31 p. 433)]. This situation is magnified for the San Joaquin Valley, as the region's flora is strikingly under-represented in the stocks of the major commercial suppliers of California native seed. Further limitations arise as the seed of a particular species often has been increased from a single collection, which can potentially result in poor genetic diversity for that particular seed lot. Additionally, the seed of many desirable, local-ecotype species can be prohibitively expensive.

The Research

The LRDP conducted numerous restoration trials (Appendix A, tables 2 and 3) with a variety of species used and/or cultivated in the Native Plant Seed Production Facility. These tables list the species used in the trials, and the species that have been identified as "core species."

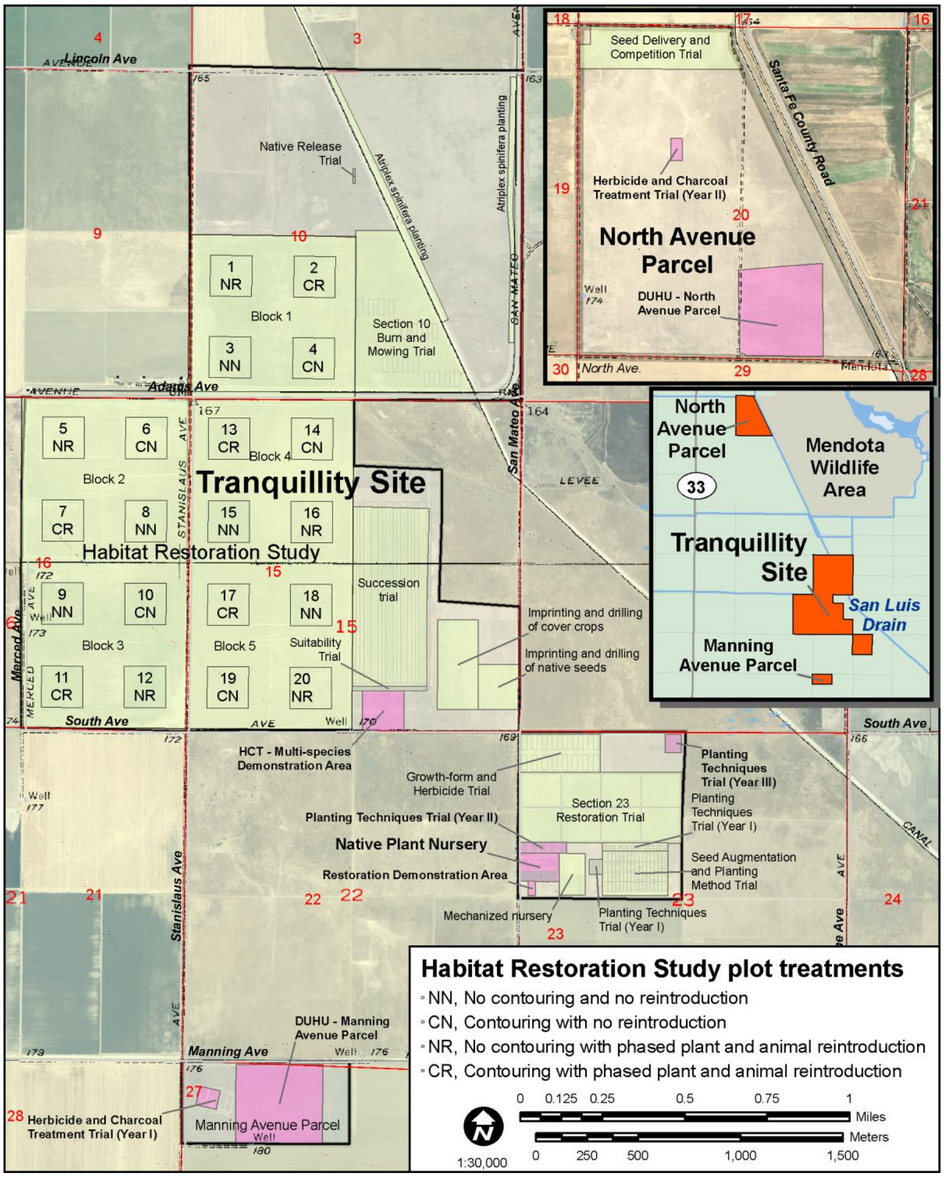

Figure 7: Restoration activities on the Tranquillity LRDP project site.

Generally, trials were designed to examine multiple factors. These factors can be grouped into six broad categories shown in Appendix A, Table 2:

- Irrigation
- Seeding techniques
- Modified planting conditions
- Non-chemical weed control
- Chemical weed control
- Other treatments

The trials are presented in chronological order in Appendix A, Table 2. Some general trends can be readily seen. The initial trials incorporated fairly "low tech" strategies, i.e., minimal weed control, with a primary focus on seeding technologies and species mixtures. Over time, as it became increasingly evident that weed competition was an overriding factor driving restoration results, the research focus shifted to weed control methods. As it became obvious that simple weed control methods were generally inadequate, the trials became more complex and incorporated more "intensive" approaches.

We present the findings of this research beginning with a discussion of our investigations of the remaining flora of the San Joaquin Valley. Following this, various strategies, concepts and techniques are summarized and presented, with a focus on the most important results (positive and negative). This discussion is structured using the six categories of Appendix A, Table 2. Finally, some broad issues regarding restoration in the western San Joaquin Valley are addressed.

When presenting research, it is often compelling to avoid discussing the shortcomings of one's endeavors. However, in restoration there is much to be gained in discussing the elements of the research that were unsuccessful. Hence, we undertake this account of our research in the spirit of "full disclosure." To quote Wilson and Ingersoll, 2004[56, p. 23], "Progress in restoration requires not only reports of successes, but also analyses of failures. Such analysis requires both a statement of the outcomes and consideration of the ecological processes responsible for success or failure".

Status of the Vegetation of the San Joaquin Valley

As noted, it is highly preferable that seed from local populations be used in restoration. However, San Joaquin Valley development is so pervasive that scant native habitat—and, hence, few sources of local seed—remain. Beginning in 1999, we have been surveying the western San Joaquin Valley for remnants of native upland vegetation in order to identify local seed sources for restoration efforts. Although this work was originally envisioned as being a relatively small component of the LRDP, it became increasingly evident that more resources should be apportioned to locating local seed sources and amplifying stocks of local seed. Concurrently, as it became evident how little “native” upland habitat remained, we modified our concept of what constituted a “local” source: expanding the collecting radius from about 24 kilometers (km) (15 miles [mi]) to about 80 km (50 mi).

> We located 41 collecting sites, ranging from a few hundred square feet to about 1,000 acres. In all, we encountered 159 native species: a small fraction of those known historically for the area. More importantly, although few of these species would be considered rare on the state level, a significant number are clearly rare on the local level. Nearly two-thirds (64.7 percent) of the species were encountered in only one to three collecting areas, and some species were represented by just a single individual. We found spinescale saltbush (*Atriplex spinifera*), a species that once dominated a large portion of valley floor[33], in just a single valley-floor site within the collecting radius (Figure 8).

Undoubtedly, many additional species and populations exist within the study area. Nevertheless, the activities outlined here represent a significant effort, and it is clear that any large-scale restoration efforts will be undertaken with a greatly reduced pallet of species.

As noted, many of the collecting areas are quite limited in area. Furthermore, a large portion of the collecting areas represent habitats that are vulnerable to human disturbance (e.g., roadsides, road cut-banks, the borders of evaporation ponds). The collecting area shown in Figure 9 clearly is subject to frequent perturbation, and would not likely be identified as an area that was contributing to the continuance of the Valley’s flora. Nevertheless, we have noted seven native species at this site, including one State Listed species (Lost Hills crownscale [*Atriplex vallicola*]), and cupped monolopia (*Monolopia major*), a species that we have encountered in just one other valley-floor site.

The Native Species Seed Production Facility (NPSPF) shown in Figure 10 was established at the Tranquillity project site in the fall of 2000. Initially, the NPSPF occupied 0.8 hectacres (ha) (2.0 acres [ac]) and the current size is 3.6 ha (8.9 ac).

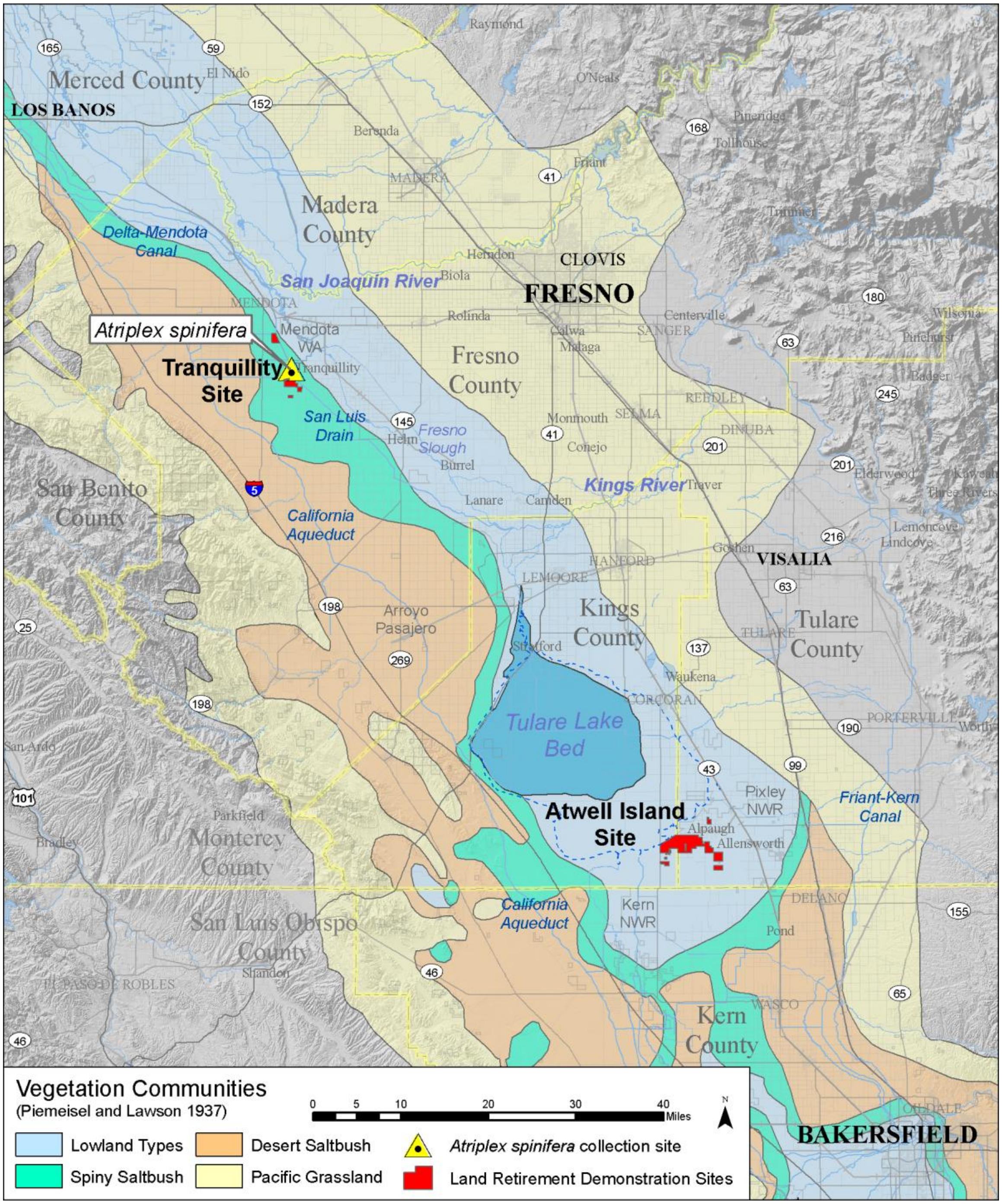

Figure 8. Vegetation of the San Joaquin Valley in the early 20th century (1937). The yellow area indicates the area dominated by spiny saltbush (*Atriplex spinifera*). The black dot indicates our sole valley-floor site for this species. The vegetation map is based on data from Piemeisel and Lawson [(33)].

Figure 9. ESRP Biologist Foung Vang collecting seed from the bank of a former evaporation pond.

Figure 10. The northern end of the NPSPF, showing beds of established perennial species.

The NPSPF has these objectives:

- Aid in the conservation of the remaining native flora
- Amplify stocks of locally-collected seed, i.e., to become a source of "foundation seed" for future restoration efforts
- Increase the number of species available for use in restoration
- Provide an accessible setting for tours, educational activities, and other forms of outreach

- Provide an on-site laboratory to investigate species' requirements

The NPSPF has developed a unique repository of local genotypes of native species, capable of serving as a foundation for obtaining the seeds needed for proposed restoration activities. Since its inception, the NPSPF has cultivated over 100 species of native plants. To dry, clean, and store seeds from the NPSPF and 'wild' collections, an approximate 139 meters^2 (1,523 feet^2) seed processing facility and warehouse was established in 2003. Since that time, a variety of seed processing equipment has been purchased and/or constructed, and the building has been "outfitted" (e.g. installing dust-collecting equipment, building shelving) as shown in Figure 11.

Figure 11. The Seed Processing Facility, showing a portion of the seed-cleaning equipment. The large machine to the left is a Clipper.

Irrigation

As with other California lowland ecosystems[23,26,29] rainfall is limited, and thus is a major limiting factor in the vegetation development and restoration of the San Joaquin Valley, and other arid and semi-arid areas[3,18,19,51].

Although weed competition may generally be more limiting than moisture in restoring San Joaquin Valley ecosystems, the amount and timing of precipitation plays a major role in restoration efforts. Supplemental (limited) irrigation can often be used, where available, to overcome these constraints. Conversely, irrigation can also be a "dual-edged sword" in restoration efforts at the Tranquillity site.

Some efforts have benefited greatly from irrigation. For example, the abundance of seeded species in some of the irrigated hedgerows installed at the Tranquillity site clearly surpassed that of any non-irrigated efforts. Likewise, a number of species that have proved very difficult to establish through direct seeding in non-irrigated applications (e.g., iodine bush [*Allenrolfea occidentalis*]; alkali heather [*Frankenia salina*]) have done extremely well when grown in the irrigated NPSPF. However, because intensive weeding is conducted routinely at the NPSPF, the seeded species are also relatively free from interspecific competition. Thus, it is not possible to completely attribute the performance of species solely to water availability.

On the other hand, irrigation clearly benefits the non-seeded species. A striking example can be seen in the Berm & Mycorrhizae Trial (Figure 12). In this trial, it was only feasible to supply irrigation to four of the five replicates. The non-irrigated plots had virtually no vegetation establishment (Figure 12A). In contrast, many of the seeded species were observed to have germinated in the sprinkler-irrigated plot. However, these plots were characterized by a near continuous cover of non-native species (Figure 12B).

Consequently, only a small number of individuals of the seeded species were able to grow to maturity. A similar situation was observed in the Suitability Trial, which was conducted during the same year and which was also sprinkler irrigated. In this trial, the percent cover of three of the six seeded species was above 10 percent at the time of monitoring (late spring), with the cover of one of these approaching nearly 20 percent. However, as with the Berm & Mycorrhizae trial, irrigation facilitated the growth of weeds, which subsequently overtopped and displaced the seeded species.

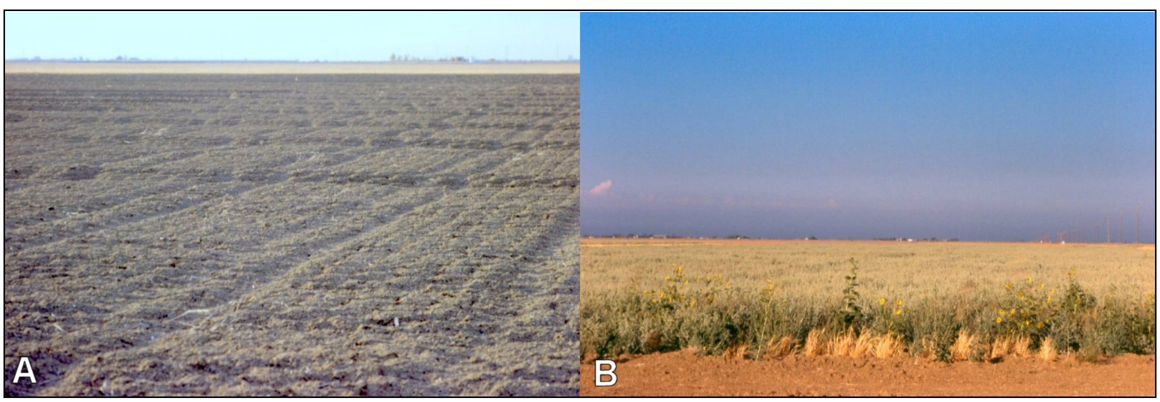

Figure 12: Comparison between non-irrigated (A) and irrigated (B) portions of the Berm & Mycorrhizae Trial.

Planting Methods

Restoration efforts at the Tranquillity site used four mechanical seeding approaches: drilling; and broadcast seeding followed by harrow raking, imprinting, or "cultipacking". Additionally, plant material transplanting (cuttings and rooted) was conducted (Appendix A, Table 2).

Each of the implements used for the seeding methods was equipped with multiple, specialized seed boxes designed to hold, agitate, and deliver seed in individual boxes according to seed size; shape; weight; and amount of inert material (e.g., hairs, awns or chaff). The experimental plot drill used in many of the drilled seeding trials was also equipped to accurately meter and uniformly place small to minute quantities of seed in a small plot.

Drilled Seeding

Our restoration research in recent years has primarily been conducted using a commercial grass drill. Drill technology optimizes seed depth placement and soil cover and potentially minimizes intra-specific and inter-row competition for seeded species. Perhaps most importantly, drilling is well suited for approaches using specialized herbicide application to suppress weeds between seeded rows (see discussion of Chemical Weed Control).

Imprinting and Cultipacker Seeding

The largest portion of the restoration work (both experimental and applied) at the Tranquillity site used broadcast seeding followed by imprinting as the seeding method. Imprinting is widely promoted as a seeding method for restoration in arid and semi-arid areas of the western U.S.[see: 14,15,36,42,43,45,46,55]. In imprinting, funnel-shaped teeth (Figure 13A) create a series of imprints in the soil (Figure 13B). These imprints concentrate rainwater, seed, litter, and topsoil, and provide a microhabitat ("micro-catchment") that protects seedlings from desiccation[14]. Additionally, soil-to-seed contact is improved by firming the seedbed surface immediately surrounding the seed.

Figure 13. A. Close-up of the teeth on the LRDP imprinter. B. A series of imprints in the clay soil at the Tranquillity site.

The results of a number of the restoration studies and related activities at the Tranquillity site do not support the routine use of imprinting on predominantly clay soils. A number of issues and observations support this finding.

Imprinting wet soil was very problematic. The sole warning regarding wet clay that we encountered in the literature came from St. John and Dixon, who advised that imprinting on clay soils should be avoided while the soils were "so wet that substantial quantities of it stick to the roller."[45, p. 18] In the unsuccessful restoration attempt on the 32.4 ha (80 ac) 'Manning Avenue Parcel,' the soils {Ciervo clay (48)} were somewhat wet (from heavy fog) during imprinting. With the exception of the initial hour in the morning, conditions during the imprinting of the Manning Avenue Parcel weren't sufficiently wet to significantly accumulate clay on the roller. Nevertheless, the soil was compacted so much that it was impossible for us to push a shovel into the soil. Not unexpectedly, germination of both seeded and 'seedbank' species was extremely limited.

Depressions formed by imprinting are unstable in the Tranquillity site's clay soils. This is perhaps a more critical issue than impenetrable wet soil. This instability can be either a fairly brief "persistence" or a "wash-out". The short persistence of the depressions results from soil slumping, and from sediment deposition accompanying surface water flows during precipitation events.

"Wash-out"—a term we applied to the deep holes that form at the base of each depression—has been observed on many of the imprinted areas at Tranquillity. This process may have particularly negative consequences for restoration efforts, as seed which failed to germinate during the initial year of imprinting may no longer be available for germination beyond the first seeding year.

Our observations at the Tranquillity site suggest that the depressions maintain their form longer, and are more resistant to washout in areas of Ciervo clay, versus those areas with Tranquillity and/or Lillis clay. Additionally, depressions imprinted in the Posochanet silt loam soils[48] of Study Area I at the Atwell Island project site (Figure 14) maintained their form far beyond what was observed at Tranquillity.

Comparisons of Drilling and Imprinting

During the initial years of the project, ESRP conducted two trials to compare imprinting and drilling[49,50]. Results from these trials suggested that the two methods were roughly equivalent, at least under conditions at the Tranquillity site. As establishment of seeded species by imprinting was extremely limited in many of the subsequent restoration efforts, we decided to undertake additional comparisons of seeding methods.

Figure 14. An well-formed imprint in the soil at the Atwell Island site (Study Area I). The yellow material in the bottom of the divot is accumulated *Lasthenia californica* "seed" (i.e., seed and floral parts).

CSU Fresno Master's student, Emily Magill (advisor Dr. John Constable), in collaboration with ESRP, undertook these comparisons as a thesis project. In this instance, three seeding techniques were compared: "broadprinting," drilling, and cultipacker-type seeding. The three seeding techniques were compared using four native species in the first year's trial (2003-04) and six species in 2004-05. Each species was planted in single-species plots (i.e., we did not compare seed mixtures). "Broadprinting" is a coined term for a modified form of imprinting in which broadcast seed is worked into the soil using a standard land imprinter (i.e., not equipped with concurrent seeding mechanisms). We use the term "cultipacker-type seeding"[55] here to clearly distinguish this method from rotary broadcasting alone (i.e., without following mechanical implements). In cultipacker-type seeding, seed is fed from the seed boxes onto a segmented trough which distributes the seed across the width of the seeder (1.5 meters [5 feet]) – in essence, a broadcast seeding. The seed drops from the trough onto the ground and is worked into the soil, first by drag chains and then by a cultipacker drawn behind the seeder. We used a Truax Pull Type Broadcast Seeder (Model WF-64) for the cultipacker-type seeding.

We anticipated that both drilling and cultipacker-type seeding might be far superior to imprinting, given the problems with imprinting noted above. Although some statistically significant differences were detected in some of the comparisons (i.e., for a particular species using a particular technique), the differences in percent cover were generally small and were not consistent across all species for a particular technique[28].

Transplanting

Transplanting is generally said to be more successful than direct seeding in restoring arid lands[2]. Transplanting was conducted in two trials, and in a larger-scale land treatment on 64.8 ha (160 ac) of the site. However, we did not compare the success of transplanting with direct seeding. In the largest-scale investigation of transplanting, seedlings of spinescale saltbrush (*Atriplex spinifera*) were grown-out in gallon-sized peat pots and transplanted into a portion of the Tranquillity site. Conditions in this portion of the site are highly saline, and direct seeding in previous restoration efforts had been particularly ineffective. Five hundred and ninety *Atriplex spinifera* were transplanted. The transplants received weekly watering until the time when rainfall was sufficient to soak the soil. More than three-quarters (78.3%) of the seedlings survived until the first monitoring period (April, 2002). However, only about a fourth (26.8%) of the 590 seedlings survived until the time of the next census (July, 2002). Nevertheless, despite this precipitous decline during the time between the first two monitoring events, survivorship was much more stable during the following year and a half, i.e., through the final monitoring (January, 2004), when a fifth (21.0%) of the 590 transplants were still living.

Modified Planting Conditions

Four methods of modified planting conditions were evaluated: furrow depth, row spacing, plant spacing, and topographic modification. Furrow depth and row spacing were evaluated in a single experiment (the Seed Augmentation and Planting Method Trial; Appendix A, Table 2). Similarly, plant spacing was evaluated in a single trial (the *Atriplex spinifera* planting trial shown in Appendix A, Table 2). Topographic modifications—which entailed the creation of low lying berms —were incorporated into a number of trials (Appendix A. Table 2) and in various restoration efforts.

Furrow Depth and Row Spacing

The Seed Augmentation and Planting Method Trial was conducted during the 2003-04 hydrologic year when rainfall was just two-thirds (65.96 percent) of the 30-year MAP (Figure 15). Therefore, all our observations of the usefulness of furrow depth and row spacing are limited to a single soil type during a particularly dry year.

We found “deep furrow” seeding (placing seed in the bottom of furrows created by leading furrow openers on the drill) was unsatisfactory for the conditions at the Tranquillity site. The poor results of “deep furrow” seeding are thought to be primarily due to the high amount of clods and deeper soil cover over seeds, incurred within the linear “micro-seedbed” in the bottom of the furrows created in these tight clay soils. Smoothing or breaking of the clods in the furrow bottoms by common “picker wheel” or “clod breaker” implements before seeding may provide more positive results for these mechanical treatments, as evidenced by pockets of high germination and emergence of seeded species where deposition of soil fines induced by precipitation runoff occurred within the furrows. The poor results from our “deep furrow” seeding treatments were in contrast to prior research indicating that furrowing is most consistently successful on fine and medium soils[53]. It is our opinion that the concept and theory of deep-furrow seeding still holds promise for enhanced moisture capture, ameliorating environmental extremes at the soil surface, and thus species establishment, if clods can indeed be minimized in the furrow bottoms.

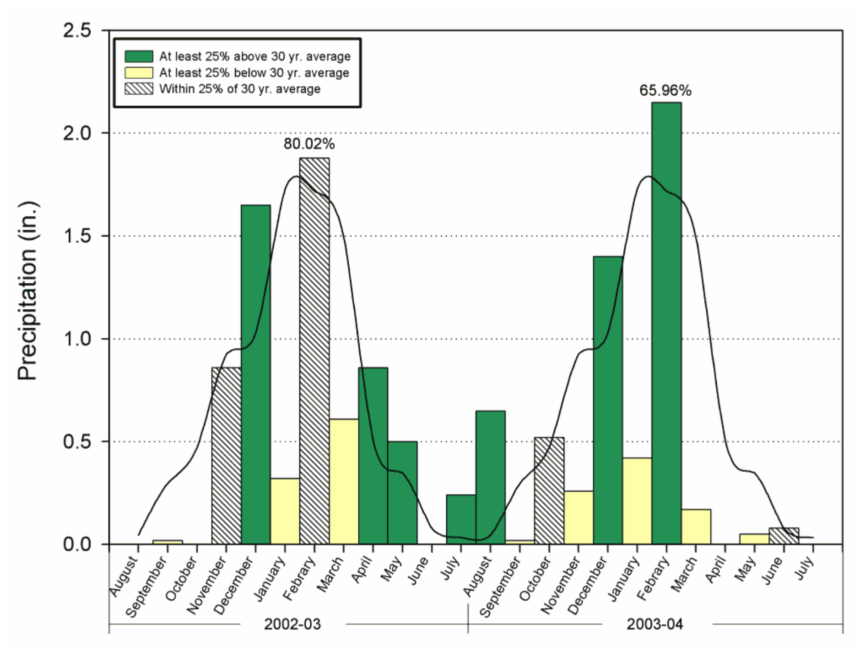

Figure 15. Precipitation at Tranquillity, California during the 2002-03 and 2003-04 hydrologic years (August, 2002 through July, 2004).

The ability to discern the effect of row spacing on plant establishment was similarly compromised by the poor growing conditions during the Seed Augmentation and Planting Methods Trial. In all subsequent restoration activities in which a plot drill was used, we have relied on a 30.5 cm (12 in) row spacing.

Transplant Spacing

Investigations of the effects of plant spacing (i.e., the distance between transplanted seedlings) on establishment were similarly unrevealing. The *Atriplex spinifera* planting trial evaluated this effect. In this trial, any effects of plant spacing were overridden by other factors (e.g., insect or wildlife herbivory, grazing, fire, site heterogeneity, and vehicle damage from maintenance activities on the adjacent irrigation canal). In particular, the fire that burned this area was particularly important, as it killed most of the shrubs before they had reached a size where effects of plant spacing would be evident (i.e., before individual plants start to compete with each other).

Topographic Modification

Topographic modification, or "berming," was easily the most confounding factor examined during our work at the Tranquillity site. In some instances, native species establishment was clearly correlated with berms and their adjacent trenches; while in other instances, there was an equally clear negative correlation between berms and species establishment. Shrubs showed both patterns most strongly. An example of a negative correlation can be seen in the Section 23 Restoration Trial (Figure 16). In this instance, shrub establishment was extremely successful in the "flats" (i.e., the areas between the berms), while shrub establishment on the berms and trenches was rare (Figure 16).

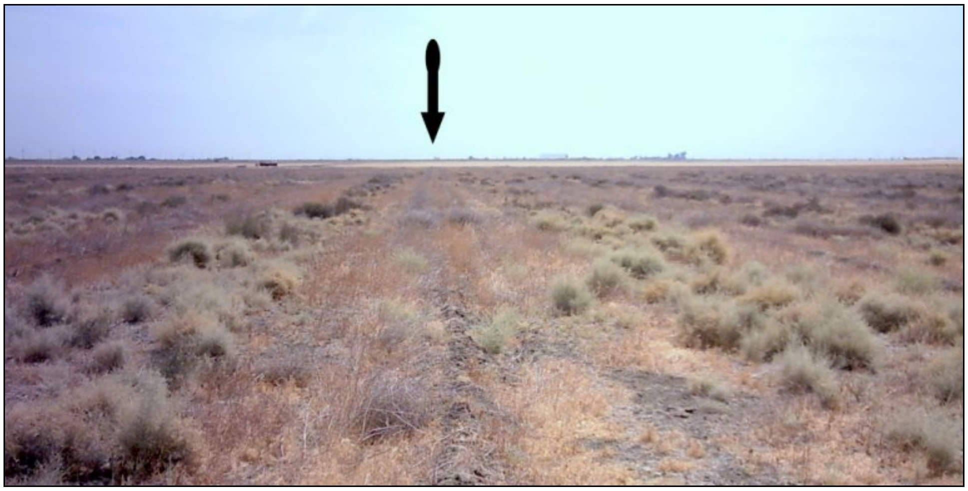

Figure 16. Shrub establishment in the Section 23 Restoration Trial. The arrow points to the center most berm in the photograph. The lighter green shrubs are allscale saltbush (*Atriplex polycarpa*); the dark green shrubs, which are more abundant towards the far end of the area, are bush seepweed (*Suaeda moquinii*).

At times (e.g., the Tranquillity Habitat Restoration Study (HRS) plots and restoration efforts on the North Avenue Parcel), the positive correlation appears more related to increased water availability (in the trenches) and perhaps from a reduced seed bank in the bermed soil resulting from soil inversion. The factors for the negative correlations are less certain. It seems likely that these negative correlations can be attributed to particular weed species that have a competitive advantage on the berms.

Non-chemical Weed Control

In all cases, the non-chemical weed control methods evaluated (pre-irrigation, mowing, and burning trials listed in Appendix A, Table 2) were not enough to overcome the weed load at the Tranquillity site. Furthermore, in one trial (the Section 10 Burning and Mowing Trial) two of these techniques combined had relatively little effect.

However, in all trials that primarily used mechanical weed control, treatments were only applied once, and no trials were continued beyond their initial year. In two of the three trials in which mowing was evaluated (Section 10 Burning and Mowing Trial and the Mowing Trial; Appendix A, Table 2), each trial was intended to be mowed multiple times throughout the growing season. However, conditions during that particular hydrologic year (2002-03) were extremely dry. During that year, the weeds did not grow much after the initial mowing and additional mowing was unwarranted.

Mowing

Mowing may also serve as a surrogate for grazing, and thus enable estimation of the potential for grazing as a weed control method in restoration efforts. Our investigations of mowing were insufficient in scope to allow such comparison. Although we have not conducted any formal experimental investigations of grazing, ESRP incorporated sheep grazing as a management tool for the Tranquillity site for the 2004-05 and 2005-06 hydrologic years. However, no formal tests were conducted to evaluate the relationship between grazing and the establishment of native plants.

Burning

Two approaches were taken to examine the utility of burning in restoration:

- Seeding areas of the site that had undergone "unplanned" burns (i.e., either through arson or by accident)

- Burning with an agricultural flamer (Figure 17).

The experiment to seed a recently burned area with native species (the Section 10 Burn and Mowing Trial, shown in Appendix A Table 2), demonstrated little promise for restoration. This poor result may have been due to the burn timing. The fire had occurred during the dry season of the preceding hydrologic year, and red brome (*Bromus madritensis*)—an invasive species which dominated the burned area—had already produced seed during that growing season.

An agricultural flamer was used in one formal experiment (the Native Release Trial; Appendix A Table 2, and Figure 17), and was also frequently used for weed control in the NPSPF. The Native Release Trial examined the possibility of promoting native seed germination by reducing competition from weeds (using burning, mowing, and two post-emergent herbicides). Plots were in an area that formerly supported a large population of the native snake's head (*Malacothrix coulteri*). The treatments were applied early in the season, after the dominant red brome had germinated but before the snake's head had germinated. In this instance, flaming appeared to do little to facilitate establishing native species. We attribute this poor response to difficulties in controlling the intensity of burning when using a handheld flamer. This intensity may have burned the snake's head seed. A tractor-drawn flamer would likely afford more uniform, temperature-controlled suppression.

Figure 17. Flaming with an agricultural flamer on the Native Release Trial (2004-05 growing season).

Pre-irrigation

Pre-irrigation, the final "non-chemical" weed control method, is a technique in which an area is irrigated before the onset of the winter rains, in order to stimulate weed germination. The weeds are then suppressed by various mechanical methods (e.g., disking), and the area is then seeded. Pre-irrigation appeared to be particularly unsuited for conditions at the Tranquillity site. In essence, a single year's application of this approach did little but stimulate weed growth. Given the costs associated with this approach, as well as the infrastructural difficulties associated with providing large-scale irrigation, pre-irrigation is not recommended as a component of any "herbicide-free" restoration strategy for retired agricultural lands in the San Joaquin Valley. Nevertheless, pre-irrigation could conceivably be used with various herbicide treatments, if time constraints require an area to be seeded before the winter rains start.

Chemical Weed Control

Chemical weed control trials at the Tranquillity site have used both pre- and post-emergent herbicides (Appendix A, Table 2). One trial—the Herbicide and Growth-form Trial—focused exclusively on post-emergent herbicides, with chemical treatments targeted to suppress either grasses, broad-leaved species (forbs), or both, and with treatment-specific seed mixtures (i.e., mixtures composed of species that would be minimally affected by the herbicide applied to that particular treatment). Although this type of approach is common in restoration, both grasses and broad-leaved weeds were well represented in the weed seed bank in the experimental area (particularly Section 23). Hence, when a grass-specific herbicide was applied, the plots were subsequently dominated by broad-leaved weeds (primarily black mustard; Figure 18). Likewise, when a herbicide selective for broad-leaf species was applied, the plots were soon dominated by the non-native littleseed canarygrass (*Phalaris minor*).

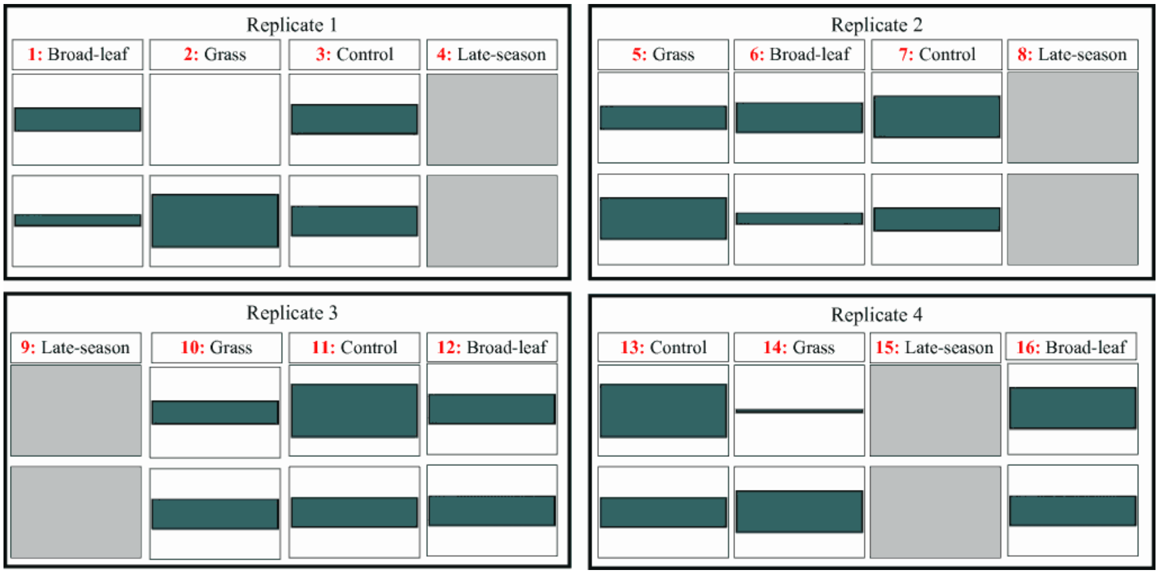

Figure 18. Graphical representation of the abundances (percent cover) of black mustard (*Brassica nigra)* (the upper half of each plot), and littleseed canarygrass (*Phalaris minor*) (the lower half of each plot). The thickness of the bar is proportional to the abundance of the species on that plot. Plots shown in gray are those that were sprayed with Roundup™ (i.e., plots where these two species had been controlled).

Broad-spectrum herbicide

The treatment that showed the most promise was an application of a broad-spectrum herbicide (e.g., glyphosate [e.g., Roundup™]) after the early-season weeds were well-developed. In this treatment, the plots had been seeded with a mixture of late-germinating native species. Although this approach was hopeful, the restoration response was not consistent across replicates. More importantly, precipitation during that year (the 2002-03 hydrologic year) was such that an unusually large amount of rain fell late in the growing season (Figure 15); hence, there was undoubtedly more moisture available for the late-germinating species than would be found in most years.

Pre-emergent herbicides

In the past three years of the project, our research focus has been centered on using selected pre-emergent herbicides (i.e., soil residual herbicides having primarily root absorption activity, and may also exhibit varying degrees of foliar activity). Herbicide selection was problematic, as various herbicides either affected the seeded species, or there was not enough information to determine the effects of these herbicides on these species. Therefore, we applied the pre-emergent herbicides with charcoal banded over the seeded drill row (seed "safening") to protect the seeded species from the subsequently application of pre-emergent herbicides. This approach is common in the ryegrass and turfgrass seed industries and is being evaluated in this research for adaptation to seeding of native species.

In the first-year's investigation of this technique (the Manning Avenue trial; Appendix A, Table 2), we compared two methods of applying the charcoal: 1) wet slurry banding - spraying a charcoal slurry band (approximately 7.5 centimeters [3 inches] wide) over the seed row (Figure 19); and 2) dry incorporation - applying the charcoal in dry powdered form into the seed row in a similar band. Results from this trial indicated that both methods were equally effective in protecting the native seed from herbicide injury within the applied band. Since that initial trial, we have relied exclusively on wet slurry banding for applying the charcoal because of its relatively simpler and more efficient field application.

Results from the first year's Herbicide and Charcoal Treatment Trial were quite promising, with three of the five herbicides demonstrating good to excellent weed suppression. Landmark MP™ (chlorsulfuron + sulfometuron methyl), Telar DF™ (chlorsulfuron), and Goal 2XL™ (oxyfluorfen) treatments demonstrated good to excellent weed suppression, with native seeded species exhibiting good emergence and survival in the latter two treatments. Emergence and vigor of seeded species in the Landmark MP™ treatment was particularly poor, but appears to be herbicide rate-dependent, as outrun areas at the end of Landmark MP™ plots where less product was applied exhibited increased emergence of seeded species while maintaining excellent weed suppression. Broadrange™ (sulfentrazone) and Cerano 5MEG™ (clomazone) provided poor weed suppression, allowing greater competition with emerging native seedlings. These latter two herbicides were granular applications, thus possibly reducing the opportunity for surface-applied charcoal to deactivate the herbicide within the drill row.

In the second year's research with pre-emergent herbicides, we attempted to "fine tune" herbicide application rates, refining these techniques for restoration applications. Specifically, various exotic species (primarily foxtail barley [*Hordeum jubatum*]. and red brome seeds were abundant on the soil surface and in the existing grass thatch. A portion of this seed fell into the furrows during drilling and was oversprayed with the charcoal slurry (hence, protected from the effects of the herbicide). As a result, the initial growth on the study plots resembled a series of "Mohawks," with the non-native grasses forming dense strips. A modified approach involving the pre-emergent herbicide and charcoal, but preceded by a broad-spectrum pre-treatment (e.g., glyphosate) appears to minimize this problem. Perennial native species in the first year's trial have continued to flourish into the present. Bush seepweed (*Suaeda moquinii*) has done particularly well, with many second generation seedlings established in a number of plots.

Figure 19. Applying the treatments (seed, herbicide, and charcoal banding) on the North Avenue Herbicide and Charcoal Treatment Trial – 2005.

Other Treatments

This heading is used to group a broad variety of factors (Appendix A, Table 2):

- Comparing seed mixtures
- Amending the soil root zone
- Using nurse crops and cover crops

Comparing seed mixtures

This comparison includes both multi-species mixtures and a suite of individual species. A few broad observations can be made. Generally, the most successfully established species were either early successional species and/or "aggressive" natives (e.g., allscale saltbush [*Atriplex polycarpa]*, goldenbush [*Isocoma acradenia*], and common spikeweed [*Hemizonia pungens]*). Some species were extremely variable in their establishment success; for example, allscale saltbush [*Atriplex polycarpa*] was very successfully established in the Section 23 Restoration Trial and did well in the HRS plots at both Tranquillity and Atwell Island. In contrast, this species had little success in both Herbicide and Charcoal Treatment Trials, as well as in the two Planting Technique trials. Most often, only a few species in the multi-species mixtures were able to become successfully established. Frequently, the poor performance of the unsuccessful species could not be attributed to competition with the other seeded species (e.g., in single species applications), but rather to non-native species encroaching on the plot.

Amending root zones

This includes salt-remediation products, seed coatings, and mycorrhizal inoculation (amending the seedbed with symbiotic root fungi). Root zone augmentation for salinity reduction (i.e., using salt-remediation products such as

HydraHume™), or augmentation for moisture conservation (polyacrylamide polymer incorporated in seed coatings), did not appear to provide immediate or long-term benefits for native species establishment. However, these products were only investigated in a single trial (the Seed Augmentation and Planting Methods Trial).

Some research has indicated that restoration of abandoned agricultural fields can be enhanced by mycorrhizal additions[(35)]. Nevertheless, it is uncertain that mycorrhizae are limiting at the Tranquillity project site. Mycorrhizal additions were only examined in a single trial, the Berm and Mycorrhizae Trial (Appendix A, Table 2). Although there was a fair amount of heterogeneity in the establishment of the seeded species, the over-riding dominance of weeds, in particular the "tumbling saltbushes" (Appendix A, Table 2) precluded detection of any treatment effect. Dr. Ted St. John, restoration and mycorrhiza specialist, visited the site in the initial stages of the project, and his evaluation was that the soils were not deficient in mycorrhizae. Additionally, a significant portion of the species that we have targeted as priority species in restoration efforts are members of the *Chenopodiaceae*—a plant family that in almost all known cases does not have strong associations with mycorrhizae.

In the Seed Augmentation and Planting Method Trial, we applied phosphate fertilizer because of the predominance of forbs and shrubs in the suite of seeded species. No differences in response to any of the augmentation treatments were detected for alkali goldfields (*Lasthenia chrysantha*). However, Great Valley phacelia (*Phacelia ciliata*) displayed a highly significant ($P<0.01$), positive response to addition of phosphate (PO_4) fertilizer alone. Other treatments (coated seed + PO_4; HydraHume + PO_4; and no augmentation [control standard]) exhibited consistently poor results. Nevertheless, as noted in the discussion of nitrogen deposition, elevated nutrient levels may lead to increased competition from weeds and increased insect herbivory. Restoration efforts may be hampered by elevated nutrient levels, rather than nutrient deficiencies.

Using nurse crops and cover crops

Interim planting of dryland barley (*Hordeum vulgare*) cover crops appears to provide suitable temporary cover during the growing season for site protection and weed suppression during periods when the fields are not in use and awaiting restoration. Barley seeded at standard agronomic seeding rates has been shown to effectively suppress most annual and perennial weeds temporarily (seasonally or annually) during years with precipitation amounts and timing at, or near, long-term annual and seasonal means. However, as we witnessed during the very wet 2004-05 hydrologic year (Figure 3), weeds (particularly the annual mustards) may still dominate in excessively wet years, even amid uniform agronomic stands of seeded barley. Grazing (preferably) or tillage may be required for interim weed suppression between harvesting the barley and seeding the following year's crop, to address the problem of late-season weed species.

Using a barley nurse crop in alternate rows with seeded natives appeared to enhance seeded species' establishment in the Seed Augmentation and Planting Methods Trial (Figure 20). In theory, the barley should ameliorate environmental extremes (heat, wind, low moisture) at the soil surface for the new seeding, and provide limited suppression of weeds. The alternate barley rows serve, in essence, as a nurse crop for seeded natives, with row spacing sufficiently wide (minimum 30.5 centimeters; 12 inches) to minimize inter-specific competition between adjacent rows.

Results from 2004 data indicate that two native species, alkali goldfields (*Lasthenia chrysantha*) and Great Valley phacelia (*Phacelia ciliata*), exhibit a highly significant ($P<0.0001$) and positive response to planting method treatment. Standard drilling (non-deep furrow) with alternate barley nurse crop rows on 30-centimeter centers showed highest establishment of these two species. Standard drilling on 30-centimeter centers without barley nurse crop ranked second in establishment, while both depths for deep-furrow drilling treatments (10-centimeter [4-inch] and 20-centimeter [8-inch]) had equally poor results.

Figure 20. Alkali goldfields (*Lasthenia chrysantha)*, the orange-flowered species, interplanted with barley (*Hordeum vulgare*) in the Seed Augmentation and Planting Methods trial.

Conclusions

Some general observations and trends can be discerned from our restoration research at Tranquillity and Atwell Island.

Unpredictable Precipitation

The most common and striking observation is the variability in response among iterations of the same treatment when tried in different locations, or in different years. A prime example can be seen in ESRP's work at the Atwell Island site (Figure 21). The habitat restoration study at Atwell Island is composed of three study areas, each containing sixteen 0.8 ha (2-ac) test plots. The study areas all received the same experimental treatments, and are separated by just 5.6 km (3.5 mi). On two of the study areas, native species establishment was extremely poor (Figure 21A, B), while restoration on the third study area was very successful (Figure 21C). This is just one of many such examples that illustrate this key consideration of intrinsic variability when evaluating restoration efforts.

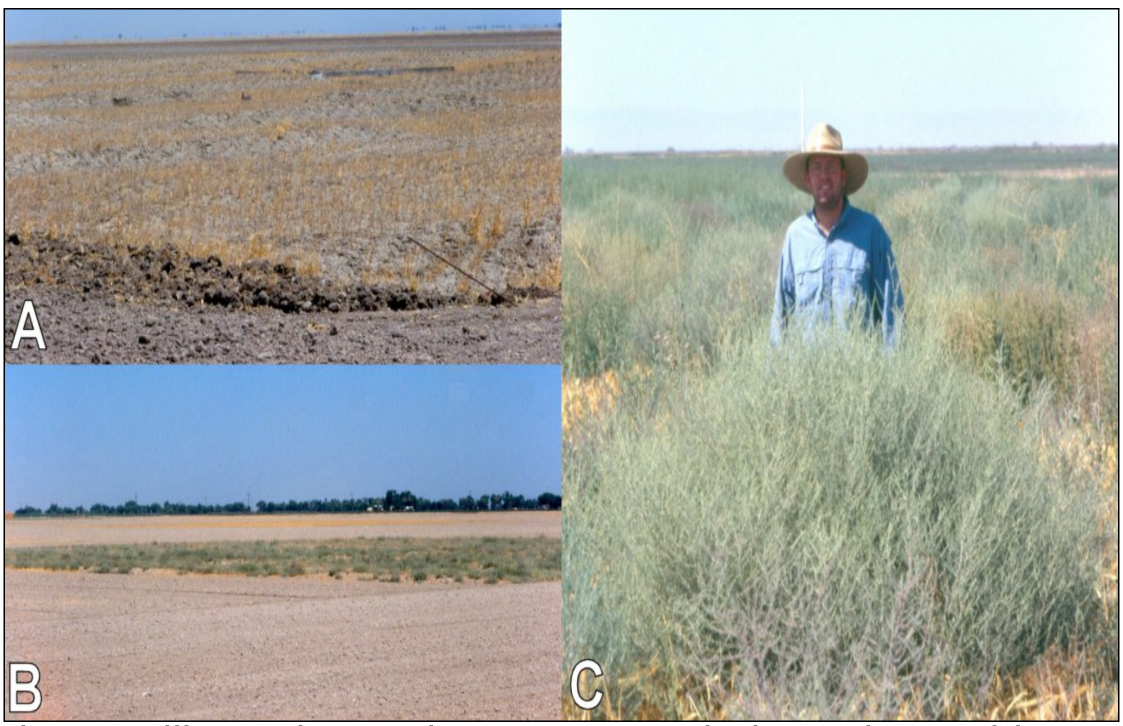

Figure 21. Differences in restoration response among the three study areas of the Atwell Island site. A. Study Area 3; B. Study Area 2; C. Study Area 1.

The pronounced variations between years in precipitation timing and amount are also extremely problematic. Literature recommendations that restoration in arid and semi-arid regions is best undertaken during "suitable years" are common[2,10,19,51]. However, given the unpredictability of precipitation amounts and patterns in the San Joaquin Valley, there can be little certainty in anticipating "suitable years" with good precipitation. For example, one trial (the Section 23 Restoration Trial) was developed to compare a particular seed mixture that had been imprinted during a relatively dry year (1999-2000; 58.1% MAP) with what was predicted to be a wet year (2002-03). However, precipitation in 2002-2003 was just 80.0 percent of MAP.

Weeds and Insects

A second prevalent pattern is that competition from weeds will most likely be the primary impediment to successful restoration, at least during all but the driest years and/or in the driest areas of the San Joaquin Valley. Although some restoration approaches using fairly minimal weed control methods have been reasonably successful (e.g., Study Area 1 at the Atwell Island site; Figure 21C), it seems inescapable that successful restoration strategies will frequently need to incorporate some form of chemical weed control.

In addition to issues attendant upon non-native plants, restoration at the Tranquillity site has been severely impacted by insect pests. The most severe problems have been from false chinch bugs (*Nysius* spp.). These insects occur in large swarms, and can quickly cover vegetation (Figure 22). As these outbreaks generally occur during the dry season, the greatest portion of the vegetation on the lands surrounding the Tranquillity sites has already senesced and the native perennial species on the LRDP appears to be a favored "target."

Figure 22. False chinch bugs (*Nysius* sp.) feeding on saltbush (*Atriplex* spp.)

Although severe infestations have not occurred during every year of the project, during most years at least one area of the Tranquillity site has been severely impacted. In extreme cases, false chinch bug damage resulted in death of most of the seeded native plant species on selected studies.

We have successfully combated these outbreaks on a small scale using Malathion™; however, fairly constant monitoring (i.e., weekly site visits) have been required in order to initiate control measures before extensive damage occurs. Fortunately, these species have not yet been a problem at the Atwell Island site. Nevertheless, if conditions at the Tranquillity site represent the majority most of the drainage-impacted lands, then pest control will undoubtedly be an essential component of any restoration activities.

Seed Bank Constraints

As much as conditions at the Tranquillity site represent typical conditions on the rest of the drainage-impaired lands, the existing seed bank will generally contribute little to the restoration of retired lands. In the six years of the Habitat Restoration Study at the Tranquillity site, few non-seeded native species have been observed on these plots, and these have generally been in low abundance. A partial exception is Great Valley Phacelia (*Phacelia ciliata*), which in wetter years has been fairly abundant on the most saline and longest-fallowed area of the Tranquillity site.

Recommendations

The research funded through the LRP-CVPIA has made significant progress in developing and refining techniques for land restoration prescriptions for LRDP lands, particularly for selecting native species, adapting techniques to site characteristics, refining planting methods, and suppressing weeds.

Weed Management

Restoring retired lands to self-sustaining, native plant communities with desirable values for wildlife habitat, site stabilization and erosion control is extremely problematic because of immediate, aggressive encroachment of weeds such as:

- Annual grasses (e.g., *Bromus madritensis, Hordeum* spp., *Avena* spp., *Phalaris* spp.);
- Perennial grasses (e.g., *Lolium perenne*)
- Annual broadleaved herbs (e.g., *Brassica, Sisymbrium, Bassia,* and *Atriplex* spp.);
- Perennial broadleaved herbs (e.g., *Acroptilon repens*)

Fully integrated weed management strategies incorporating an array of techniques (chemical, mechanical, cultural, pyric, and biological) will be needed to suppress weeds during the native species establishment period of three to five years. Single-year or single-technique approaches will typically be insufficient to suppress weeds so that establishing native vegetation can sustain itself and provide intrinsic weed suppression.

Weed management (suppression, control, or eradication, as applicable on a site-by-site basis) is, and will continue to be, the overriding limitation to successfully restoring native plant communities on retired (dewatered) agricultural lands in the San Joaquin Valley. Restoration can probably be accomplished within three to five years of seeding on most sites, ***IF*** weed suppression can be adequately planned, implemented, and sustained through the establishment period, and if insect control measures are applied when needed.

Moisture Conservation

Moisture conservation is second only to weed management as a primary concern in establishing native plant communities. The western San Joaquin Valley's semi-arid environment is characterized by long-term mean annual precipitation less than 25 centimeters (10 inches). Fine-textured soils (clays, clay loams) may exhibit high moisture retention, but slow release rates for plant root uptake may be limiting. As a result, moisture capture and conservation are equally paramount for successful revegetation. Traditional as well as innovative measures for moisture conservation must be integrated with seedbed preparation and/or seeding applications, including amelioration of both environmental and anthropogenic moisture depletion impacts. Examples of these practices include:

- Cover crops including species such as salt-tolerant varieties of common barley (*Hordeum vulgare*); salt-tolerant varieties of grain, forage or sudan sorghums (*Sorghum spp*.) or millets (*Panicum miliaceum*)

- Soil surface roughening to reduce effects of wind, including coarse disking, ripping, chiseling or plowing

- Artificial, designed micro-relief (depressions) for moisture capture, including contour berms and associated borrow areas, contour furrowing, land imprinting (on suitable soils), deep-furrow seed drilling, pitter-seeding, etc.

- Similar biotic and/or abiotic measures that combine moisture capture and conservation (retention) with weed suppression capabilities

These moisture conservation practices are also often combined with "wind barrier" rows or strips of dryland-adapted, salt-tolerant perennial grasses alternating with blocks of seeded native mixtures, initially established under limited irrigation (e.g., tall wheatgrass, [*Thinopyrum ponticum*]; creeping wildrye, [*Leymus triticoides*]).

To remain cost-effective, however, moisture conservation measures must be undertaken within the practical context of routinely available or easily modifiable tillage, seedbed preparation, and seeding equipment and seed materials. These practices are primarily applied during non-use periods (i.e., no seeding or crop production). These measures are alternated in time with routine tillage, herbicide application, and/or grazing to reduce weed load before seeding native plants.

Species Selection

Based on current soil and climatic capabilities and constraints characteristic of retired agricultural lands in the Tranquillity locale, restored native plant communities will typically consist predominately of shrubs and forbs, with native grasses as a minor component. These communities reflect the realistic habitat restoration capabilities of these formerly irrigated agronomic fields and soils. This proposed relative plant composition also approaches reference plant communities and habitats within the western San Joaquin Valley (e.g., Alkali Sink Ecological Reserve) that are recognized as exhibiting desirable habitat values for targeted species (threatened and endangered species, as well as other, more common components of the fauna), site stability, and weed suppression.

Plant Criteria

The LRDP research to date has generally identified and refined species selection and mixture formulations. Numerous species (see Appendix A, Tables 2 and 3) have been collected and evaluated. Desirable traits and adaptation criteria for plants for use in the LRDP include:

Local source materials

- First preference / priority – endemic to west-central San Joaquin Valley
- Second preference / priority – endemic to southern San Joaquin Valley
- Third preference / priority – endemic to southern California sites of similar soils, latitude, elevation, and climate

Propagation and Availability

- Ease of seed harvest, cleaning, conditioning, processing, viability testing and storage – using mechanized and/or seed industry standard methods wherever possible
- Availability and quantity of seed (commercial stocks and non-commercial harvest)
- Multiple purpose utility (e.g., forage quality, palatability, absence of phytotoxins, etc.)

Ease of establishment

- High germination, seedling vigor and sustainability
- Are adaptable and respond well to standard seedbed preparation and planting methods
- Suppression of / resistance to / tolerance of weed competition
- Reproductive success (sexually - seed production; asexually – vegetative spread by tillering, sprouting, root extension)
- Favorable pollination requirements (in terms of local insect and bird populations)
- Insect and disease resistance

Many species possess characteristics that facilitate successful germination, seedling growth, establishment, and productivity under irrigated or otherwise intensively managed conditions. Only a subset of these species, however, satisfy the selection criteria above within the context of adaptation to non-irrigated, highly disturbed, saline/sodic, weed-infested field sites characteristic of the vast majority of agronomic fields likely to be retired from irrigated agriculture.

Cost Control

In addition to adapting to these field growth conditions, an equally important factor is cost-effectiveness in light of programmatic budget constraints. Cost control will place emphasis on the commercial availability of a significant proportion of the recommended species, particularly for local ecotypes of perennial shrubs and grasses known to be commercially available in most years (i.e., in California's southern Central Valley generally, and in the western San Joaquin Valley specifically).

Vegetation costs will inflate significantly if seed mixtures are narrowly formulated to rely heavily on species that:

- Are not commercially available
- Are characterized by reduced (often infrequent and dispersed) field populations, limiting seed collection sources
- Require manual (i.e., non-mechanized), often specialized techniques for seed collection, cleaning, conditioning, storage or viability testing

Recommended Seed Mixtures

The following recommendations reflect LRDP field research study and NPSPF results; extensive literature review; consultation with academia, professional organizations, commercial firms, and individuals who are knowledgeable in revegetation science within the San Joaquin Valley; and the authors' professional judgment.

These species (as well as additional species listed in Appendix A, Tables 2 and 3) meet most of the adaptation criteria for desirable native plants, and are recommended to form the core or key set of species from which to tailor individual seed mixtures. Site and environmental constraints are anticipated to fall predominantly within four generalized physiographic regimes. These regimes are classified based primarily on soil moisture and salinity limitations. Within these four regimes, species selection would be further guided and constrained by overriding objectives of:

- Rapid establishment to stabilize the site and suppress weeds during the establishment year(s)
- Species diversity, structure, function and abundance that approaches or meets ecological and botanical habitat requirements and goals
- Cost-effectiveness, with priority on species having preferred local ecotypes that are commercially collected, propagated and available.

The sections below provide ***conceptual*** examples of possible seed mixtures, and a list of key species that would be generally compatible with different physiographic regimes. Individual seed mixtures, reflecting variable proportions of shrubs, forbs and grasses, will be specifically tailored and formulated to address varying field conditions and environmental constraints imposed on a site-by-site basis as lands are retired from irrigated agriculture.

Mesic with low salinity

This regime is characteristic of predominantly mesic, less saline/sodic sites receiving sub-irrigation from ditch, canal or reservoir seepage. The key species would include higher proportions of grasses and annual / perennial forbs, and fewer Chenopod shrubs and forbs.

Species	Common Name	Family	Life-form
Astragalus asymmetricus	San Joaquin milkvetch	*Fabaceae*	perennial herb
Distichlis spicata	inland saltgrass	*Poaceae*	perennial grass
Frankenia salina	alkali heath	*Frankeniaceae*	perennial herb
Heliotropium curassavicum	seaside heliotrope	*Boraginaceae*	perennial herb
Isomeris arborea	bladderpod	*Capparidaceae*	shrub
Lasthenia chrysantha	alkali goldfields	*Asteraceae*	annual herb
Layia glandulosa	white layia	*Asteraceae*	annual herb
Leymus triticoides	creeping wildrye	*Poaceae*	perennial grass
Phacelia ciliata	Great Valley phacelia	*Hydrophyllaceae*	annual herb
Sporobolus airoides	alkali sacaton	*Poaceae*	perennial grass
Trichostema ovatum	San Joaquin bluecurls	*Lamiaceae*	annual herb

Mesic with high salinity

These sites would typically be ephemerally mesic, highly saline/sodic in nature, receiving designed surface flows or point-source inundation of saline tailwater (e.g., evaporation ponds). The key species would be comprised predominantly of halophytic Chenopod species (e.g., *Allenrolfea*, *Suaeda*), with few to no grasses.

Species	Common Name	Family	Life-form
Allenrolfea occidentalis	iodinebush	*Chenopodiaceae*	shrub
Amsinckia vernicosa	green fiddleneck	*Boraginaceae*	annual herb
Atriplex lentiformis	quailbush	*Chenopodiaceae*	shrub
Heliotropium curassavicum	seaside heliotrope	*Boraginaceae*	perennial herb
Hemizonia pungens	common spikeweed	*Asteraceae*	annual herb
Hutchinsia procumbens	prostrate Hutchinsia	*Brassicaceae*	annual herb
Kochia californica	rusty molly	*Chenopodiaceae*	shrub
Suaeda moquinii	bush seepweed	*Chenopodiaceae*	perennial herb

Arid with high salinity

These sites would characteristically be arid, with moderately to highly saline/sodic conditions. Key species would form a mixture of shrubs, forbs and grasses, and would emphasize halophytic species.

Species	**Common Name**	**Family**	**Life-form**
Allenrolfea occidentalis	iodinebush	*Chenopodiaceae*	shrub
Amsinckia vernicosa	green fiddleneck	*Boraginaceae*	annual herb
Atriplex polycarpa	allscale saltbush	*Chenopodiaceae*	shrub
Grindelia camporum	gumplant	*Asteraceae*	perennial herb
Gutierrezia californica	California matchweed	*Asteraceae*	subshrub
Hemizonia pungens	common spikeweed	*Asteraceae*	annual herb
Hordeum depressum	alkali barley	*Poaceae*	annual herb
Isocoma acradenia	goldenbush	*Asteraceae*	shrub
Lasthenia chrysantha	alkali goldfields	*Asteraceae*	annual herb
Layia glandulosa	white layia	*Asteraceae*	annual herb
Phacelia ciliata	Great Valley phacelia	Hydrophyllaceae	annual herb
Sesuvium verrucosum	western sea-purslane	*Aizoaceae*	perennial herb
Sporobolus airoides	alkali sacaton	*Poaceae*	perennial herb
Suaeda moquinii	bush seepweed	*Chenopodiaceae*	perennial herb

Arid with low salinity

These sites would typically be arid and less saline / sodic. Key species constitute a mixture comprising a broader spectrum of adapted species, and exhibiting a greater proportion of forbs and grasses.

Species	**Common Name**	**Family**	**Life-form**
Atriplex polycarpa	allscale saltbush	*Chenopodiaceae*	perennial shrub
Atriplex spinifera	spinescale saltbush	*Chenopodiaceae*	perennial shrub
Eriogonum fasciculatum	California buckwheat	*Polygonaceae*	perennial herb
Grindelia camporum	gumplant	*Asteraceae*	perennial herb
Hordeum depressum	alkali barley	*Poaceae*	annual herb
Isocoma acradenia	goldenbush	*Asteraceae*	perennial shrub
Isomeris arborea	bladderpod	*Capparidaceae*	perennial shrub
Lasthenia chrysantha	alkali goldfields	*Asteraceae*	annual herb
Layia glandulosa	white layia	*Asteraceae*	annual herb
Malacothrix coulteri	snake's head	*Asteraceae*	annual herb
Mentzelia laevicaulis	blazing star	*Loasaceae*	annual herb
Phacelia ciliata	Great Valley phacelia	*Hydrophyllaceae*	annual herb
Phacelia tanacetifolia	tansy-leaved phacelia	*Hydrophyllaceae*	annual herb
Poa secunda	one-sided blue grass	*Poaceae*	perennial herb
Sesuvium verrucosum	western sea-purslane	*Aizoaceae*	perennial herb

Seedbed Preparation

Standard seedbed preparation measures (as routine practices for agricultural use in the project locale) appear adequate for soils characteristic of the study area. These preparations are typically standard tandem (offset) disk tillage followed by cultipacking (using a "ring roller" or similar mechanical measure for clod reduction, seedbed firming and smoothing). On sites with a dense "plow-pan" (long-duration tillage layer) of compressed clays below the soil surface, deep chiseling or ripping may be necessary to improve soil tilth (i.e., friability, moisture infiltration, and plant root penetration capabilities). If these latter measures are required, follow-up disk tillage and/or cultipacking may be needed to reduce clods brought to the soil surface by the chisel or ripping operation.

The poor results from "deep furrow" drilled seeding (placing seeds in the bottom of furrows created by leading furrow openers on the drill, or by previous furrow tillage) were considered to be primarily attributable to the high amount of clods and deeper soil cover over seeds within the linear "micro-seedbed" in the bottom of the furrows created in these tight clay soils. Smoothing or breaking of the clods in the furrow bottoms by common "picker wheel" or "clod breaker" implements before seeding may provide more positive results for these mechanical treatments. This is clear from the pockets of high germination and emergence of species where deposition of soil fines induced by precipitation runoff occurred within the furrows. The concept of deep-furrow seeding still holds promise for enhanced moisture capture, improvement of environmental extremes at the soil surface, and native species establishment if clods can be minimized in the furrow bottoms.

Using barley as a nurse crop in alternate rows with seeded natives appears to aid germination in some native species by ameliorating environmental extremes (heat, wind, low moisture) at the soil surface for the new seeding and by providing limited suppression of weeds. The alternate barley rows need to be spaced wide enough (minimum 30 cm [12 in]) to minimize inter-specific competition between adjacent rows. On sites where prior weed suppression measures were not efficient or are otherwise constrained, this approach may provide a degree of added weed suppression during the first seeding (establishment) year that can be augmented with subsequent herbicide applications, as appropriate.

LRDP studies evaluating selected soil amendments indicate that soil root zone augmentation using salt-remediation products (e.g., HydraHume™), fertilizers, mycorrhizal inoculation, or polyacrylamide polymer (incorporated in seed coatings) does not appear to provide immediate or long-term benefits for native species establishment. Super-treble phosphate (PO_4) fertilizer did help establish the Great Valley phacelia (*Phacelia ciliata*), but no other tested species demonstrated any response to phosphate fertilization. Nitrogen fertilizer was not evaluated because most of the native species in LRDP restoration efforts are dicotyledonous plants which have a limited response to nitrogen augmentation. Likewise, as described previously, nitrogen addition may severely exacerbate pressure from annual weeds.

Seeding Methods

The LRDP research trials and demonstrations evaluated many seeding techniques and equipment. These evaluations included commercial standard rangeland (grass) drills, “broadcast”-type grass drills (e.g., Trillion™), rangeland imprinters with/ and without attached seeding mechanisms, standard agronomic grain drills, and mechanized or manual rotary broadcast seeders followed by harrowing or similar mechanical measure for assuring adequate soil-to-seed contact and cover. All commercial drills were equipped with multiple, specialized seed boxes designed to hold, agitate, meter, and deliver seed (including mixtures of species) in individual boxes according to seed size, shape, weight, and amount of non-seed material. Rangeland imprinters are designed to create a pattern of micro-catchments on the soil surface to enhance capture and retention of precipitation, and also to improve soil-to-seed contact via firming of the seedbed surface immediately surrounding the seed.

Commercial grass drills exhibited higher degrees of consistent success in establishing native vegetation than did methods involving grain drills or broadcast technology. Drills optimize seed depth placement and soil cover; minimize intra-specific, inter-row competition for seeded species; and facilitate specialized herbicide application for weed suppression between seeded rows (see discussion of Weed Management).

“Broadprinting” (using a land imprinter following broadcast seeding) also yielded moderately successful results in first-year germination and emergence of seeded species. However, patterns of micro-catchments (depressions) created by the imprinter are generally unstable on typical study site soils (primarily fine-textured clays). This instability allows rapid filling from sediment deposition with surface water flows during precipitation events. The ability to capture moisture and subsequent soil moisture availability for root uptake are then reduced or negated, thereby reducing seeding establishment success beyond the first seeding year. Further, imprinting depressions on some of soils at the Tranquillity site tended to develop deep fissures, which also reduced the potential for seedling establishment.

Weed Management

Interim planting of dryland barley cover crops appears to provide suitable temporary cover during the growing season to protect the site and suppress weeds when the field is not in use and awaiting restoration. This period is usually the time between cessation of cropping and preparation of the seedbed for habitat restoration seeding. Areas planted to cover crops may also include buffer zones planted between experimental or demonstration revegetation studies. Barley seeded at standard agronomic seeding rates has been shown to be effective in temporary (seasonal or annual) suppression of most of the annual and perennial weeds during years with precipitation amounts and timing at or near long-term annual and seasonal means. The barley crop may also simultaneously yield marketable products for grain, grazing, straw, etc. Field scouting showed that occasional tillage may be required for interim weed suppression between harvesting the barley and seeding the following year’s crop of barley.

Without barley (or other suitable dryland cover crop) before restoration, repeated tillage, herbicide applications, and/or grazing will be needed to suppress weeds. An array of herbicides with foliar contact and/or soil residual capabilities are labeled for use in California (e.g., glyphosate, 2,4-D, dicamba, oxyfluorfen, simazine, sethodim). Herbicides that exhibit soil residual activity should be chosen and applied in accordance with local ordinances and labeling restrictions for sensitive groundwater restriction zones in Fresno County and neighboring counties.

When restoration activities are delayed, we recommended treating the fields in the year(s) leading to the planned restoration with:

- Initial tillage (to reduce existing weed standing crop and seed production, and to stimulate germination of the weed seed bank)

- Subsequent residual herbicide(s) to suppress weed regrowth through the growing season

This process may require repeat annual treatments during the delay to be fully successful, depending upon duration of the delay and budget. This approach will minimize the weed load (seed bank plus growing weeds) leading into the planned restoration year. Since no native species would be seeded during preceding year(s), designed formulation and application of herbicide tank mixes (as needed) that widen the spectrum of target weed species across multiple weed growth forms and life histories is also facilitated.

Several tested herbicides demonstrated good to excellent weed suppression. Seeded native species generally exhibited good emergence and survival using charcoal banding concepts. Charcoal banding (wet slurry) over the seed row appears to be a practical and cost-effective measure for multi-species weed suppression, and protection for drilled native seedings from the effects of applied herbicides. Conversely, broadcast seeding methods are not amenable to this technique because seeded species are not in distinct rows that are protected by the charcoal. This type of charcoal banding requires minimal modifications to existing drill and tractor equipment, using herbicide spraying equipment, pumps, and tractor saddle tanks common to agronomic applications. This approach would also be amenable to alternate-row barley nurse crop seeding, as described above.

Further study is warranted to refine experimental approaches. Research should evaluate performance across additional seeded species and different application rates for charcoal and herbicides, within the herbicide types shown to be effective in these studies.

If one (or more) of the herbicides that prove superior in weed suppression and safety to seeded natives carry restricted labeling for use in California and/or Fresno County, a special local need permit may be pursued through the California Department of Agriculture, Fresno County Department of Agriculture, and/or the Environmental Protection Agency for broader-scale use within the CVPIA-Land Retirement project.

Insect Control

Control or suppression of insect damage to seeded native species, particularly from false chinch bugs (*Nysius* spp.), is also a key consideration. A large portion of the retired agricultural lands and fallowed fields in the western San Joaquin Valley typically support dense populations of exotic plant species (e.g., London rocket [*Sisymbrium irio*] and mustard [*Brassica* spp.]) that are associated with the chinch bug life-cycle. These outbreaks generally occur during the dry season, when the greatest proportion of the vegetation on the lands surrounding the Tranquillity sites has already senesced. As a result, the native perennial species on the Tranquillity site appear to be favored "targets." During most years, at least one area of the Tranquillity site has been severely impacted.

Constant monitoring (i.e., weekly site visits) during the dry season is necessary to adequately detect false chinch bug presence and levels of infestation. This frequent scouting helps initiate control measures before extensive damage occurs. This activity should be incorporated into restoration plans as a required measure, having equal importance with all other revegetation activities. When significant infestations occur, immediate localized treatment using products such as Malathion™ has successfully reduced or eradicated the infestation for that season. Reduced levels of infestation may also be achieved by using attractant traps and/or insecticide-treated baits. To the extent that conditions at Tranquillity represent most of the drainage-impacted lands, pest scouting and applied pesticidal or trap control measures will undoubtedly be essential components of any restoration activities.

Native Plant Seed Production Facility Continuation and Management

We recommend the continuance of the LRDP's Native Plant Seed Production Facility (NPSPF), as it holds importance to the LRDP botanically and functionally within the context of:

- Research, demonstration, and education as a unique collection of numerous native species endemic to the western San Joaquin Valley

- Supplying "foundation" seed from numerous core species important to the LRP (Appendix A, Tables 2 and 3). This will facilitate provision of seed to commercial growers to increase the seed supply for a larger-scale program.

Future Research and Programmatic Direction

Grazing

Grazing trials incorporating sheep are needed to evaluate:

- How this management tool (herbivory via prescribed, controlled grazing management) could be integrated with herbicidal and mechanical measures for suppressing grass and broadleaved weeds within seeded plant communities

- How resistant or tolerant established, seeded native species will be to sheep grazing

These trials would evaluate effects of varied timing, grazing intensity (stocking rates), and duration of grazing on efficacy of weed suppression simultaneous with evaluation of survival and vigor of seeded natives under these grazing regimes. The herbicide / activated charcoal trials (Manning and North Avenue studies) and portions of the HRS are most suited for this application because they have adequate, established seeded natives. Grazing trials are planned to start on one or more of these study sites in early 2007.

Herbicide / Charcoal Product and Rate Refinement

Greenhouse and spray chamber experiments are needed to further characterize, refine, and quantify the most efficacious commercial products and rates of herbicide(s) and activated charcoal, using characteristic soils and seeded native species previously evaluated within the LRDP as indicators. Additional plant species (a minimum of 50 percent of the core species as listed in Appendix A, Tables 2 and 3) need evaluation to test herbicide sensitivity under varying charcoal application regimes. This testing would result in a concise, focused recommendation for weed suppression in LRDP native seedings, facilitating a reduced, but validated, number of herbicide and charcoal products and rates.

Follow-up (secondary) Herbicide Treatment (Products, Rates, Timing)

Further testing is needed to determine what products and rates would be effective for follow-up (secondary) herbicide treatment on established stands of seeded native species. Activated charcoal treatment for seed safening is only valid for the first establishment year (i.e., growing season) using drilled seedings. After emergence and establishment of seeded natives, charcoal cannot be re-applied in ways that would permit understory weed suppression. Various herbicides are available as selections for weed suppression, but little is known about their impacts on existing native species. Herbicides need to be tested in both field and greenhouse applications (depending on the seeded stand composition and dominant weed species) to determine optimum combinations of weed suppression and native species tolerance.

Infrastructure for seed collection, conditioning, cleaning, storage, and commercial increase (Natural Resources Conservation Service)

Ongoing collaboration with the NRCS (Lockeford Plant Materials Center), interested native seed suppliers, and the California nursery industry is still critical. Considerable research is still needed, particularly to determine:

- Seed harvest, pre-conditioning (scarification, stratification), and storage techniques
- Supplemental water needs during initial plant establishment phases (as applicable)
- Economically sound infrastructure and logistics to connect seed production to demand

The latter activity entails developing and disseminating strategies and techniques that integrate Reclamation's research results with end user land retirement needs, CVPIA and Westlands Water District (WWD) stakeholders, NRCS Plant Materials Centers, and the commercial seed industry. Developing revegetation protocols, agency / commercial / private infrastructure, and product (native seed, planting guidelines) delivery avenues sufficient to fully address land retirement needs on a landscape scale is particularly important.

Selected Management Implications

Costs

Revegetation costs will vary greatly, depending on costs for materials, equipment, and labor upon initiation of restoration activities, as well as restoration objectives. The materials cost for seed and herbicides will vary the most. To the extent that greater proportions of species in seed mixture formulations are commercially available, and higher proportions of selected herbicides are in common use in the project locale – revegetation costs will be significantly and proportionately reduced.

Actual costs can be formulated for existing revegetation trials in the LRDP, but further analysis is needed to refine, normalize, extrapolate, and project these costs to future landscape-scale applications. These costs, however, are based on experimental trials incorporating varied, often innovative techniques and materials. Further analysis and refinement is required to assure that cost estimates represent actual field- or landscape-scale applications using established protocols and standard, commonly available equipment.

Revegetation Strategies in Relation to T&E Habitat Restoration Objectives and Desired Revegetation Trajectories

Lead administrative and technical agencies and staff involved in the LRP need to address specific issues of concern. Clarifying these issues, coupled with better definition of stated habitat objectives, will permit improved planning and more concise recommendations for habitat restoration via native plant community revegetation efforts. Fundamental definitions and decisions are:

1. Define the true target wildlife species (and associated habitat goals) for the LRP. Are we addressing simply threatened and endangered species, or simply non-listed species, or a combination of both? Formulating seed mixtures, seedbed preparation techniques, and weed management prescriptions will vary greatly between these targeted species' and their habitat requirements.

2. Determine goals using specific habitat profiles. Provide concise descriptions of habitat profiles for each targeted wildlife species (needs and characteristics such as Habitat Suitability Indices or similar evaluations) to use as guides and planned trajectories for revegetation recommendations.

3. Define and delineate ecogeographical "core" areas; "linkage corridors;" and their relationships, priorities, and geographical juxtaposition to LRP habitat restoration efforts as projected for landscape-scale efforts in the future.

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Appendix A. Tables

Table 1. Species that have been seeded in the various restoration trials at the Tranquillity site, including common name, botanical family, and growth-form/life history. Core species (i.e., species considered as key components of restoration strategies) are bolded.

Species	Common Name	Family	Growth Form/Life History
Allenrolfea occidentalis	iodinebush	Chenopodiaceae	shrub
Amsinckia menziesii	Menzie's fiddleneck	Boraginaceae	annual herb
Amsinckia vernicosa	green fiddleneck	Boraginaceae	annual herb
Aristida ternipes var. hamulosa	Spreading threeawn	Poaceae	perennial herb
Artemisia californica	California sagebrush	Asteraceae	shrub
Astragalus asymmetricus	San Joaquin milkvetch	Fabaceae	perennial herb
Astragalus lentiginosus	freckled milk-vetch	Fabaceae	annual or perennial herb
Atriplex coronata	crownscale	Chenopodiaceae	annual herb
Atriplex covillei	leafcover saltweed	Chenopodiaceae	annual herb
Atriplex fruticulosa	valley saltbush	Chenopodiaceae	perennial herb
Atriplex minuscula	lesser saltscale	Chenopodiaceae	annual herb
Atriplex polycarpa	allscale saltbush	Chenopodiaceae	shrub
Atriplex spinifera	spinescale saltbush	Chenopodiaceae	shrub
Bromus carinatus	California brome	Poaceae	perennial herb
Camissonia californica	California suncup	Onagraceae	annual herb
Elymus glaucus	blue wildrye	Poaceae	perennial herb
Elymus multisetus	big squirreltail	Poaceae	perennial herb
Eremalche parryi	Parry's mallow	Malvaceae	annual herb
Eriogonum fasciculatum	California buckwheat	Polygonaceae	shrub
Eschscholzia californica	California poppy	Papaveraceae	annual herb
Frankenia salina	alkali heath	Frankeniaceae	perennial herb
Gilia tricolor	bird's-eye gilia	Polemoniaceae	annual herb
Grindelia camporum	gumplant	Asteraceae	perennial herb
Gutierrezia californica	California matchweed	Asteraceae	perennial herb
Heliotropium curassavicum	seaside heliotrope	Boraginaceae	perennial herb
Hemizonia pungens	common spikeweed	Asteraceae	annual herb
Holocarpha obconica	San Joaquin tarweed	Asteraceae	annual herb
Hordeum depressum	alkali barley	Poaceae	annual herb
Hordeum vulgare	barley	Poaceae	annual herb
Hutchinsia procumbens	prostrate hutchinsia	Brassicaceae	annual herb
Isocoma acradenia	goldenbush	Asteraceae	shrub
Isomeris arborea	bladderpod	Capparaceae	shrub
Kochia californica	rusty molly	Chenopodiaceae	perennial herb
Lasthenia californica	California goldfields	Asteraceae	annual herb
Lasthenia chrysantha	alkali goldfields	Asteraceae	annual herb
Layia glandulosa	white layia	Asteraceae	annual herb
Lessingia glandulifera	valley lessingia	Asteraceae	annual herb

Species	Common Name	Family	Growth Form/Life History
Leymus triticoides	creeping wild-rye	Poaceae	perennial herb
Lotus scoparius	deerweed	Fabaceae	perennial herb
Lupinus bicolor	bicolored lupine	Fabaceae	annual or perennial herb
Lupinus succulentus	arroyo lupine	Fabaceae	annual herb
Machaeranthera carnosa	shrubby alkali aster	Asteraceae	shrub
Madia elegans	common madia	Asteraceae	annual herb
Malacothrix coulteri	snake's head	Asteraceae	annual herb
Mentzelia laevicaulis	smooth-stem blazing star	Loasaceae	perennial herb
Monolopia major	cupped monolopia	Asteraceae	annual herb
Monolopia stricta	Crum's monolopia	Asteraceae	annual herb
Nassella cernua	nodding needlegrass	Poaceae	perennial herb
Nassella pulchra	purple needlegrass	Poaceae	perennial herb
Phacelia ciliata	Great Valley phacelia	Hydrophyllaceae	annual herb
Phacelia tanacetifolia	tansy-leafed phacelia	Hydrophyllaceae	annual herb
Sesuvium verrucosum	Western sea-purslane	Aizoaceae	perennial herb
Sporobolus airoides	alkali sacaton	Poaceae	perennial herb
Suaeda moquinii	bush seepweed	Chenopodiaceae	sub-woody perennial
Trichostema ovatum	San Joaquin bluecurls	Lamiaceae	annual herb
Vulpia microstachys	small fescue	Poaceae	annual herb
Wislizenia refracta	jackass clover	Capparaceae	annual or perennial herb

Table 2. Restoration techniques and experimental factors examined in research conducted at the Tranquillity site. Items marked with an asterisk were used in a trial but were not experimental factors in that particular trial.

		Planting Method				Modified Planting Conditions				Non-Chemical Weed Control			Chemical Weed Control			Other Treatments		
Trial	Irrigation	Drilling	Imprinting	Cultipacker	Transplanting	Furrow Depth	Row Spacing	Plant Spacing	Topography	Pre-irrigation	Mowing	Burning	Post-emergents	Pre-emergents	Activated Charcoal	Seed Mix Comparison	Rootzone Amendments	Nurse Crop/Cover Crop
Habitat Restoration Study			√*		√*				√									√*
Imprinting vs. Drilling of Native Species Trial		√	√															√*
Imprinting vs. Drilling of Cover Crops Trial		√	√													√		√
Atriplex spinifera Planting					√*			√										
Berm and Mycorrhiza Trial	√*		√*						√								√	
Succession Trial			√*													√		√
Suitability Trial	√*		√*													√		
Growth Form and Herbicide Trial			√*										√			√		
Pre-irrigation Trial	√		√*							√								
Section 10 Burn and Mowing Trial			√*							√	√							

		Planting Method				Modified Planting Conditions				Non-Chemical Weed Control			Chemical Weed Control			Other Treatments		
Trial	Irrigation	Drilling	Imprinting	Cultipacker	Transplanting	Furrow Depth	Row Spacing	Plant Spacing	Topography	Pre-irrigation	Mowing	Burning	Post-emergents	Pre-emergents	Activated Charcoal	Seed Mix Comparison	Rootzone Amendments	Nurse Crop / Cover Crop
Mowing Trial			√*								√							
Section 23 Restoration Trial			√*						√ *							√		
Seed Augmentation and Planting Method Trial		√ *				√	√									√	√	√
Planting Techniques Trial (Year I)		√	√	√												√		
Herbicide and Charcoal Treatment Trial - Manning		√ *											√*	√	√	√		
Planting Techniques Trial (Year II)		√	√	√												√		
Seed Delivery and Competition Trial			√	√					√ *							√		
Native Release Trial											√	√	√					
Herbicide and Charcoal Treatment Trial - North Avenue		√ *											√*	√	√	√		
Herbicide and Charcoal Treatment Demonstration		√ *												√	√	√		
Planting Techniques Trial (Year III)			√															

Table 3. List of species, the trials in which they were used, and their use in the Native Plant Seed Production Facility (NPSPF). Note: not all species cultivated in the NPSPF are listed in this table. Rather, this table lists only species used in an experimental setting, and species identified as "core species" (in boldface). Species which are recorded as "—" for all years are those for which local populations are known, but which have not been cultivated in the NPSPF. Species with no data recorded for the NPSPF are those for which no local populations are known. Key: "EP" — "Established perennials", i.e. perennial species which had been planted during a previous year. "V" — Species that were not planted during that particular year, but which became established as "volunteers."

Species	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	Native Seed Production Facility 2001-02	2002-03	2003-04	2004-05	2005-06
Allenrolfea occidentalis	√				√	√		√	√	√		√					√		√		—	√	EP	EP	EP
Amsinckia menziesii			√																		√	√	V	V	V
Amsinckia vernicosa																					—	—	—	√	√
Aristida ternipes var. *hamulosa*								√				√													
Artemisia californica																					—	—	√	√	EP
Astragalus																					—	—	√	√	EP

Species	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	Native Seed Production Facility 2001-02	2002-03	2003-04	2004-05	2005-06
asymmetricus																									
Astragalus lentiginosus																					—	√	√	√	√
Atriplex coronata																	√				—	—	√	√	V
Atriplex covillei																					—	—	—	√	V
Atriplex fruticulosa																					—	—	√	√	EP*
Atriplex minuscula																					—	—	√	√	√
Atriplex polycarpa	√		√		√	√		√	√			√	√	√	√	√	√		√		√	√	EP	EP	EP
Atriplex spinifera	√			√	√	√				√											—	√	√	EP	EP
Bromus carinatus	√	√			√	√	√	√				√									—	—	—	—	—
Camissonia californica																					—	—	—	—	√

Species	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	Native Seed Production Facility				
																					2001-02	2002-03	2003-04	2004-05	2005-06
Elymus glaucus							√																		
Elymus multisetus							√																		
Eremalche parryi																					—	—	—	√	√
Eriogonum fasciculatum							√														—	—	√	EP	EP*
Eschscholzia californica								√													—	—	—	—	
Frankenia salina	√				√	√		√	√	√		√									√	√	EP	EP	EP*
Gilia tricolor								√				√									—	√	—	V	—
Grindelia camporum								√			√	√			√	√	√	√	√		—	√	EP	EP	EP
Gutierrezia californica																					—	—	√	√	EP*
Heliotropium curassavicum	√				√	√		√			√						√				—	√	√	EP	EP
Hemizonia	√				√	√		√	√	√	√	√	√	√		√	√				√	√	√	√	√

Species	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	Native Seed Production Facility				
																					2001-02	**2002-03**	**2003-04**	**2004-05**	**2005-06**
pungens																									
Holocarpha obconica																	√				—	√	√	√	√
Hordeum depressum			√															√	√		—	—	—	√	√
Hordeum vulgare		√																							
Hutchinsia procumbens																					—	—	—	√	√
Isocoma acradenia	√		√		√	√							√								√	√	√	EP	EP
Isomeris arborea																					—	√	√	√	EP*
Kochia californica																					—	√	√	EP	EP*
Lasthenia californica	√		√		√	√		√	√	√		√									—	√	√	√	—
Lasthenia chrysantha													√						√		√	√	√	√	√

																					Native Seed Production Facility				
Species	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**
Layia glandulosa																√	√		√		—	—	—	—	V
Lessingia glandulifera																					—	—	√	√	√
Leymus triticoides	√	√	√		√	√																			
Lotus scoparius																					—	—	√	√	√
Lupinus bicolor								√				√									—	—	√	√	√
Lupinus succulentus																					—	—	—	—	√
Machaeranthera carnosa																					—	—	—	√	—
Madia elegans																					—	—	—	—	√
Malacothrix coulteri																					—	√	√	√	√
Mentzelia laevicaulis																					—	—	√	√	—
Monolopia major																					—	—	—	—	√

	Habitat Restoration Study (HRS)	Imprinting & Drilling: Natives	Imprinting & Drilling: Cover Crops	Atriplex spinifera Planting	Berm & Mycorrhizae Trial	Succession Trial	Suitability Trial	Growth-form & Herbicide Trial	Pre-irrigation Trial	Section 10 Burn & Mowing Trial	Mowing Trial	Section 23 Restoration Trial	Seed Augmentation & Planting	Planting Techniques Trial: Year I	Herbicide and Charcoal Trial – Manning	Planting Techniques Trial: Year II	Seed Delivery & Competition Trial	Herbicide and Charcoal Trial - N.A.P.	Herbicide and Charcoal Demonstration	Planting Techniques Trial: Year III	Native Seed Production Facility				
Species																					**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**
Monolopia stricta																	√				—	√	√	√	√
Nassella cernua							√	√													—	—	—	—	—
Nassella pulchra							√	√				√													
Phacelia ciliata								√			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Phacelia tanacetifolia																					—	—	√	√	√
Sesuvium verrucosum									√	√	√						√		√		—	√	√	EP	EP
Sporobolus airoides	√		√		√	√		√		√		√	√								√	√	√	√	EP*
Suaeda moquinii	√		√		√	√		√	√			√	√	√	√	√		√	√		√	√	√	√	EP
Trichostema ovatum													√								—	√	√	√	V
Vulpia microstachys	√	√	√		√	√		√	√			√							√		—	—	—	√	—
Wislizenia refracta																					√	√	√	√	√