CENTRAL VALLEY PROJECT IMPROVEMENT ACT LAND RETIREMENT DEMONSTRATION PROJECT

A SYNTHESIS OF NATIVE PLANT SEED PRODUCTION EFFORTS IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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INTRODUCTION

The San Joaquin Valley was historically composed of grassland, vernal pool, saltbush scrub, riparian forest, oak woodland, and freshwater marsh habitats (Piemeisel and Lawson 1937; Schoenherr 1992; Barbour et al. 1993; Wallender et al. 2002; Kelly et al. 2005). Since the gold rush and oil boom of the 19th century, the natural communities of the San Joaquin Valley have undergone extensive land conversion for agricultural, industrial, and urban uses. By 1958, approximately one-half of the natural communities in the San Joaquin Valley had been converted (USFWS 1980). The rate of habitat loss accelerated following the completion of the Central Valley Project and State Water Project, which increased the availability of water for agricultural and urban uses (USFWS 1998). By 1979, of the over 3.4 million ha of historical habitat on the San Joaquin Valley floor, only approximately 149,734 ha (4.4%) was undeveloped (USFWS 1980), and considerable additional development has occurred since then.

As a result of poor natural drainage and the application of surface irrigation water, extensive tracts of formerly productive farmland in the western San Joaquin Valley have become characterized by drainage-related problems (SJVDP 1990). These problems include elevated salinity and selenium concentrations in the soil and groundwater, and subsurface accumulation of drainage water (SJVDP 1990, Letey et al. 2002, Schoups et al. 2005). The collection, storage, and disposal of drainage water is problematic and of significant environmental concern (Letey et al. 2002). During the early 1980's, the storage of irrigation drainage water in the Kesterson Reservoir at the San Luis National Wildlife Refuge resulted in a high incidence of bird deaths and reproductive deformities that were attributed to the high selenium concentration in the drainage water (Ohlendorf et al. 1986, Ohlendorf 2002). Land retirement (i.e., the removal of land from agricultural production) is one management approach that will reduce the accumulation of drainage water (SJVDP 1990, Letey et al. 2002). Under the Central Valley Project Improvement Act of 1992, a Land Retirement Program was established to purchase impaired farmlands from willing sellers. A Land Retirement Team (LRT) composed of representatives from the U.S. Department of Interior's Bureau of Reclamation, U.S. Fish and Wildlife Service, and Bureau of Land Management, was charged with the task of implementing the Land Retirement Program.

Because relatively little information was available on the physical and biological effects of land retirement and the feasibility of habitat restoration on retired farmland in the San Joaquin Valley, the LRT initiated a five-year Land Retirement Demonstration Project (LRDP) in cooperation with the California State University Stanislaus' Endangered Species Recovery Program (ESRP). One of the goals of the demonstration project was to develop methods for restoring self-sustaining native upland communities.

Land retirement without subsequent restoration efforts or some form of active management would likely result in weed-infested fields with little habitat value. However, with appropriate restoration, select areas of retired farmland could provide wildlife habitat and function as linkages and corridors between existing habitat areas. In addition to providing habitat for common species, the restoration of retired farmland could potentially contribute to the recovery of endangered and threatened plant and animal species.

In some restoration scenarios, the soil seed bank could potentially play a role in the re-establishment of native vegetation. However, due to the duration and intensity of disturbance associated with agricultural production in the western San Joaquin Valley, native species are virtually absent from the soil seed bank of the retired lands (USDI 2005). Limited potential for the soil seed bank to contribute to the restoration of formerly cultivated land has been documented in other regions including England (Graham and Hutchings 1988, Hutchings and Booth 1996), France (Römermann et al. 2005; Buisson et al. 2006), and the Netherlands (Blomqvist et al. 2003).

In some instances, disturbed land could potentially be colonized by native species from surrounding areas of intact native vegetation. However, in the western San Joaquin Valley, the acreage of retired farmland far exceeds that of remaining native habitat, and the potential for colonization of native species is low. In addition, some studies have shown that even when abandoned farmland is adjacent to remnant native habitat, colonization of native species proceeds slowly due to limited seed dispersal (Hutchings and Booth 1996, Buisson et al. 2006).

Due to the minimal contribution of the seed bank to the re-establishment of native vegetation and the limited potential for native species to colonize retired lands in the western San Joaquin Valley, a passive restoration approach—removing the stresses that caused the original degradation and then allowing natural succession—would not be sufficient to re-establish native vegetation (Allen 1995). Therefore, an active restoration approach, the re-introduction of native species to the retired lands through seeding, was deemed necessary. Due to the potential for seed from non-local sources to be maladapted to local environmental conditions (McKay et al. 2005; Knapp and Rice 1997; Belnap 1995), a key objective of the proposed restoration efforts was to utilize local seed sources.

Local genotypes of San Joaquin Valley native plants are largely unavailable from commercial suppliers, and the amount of seed that could be responsibly collected from the remaining areas of native habitat would be insufficient to support regional restoration efforts. In response to this lack of native seed availability, ESRP established a native plant seed production program in 2001.

The primary objectives of the seed production program were to augment available commercial sources of native seed and to increase the number of San Joaquin Valley upland species that could be used in local restoration activities. Seed production activities were conducted at a native plant field nursery, located approximately 3 miles southwest of the town of Tranquillity in Fresno County, California, and at a seed-processing warehouse in Fresno, California. Locally collected seeds were planted in the nursery for seven consecutive growing seasons (2001-2008), to increase available seed supplies through field propagation. Because relatively little information was available on the propagation of most local species, many of our efforts were 'trial and error' in approach. However, many valuable insights into native plant propagation and seed production were gained as a result.

The purpose of this document is to communicate the knowledge that we have gained from cultivating San Joaquin Valley native species for the purpose of seed production. The document includes background on the inception of the nursery; a description of nursery site conditions; a summary of the methods that we used for seedbed preparation, planting, seed harvesting, weed management, and pest control; an overview of seed processing equipment that we used; and a discussion of the challenges that we encountered.

SEED COLLECTION FROM REMNANT HABITAT

We conducted an extensive search for local native plant populations in the western San Joaquin Valley from which seeds could be collected and planted in the nursery. Initially, our search was conducted within a 24.1-km (15-mi) radius, measured from the nursery. As our search progressed and the scarcity of remaining native habitat became apparent, we had to continually redefine our concept of “local”. Over time, our search radius expanded to a maximum distance of 80.5-km (50-mi) from the nursery (hereinafter referred to as the survey area), in order to increase the number of species and populations encountered. Consequently, the survey area incorporated sites on the valley floor (i.e., the area in which restoration of retired agricultural lands will be undertaken), as well as in the foothills of the Coast Range.

Within the survey area, we identified 41 sites from which seeds of native species could be collected. Eleven of the sites were single parcels, and 30 of the sites were an aggregration of smaller, more or less contiguous habitat remnants. Four of the sites were ecological reserves or wildlife areas that are managed by the California Department of Fish and Game (CDFG) (Figure 1). The sites that we identified on the valley floor were scattered, isolated remnants of native vegetation and serve to illustrate the amount of land conversion that has occurred in the region (Figure 2). In contrast to the valley floor, the foothill habitat within our survey area has not been extensively converted for agricultural or urban use. Therefore, the sites that we identified in the foothills were situated within an area of relatively intact habitat.

Figure 1. The Alkali Sink Ecological Reserve managed by the California Department of Fish and Game supports over 40 native plant species and was a valuable source of native seed for our project.

Figure 2. A site located on the valley floor from which we collected native seed. The site has a high proportion of non-native weedy species, is subject to periodic disking and brush removal, and is located within a matrix of agricultural fields. Yet, the site supports 28 native species, four of which we did not find at any other location. Considering the level of disturbance on the site and in the surrounding area, the plant diversity present is surprising.

As a result of intermittent field surveys conducted within the search radius from 2000-2007, we documented a total of 158 native species (Appendix A). From 2001-2008, we collected seed from 128 species.

Conservative guidelines recommend that seed should be collected from as close to the restoration site as possible i.e., within 100 meters distance for herbaceous plants and within one kilometer for woody plants (Linhart 1995). In a region such as the San Joaquin Valley that has been subject to widespread land conversion, it would be impossible to meet these recommendations due to the scarcity of remaining native habitat. If we had limited our search radius to a one-kilometer distance from the nursery site, we would have encountered only five native species, all of which were herbaceous annuals.

Seed sourcing efforts for restoration purposes should attempt to capture as much genetic diversity as possible to ensure the functionality, resilience, and viability of newly established populations (Broadhurst et al. 2006, Broadhurst et al. 2008). Whenever possible, we collected seed from at least 50 individuals per wild population. However, for some species, the seeds planted in the nursery were collected from a small number of individuals (e.g., less than 10). Though seed production efforts can augment the availability of seed for restoration, the maximum genetic diversity of a seed lot is essentially fixed at the time of wild seed collection (Kitzmiller 1990).

THE SEED PRODUCTION PROGRAM

When propagating plants for ecological restoration, it is important to try to prevent shifts in population genetic composition, in order to maintain genetic variability (Meyer and Monsen 1992). Therefore, we endeavored to avoid bias towards any particular plant traits and to minimize the potential for artificial selection. Nevertheless, we acknowledge that a certain amount of selection likely occurred. The best way to avoid genetic shifts during propagation is to increase seed in an environment as similar as possible to the target site, i.e., the site to be restored (Knapp and Rice 1994). If plants are grown under conditions that are dissimilar to that of the target environment, the different selective pressures may result in seed that is adapted to the growing environment rather than the restoration site (Knapp and Rice 1994).

NURSERY SITE DESCRIPTION

The nursery site was formerly used for irrigated agriculture and is located within the drainage-impaired portion of the western San Joaquin Valley. Therefore, the nursery site shares a similar history of disturbance with the tracts of retired farmland for which restoration has been proposed. Site characteristics resulting from disturbance associated with agricultural production include highly modified soil structure, shallow water tables, elevated soil salinity, and prevalence of non-native weedy species. Inherent site characteristics shared by the nursery and the retired farmlands include a semi-arid climate and fine-textured soils.

The nursery site is located in proximity to the 323.75 ha (800 ac) Habitat Restoration Study (HRS) that was conducted from 1999-2004, in order to examine the responses of wildlife to restoration efforts. For a detailed discussion of the results of the Habitat Restoration Study, please refer to the five-year report of the Land Retirement Demonstration Project.

The San Joaquin Valley has a Mediterranean climate that is characterized by hot, dry summers and cool, wet winters. Estimated long-term mean annual precipitation[A] for the nursery site is 22.03 cm (8.67 in), of which approximately 80 percent (17.63 cm) is received during the winter monsoonal period of November through March (NOAA 2007). Precipitation is highly variable spatially and temporally, with pronounced differences year-to-year and within-year (Figure 3).

The soil type at the nursery site is Tranquillity clay. Though fine-textured soils exhibit high moisture retention, the availability of moisture to plants can be limited (Ritter and Lair 2006). Also, clay soils will swell when wet and shrink when dry, resulting in large cracks in the soil (Figure 4), which can negatively affect plant establishment and growth (Ritter and Lair 2006). During the winter monsoonal period, a rain event will cause the clay soils to become slick and sticky, thus preventing vehicle traffic on the unpaved road to the nursery. It is also difficult to walk on wet clay soils, because several inches of thick mud will accumulate on one's boots.

[A] Based on 30 years of precipitation data (1976-2006) from four weather stations (Cooperative Station ID #'s 43083, 45118, 45119, 45120) located in the western San Joaquin Valley.

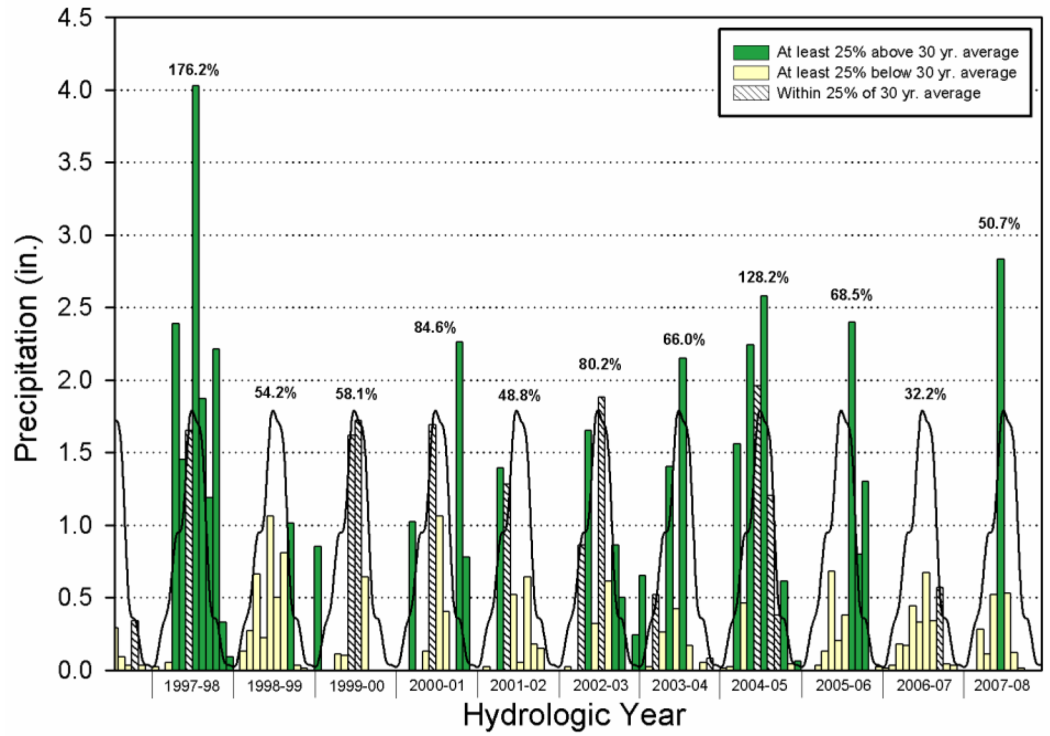

Figure 3. Precipitation during the course of seed production activities (2001-2008) conducted at the native plant field nursery near Tranquillity, CA. The hydrologic year is presented as August 1 through July 31. The bars represent monthly totals; the solid line represents the 30-year mean annual precipitation (MAP). Monthly data are from the California Irrigation Management Information System (CIMIS) Station #105. Values above the bars indicate the percentage of MAP represented by that particular year's precipitation.

Figure 4. The clay soils at the nursery shrink when dry, resulting in large cracks in the soil. If a large crack develops in the rooting area of a shrub, it frequently introduces sufficient stress such that the shrub is severely damaged or killed.

NURSERY INCEPTION

When we initiated the seed production program, information on propagation, harvesting, and seed processing techniques was non-existent or insufficient for a majority of the targeted native species. Therefore, we needed to learn the phenological patterns (e.g., timing of germination, flowering period, seed ripening period, and seed collection window) of numerous species. We developed seed harvesting and processing methods for many species, within the constraints of available equipment and staff time. We also had to experiment with various weed control methods and respond to setbacks and complications that included insect damage, the threat of trespass sheep grazing, drought conditions, vandalism, and wildlife herbivory.

TIMELINE OF NURSERY PRODUCTION

Propagation efforts at the nursery were initiated in 2001 and continued through 2008, for seven growing seasons. By our definition, a growing season begins in the fall when seeds of annual species are planted and ends during the next fall, when seed harvest from warm season annual species is completed. Therefore, a growing season spans two calendar years.

Beginning in 2003, nursery-produced seed was utilized in various restoration trials (Ritter and Lair 2006) in the Tranquillity area. Nursery-based activities and associated seed processing work concluded following the 2007-08 growing season. If funding had continued to be allocated toward the restoration of retired farmland in the western San Joaquin Valley, the native seed stock produced at the nursery would have provided a valuable seed source for additional restoration trials. If large-scale restoration efforts had been initiated, nursery-produced seed could have been provided to commercial growers so that available seed supplies could be further amplified.

NURSERY SIZE

During the 2001-02 growing season, an area of approximately 0.6 ha (1.5 ac) was planted, at a site located a short distance away from the nursery's current location. In the second year (2002-03 growing season), the nursery was relocated to a site that had slightly better soils and improved access to irrigation, and was expanded to approximately 1.6 ha (4 ac). Also, weed control measures were applied to an additional 0.8 ha (2 ac) in order to prepare that area for future nursery expansion. During the third year (2003-04 growing season), ca. 0.2 ha (0.5 ac) of the area that was prepared during the previous year was put into production. Also, an additional 1.6 ha (4 ac) to the east of the nursery was established as a "mechanized nursery", in which eight species were grown in single-species blocks (0.2 ha; 0.5 ac). In contrast to the "main" portion of the nursery, which was reliant on extensive hand labor, cultivation and harvesting in the mechanized nursery emphasized machine-based technologies (e.g., the tractor, sprayer, and mechanical seed harvester). During the 2004-05 growing season, the nursery was slightly reduced in area: the main nursery was reduced to ca. 1.6 ha (4 ac) and the mechanized nursery was reduced to ca. 1.4 ha (3.5 ac). During the 2005-06 growing season, the main nursery was reduced slightly to ca. 1.1 ha (2.7 ac), and the mechanized nursery was not maintained. The nursery was maintained at ca. 1.1 ha during the 2006-07 and 2007-08 growing seasons.

NUMBER OF SPECIES CULTIVATED

The number of species in cultivation rose steadily over the first four growing seasons, with the peak number of species (85) planted during the 2005-06 growing season (Table 1). Due to changes in funding and allocation of staff time, fewer species were cultivated during the 2006-07 and 2007-08 growing seasons.

Table 1. The number of native plant species cultivated at the field nursery over the course of seven growing seasons.

Growing season	Number of species in cultivation
2001-02	18
2002-03	31
2003-04	67
2004-05	84
2005-06	85
2006-07	50
2007-08	63

STAFF ALLOCATION

Staff time allocated to nursery operations would fluctuate throughout the year. During the fall months, seedbed preparation, planting of annual species, seed harvest from a few perennial species, and application of pre-emergent herbicide were the primary activities. We visited the nursery infrequently during the winter when the plants were dormant and there was no seed harvesting to be done. During the spring and summer months, substantial labor would be devoted to weed control and seed harvesting, and pest control was sometimes necessary during the dry season.

We utilized contract labor for nearly all aspects of nursery-based work: planting, transplanting, weeding, seed collection, and fence construction. During the last two growing seasons, we also utilized contract labor for seed processing work.

SEEDBED PREPARATION

After we finished harvesting seed from the annual species each fall, a local farmer disked the annual planting beds with an Allis-Chalmers 9190 tractor to clear the soil surface of thatch and other remaining biomass. Following this, we used a Kubota B7500 HSD tractor with an attached rototiller implement to further break up large dirt clods. We then shaped the planting beds and adjacent furrows using the tractor and an attached lister implement (also known as a furrow maker). Following this, a cultipacker (also known as a ring-roller) was drawn over the beds, to level them and to break up any remaining large clumps of soil. The furrows were necessary to facilitate flood irrigation and provided an area to travel on foot between beds. When measured from the middle of a furrow to the middle of the next furrow, the planting beds for perennial species were approximately 2 meters wide, and the beds for annual species were approximately 1 meter wide (Figure 5).

Figure 5. Looking east across the annual planting beds at the nursery during March 2007. The planted species had not yet germinated due to below average winter rainfall.

PLANTING

TIMING

Each fall, between October and January, we hand sowed seeds of both annual and perennial species onto the mounded planting beds and then raked a thin layer of soil over them (Figure 6). Because the viability of our seed lots was unknown, we would seed them heavily, in order to ensure ample germination. The volume of plant material that we sowed was dependent on seed size, the amount of chaff contained in the seed lot, and the age of the seed lot. If a seed lot contained a significant amount of chaff or had been in storage for a few years and had potentially reduced viability, we would sow a proportionately larger volume of material.

Planting seeds before the winter monsoonal period would maximize the likelihood that the seeds would receive sufficient precipitation to germinate. It was also advantageous to sow seeds before winter rains, because the nursery sometimes could not be accessed for several days following a rain event, and planting was sometimes delayed as a result. However, planting seeds early in the season could limit our opportunities to control the growth of cool season weeds. In some years, we held off on planting the natives until a flush of weed growth occurred in response to the first rain event. We would then control the weeds through tilling or the application of a post-emergent herbicide, before sowing seeds of native species. This is the same approach as the pre-irrigation method (see section *Pre-irrigation*) but utilizes natural rainfall rather than irrigation water. Our objective was to deplete the amount of weed seeds in the soil seed bank, thereby reducing weed germination later in the growing season.

Figure 6. Seeds were hand sown onto mounded planting beds and a thin layer of soil was then raked over them.

Annual species that are native to the San Joaquin Valley typically exhibit either cool season or warm season phenology. Cool season annuals germinate in response to fall and winter rainfall and complete their life cycle during spring, before the onset of high daily temperatures. Warm season annuals typically germinate in response to late winter or spring rainfall and complete their life cycle under the hot, dry conditions of the summer months. We typically planted seeds of all annual species in the fall, but seeds of warm season annuals could likely be planted as late as February, without any negative effects on their potential to germinate.

Perennial species are not as easily categorized as cool season or warm season species. The seeds of some perennial species (e.g., *Allenrolfea occidentalis, Atriplex polycarpa, Gutierrezia californica*) cannot be harvested until November, December, or January and therefore cannot be planted until later in the season, following seed processing.

SEED DORMANCY

Plant propagation can potentially lead to inadvertent selection of genotypes with lower levels of seed dormancy (Jones and Johnson 1998). When a seed lot was planted at the nursery, seeds that germinated readily and survived to produce seed would have passed on their genetic material, whereas seeds that remained dormant would not be represented in the seed lot that is harvested from nursery-grown plants. Because a high germination rate maintains genetic diversity (Kitzmiller 1990), the best insurance against unwanted selection is to apply a seed treatment that breaks dormancy in every viable seed (Meyer and Monsen 1992). However, we did not use any dormancy-breaking treatments to enhance germination. It would have been a significant challenge to identify treatments that could break dormancy in every seed in a variety of species, and we did not have the resources for that endeavor.

FERTILIZER AND SOIL AMENDMENTS

Plants were not fertilized and we did not use any soil amendments (e.g. organic matter, salt remediation products, mycorrhizal inoculants)[B]. There would have been little value in amending the growing conditions at the nursery because even if native plant growth were enhanced, these types of additions would not be feasible on a large scale, such as hundreds or thousands of acres of retired farmlands.

INTER-POPULATION GENE FLOW

For several species, we planted multiple seed lots that had been collected from geographically distinct wild plant populations. Though we endeavored not to plant seed lots that were of the same species but from different parent populations adjacent to each other, cross-pollination via wind or pollinator activity potentially occurred. Pollen flow between plants derived from different source populations can be considered undesirable when cultivating plants for the purpose of seed production (Knapp and Rice 1994), yet can be difficult to prevent (Smith et al. 2007).

SEED HARVESTING

Due to the relatively small scale of the nursery, we did nearly all of the seed harvesting by hand. Our approach was to harvest seed as efficiently as possible (e.g., minimize the amount of time spent collecting) without being concerned about the volume of chaff (e.g. pieces of branches, stems, leaves, floral structures, and seed coverings) that was collected along with the seed. We would then transport the harvested material to the seed-processing warehouse where we had a variety of equipment that could separate seeds from chaff. If we had not had access to such equipment, we would have had to spend more time on seed harvesting in order to reduce the amount of chaff that was collected.

To reduce the potential for inadvertent selection, seed should be harvested from the entire planted population (without regard to plant size, vigor, or seed output) and seed should be harvested several times during the seed collection window, in order to capture seeds from phenologically extreme plants (Knapp and Rice 1994; McKay et al. 2005). Mechanical or single date harvesting will select for uniformity of time to maturity (Knapp and Rice 1994) and only collects a subset of the available seed (Smith et al. 2007).

Seeds of cool season annuals can typically be collected from May through June, whereas seeds of warm season annuals can typically be collected from July through October. Perennials are not as easily categorized as cool season or warm season species. As mentioned previously, the seeds of some perennial species (e.g., *Allenrolfea occidentalis, Atriplex polycarpa, Gutierrezia californica*) cannot typically be collected until at least November.

[B] Studies that evaluated the use of selected soil amendments did not indicate that they provide benefits for native species establishment on the retired agricultural lands (Ritter and Lair 2006, p. 47).

For a few annual species that retain their seeds well as they senesce (e.g., *Castilleja exserta, Daucus pusillus, Guillenia lasiophylla, Hemizonia pungens, Salvia columbariae*), we would typically wait for all the seeds on a given plant to mature and then collect the whole plant. However, seed collection on more than one date was sometimes necessary, to collect both early and late maturing plants. With this approach, it is possible that a fraction of the early-maturing seed will have been dispersed before plants are collected. *Wislizenia refracta* is another annual species that retains its seed well as it senesces. However, due to the large biomass of *W. refracta* plants, we selectively harvested fruit-bearing stems rather than whole plants.

For annual species with seeds that mature indeterminately and become dispersed continuously over a several week period (e.g., *Holocarpha obconica, Lessingia glandulifera, Lupinus succulentus, Trichostema ovatum*), seed harvest on multiple dates was necessary. For these species, it was not a good approach to wait for all of the seeds on a given plant to mature, with the intention of collecting the whole plant. By the time the last of the seeds were mature, a significant portion of the seed crop would already have been dispersed. Harvesting seed from these species was often time-consuming because mature seeds or fruits had to be harvested selectively. Sometimes it was possible to harvest stems that were bearing numerous mature fruits. However, in many cases, stems would bear open flowers, immature fruits, and mature fruits at the same time and therefore it was not ideal to harvest them.

For some species in the family Asteraceae that have 'fluffy' seed (e.g., *Isocoma acradenia, Lepidospartum squamatum, Malacothrix coulteri*), we would vacuum seeds off plants, using a shop vacuum and gas-powered generator. If a significant quantity of seed had been dispersed from the plants just before a seed collection visit, we would vacuum seed off the ground from the base of the plants. This method is not ideal because of potential for contamination with seeds of other species or deterioration in seed quality. However, if the seed appeared to have fallen recently and had not become damp or mixed with soil and plant litter, a seed collection of reasonable quality could be made.

For *Allenrolfea occidentalis* and *Atriplex polycarpa*, both shrubs, we would strip fruits from plants by hand or shake fruits off branches into a collecting bag. For *Atriplex spinifera*, a shrub, we would clip fruit-bearing branches from plants because it is painful to strip fruits from plants by hand, due to the plants' spiny nature.

For species that have seeds contained in pods (e.g. *Astragalus lentiginosus, A. oxyphysus, Isomeris arborea),* we would strip mature pods from plants by hand.

For *Frankenia salina* and *Sesuvium verrucosum*, both perennial herbs, we would harvest only one-third of the fruit bearing stems so that the plants would persist from year to year.

For *Grindelia camporum*, a perennial herb, or *Eriogonum fasciculatum*, a shrub, we would hand strip or clip seed heads from plants.

We used large woven polypropylene bags to contain and transport harvested plant material, and to store processed seed (Figure 7). The bags are sturdy, lightweight, reusable, inexpensive, and can be written on with permanent marker. Once full, we would staple them closed before transporting them from the nursery to the seed-processing warehouse. Harvested plant material should not be stored in the bags for more than a day or so, particularly in warm temperatures. The bags are not very breathable and even the low moisture content of senesced plant material could potentially lead to mold growth.

Seed collecting guidelines for California native plants are available from the Rancho Santa Ana Botanic Garden:

http://rsabg.org/horticulture/Seed%20Program/Seed%20Collection%20Guidelines.pdf

Figure 7. Woven polypropylene bags were used to transport harvested plant material to the seed-processing warehouse.

MECHANICAL HARVESTING

During two growing seasons, we experimented with mechanical harvesting techniques for select species. We wanted to develop methods that would allow us to collect seed from plants on more than one date. However, this proved to be difficult. Both the mower and the mechanical harvester that we used would collect entire plants, and did not leave any plant material that could be collected on future dates.

When we used a mower to collect low-growing species such as *Lasthenia chrysantha* and *Phacelia ciliata*, a significant amount of soil was collected along with the plants. The inclusion of the soil with the harvested plant material significantly increased the amount of time required for seed processing. Therefore, for low-growing species, the time that we gained through efficiency in seed harvesting was essentially lost due to our reduced efficiency in seed processing.

GREENHOUSE PROPAGATION

During a few growing seasons, we raised seedlings of select species at the California State University, Fresno (CSU-Fresno) greenhouse and then transplanted them into the nursery. We selected species for greenhouse propagation based on either limited seed supply or past difficulties with growing them from seed at the nursery. When our seed supply for a given species was limited, we were concerned that if we sowed the seeds directly at the nursery, they could fail to germinate or become lost to predation.

We sowed seeds of both annual and perennial species in trays that contained individual Ray Leach "Cone-tainer"™ cells (Figure 8). We filled each cell to within 1 cm of its surface with Sunshine potting soil. We sowed the seeds on the soil surface and then covered them with an approximately 3-mm layer of soil, followed by an approximately 3-mm layer of perlite. We installed an automatic watering system at the greenhouse, to ensure consistent levels of soil moisture for the germinating seeds. We found that an advantage of sowing seeds in planting tubes, rather than a tray or flat, is the reduced potential for roots of neighboring seedlings to become entangled.

We planted seeds in the greenhouse during September, October, and November and we believe that planting the seeds during November or December with the goal of transplanting seedlings during January would be ideal. In a year with below average winter rainfall, February would not be too late to transplant seedlings. The unpredictable timing of fall and winter rainfall made it difficult to produce seedlings at the appropriate time of year for transplanting. During one year, we transplanted seedlings into the nursery during early December. However, due to minimal rainfall there had been virtually no germination of any plants, including weeds, at the nursery. Once we transplanted the seedlings, they were essentially the only living annual vegetation around and were promptly devoured even though they were located inside of fenced herbivore exclosures. In hindsight our timing was clearly less than ideal but the seedlings had been outgrowing their planting tubes and would have needed to be repotted, thus requiring additional materials, labor and greenhouse space.

Ideally, seedlings should be transplanted following winter or spring rains. It may be advisable to hold off on sowing seeds at the greenhouse until some fall or winter rainfall has been received at the transplanting site. This would ensure that the seedlings' growth is not too advanced in comparison to the surrounding vegetation. We found that an additional benefit of waiting for rainfall is that it becomes easier to dig holes in the soil for transplanting purposes.

Undoubtedly it was a shock for the seedlings to be transferred from a greenhouse environment to the relatively harsh conditions of the nursery. When moving seedlings from one growing environment to another, it is important to try to acclimate the seedlings. During one season of greenhouse propagation efforts, we moved seedlings to an outdoor area of the CSU-Fresno greenhouse, in order to begin acclimating them to outdoor environmental conditions such as wind, strong sunlight, and greater temperature fluctuation. This process of acclimation is often referred to as "hardening off", and advice on how to do it is widely available on gardening websites.

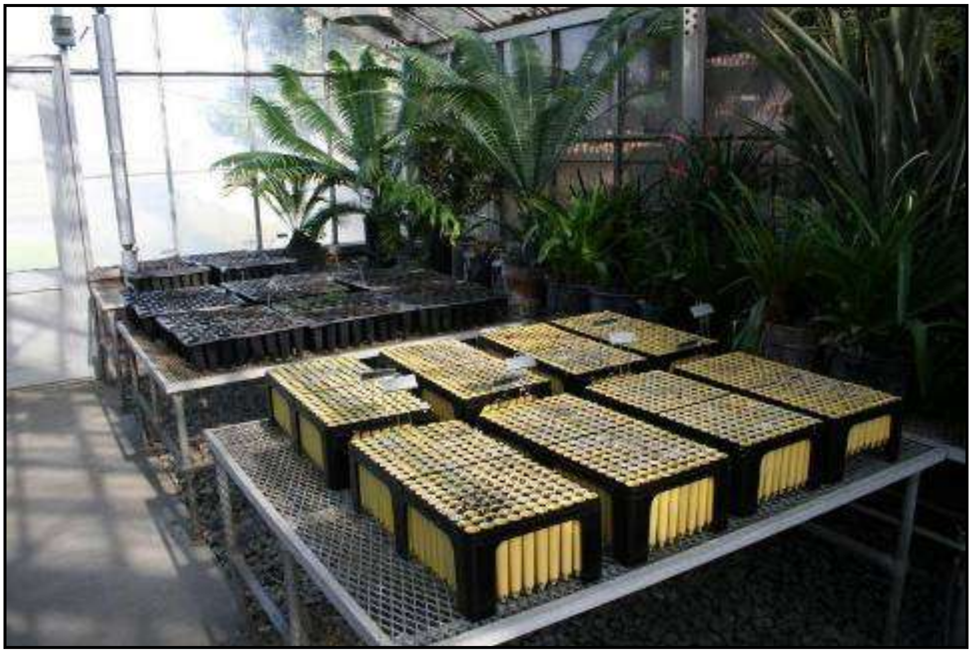

Figure 8. At the California State University, Fresno greenhouse, seeds were sown in trays that contained individual Ray Leach “Cone-tainer”™ cells.

TRANSPLANTING

Following bed preparation with a gas mini-tiller, we secured landscape fabric[C] over the planting beds, which helped to suppress weed growth and retain soil moisture. We then cut openings in the landscape fabric in order to dig and prepare holes for the transplanted individuals. We removed seedlings from their tubes, placed them in the prepared holes, surrounded them with a mixture of equal parts potting soil and native nursery soil, and then watered them deeply (Figure 9). We sometimes had difficulty with gently removing the seedlings from their planting tubes. If a seedling and its associated soil could not be easily released from the tube, we would sacrifice the tubes by cutting them off with scissors.

All transplanted seedlings were covered with floating row cover, a lightweight fabric that helps to protect plants from frost, wind damage, herbivory, and moisture loss, while still allowing sunlight in. One undesirable effect of using row cover is that weeds also thrived under its protection. We used biodegradable plastic stakes (Bio-STAKE™) to anchor the row cover to the soil. In the absence of adequate rainfall, we watered the transplants on a weekly or sometimes twice weekly basis in order to help their roots become established. However, in the absence of a drip irrigation system, it was very labor intensive to remove lengths of row cover in order to water the transplants. Some brands of row cover have pores large enough to allow water to pass through, but that was not true of the row cover that we used[D].

[C] We used WeedBlock 6+ available from Forestry Suppliers, Inc.

[D] We used point bonded 1.25 oz. row cover from Harris® Seeds

To water transplants, we would typically transport a 208-liter (55 gallon) plastic drum of water to the nursery and use a siphon pump[E] to repeatedly fill 7.6-liter (2 gallon) watering cans. On a few occasions, we used a gas-powered pump and a hose to water the transplants, rather than pumping the water by hand. We transported the pump and a drum of water in the bed of a truck and one person would water the transplants with the hose while another person would prime the pump.

In summary, we found the greenhouse propagation and transplanting work to be labor-intensive and only marginally successful. The transplanted seedlings often suffered a high rate of mortality. This is of concern because if a seed lot is small to begin with and numerous seedlings die, the genetic variability of the seed lot will have been further reduced. We believe that it would have been ideal to focus our efforts solely on perennial species, because the successful establishment of a perennial species at the nursery would result in the long-term benefit of seed harvest over multiple years in comparison to the short-term benefit (e.g., a single seed harvest) of transplanting an annual species.

Figure 9. Narrowleaf goldenbush (*Ericameria linearifolia*) plants, eight months after being transplanted into the nursery as seedlings. Seeds were planted in the greenhouse during September 2007, and seedlings were transplanted into the nursery during November 2007.

[E] We used Model # 833123 from the Global Industrial Company.

WILDLIFE HERBIVORY

We had continuous problems with wildlife feeding on nursery-grown plants. Because the nursery is located within a disturbed landscape that is dominated by non-native weedy species, the nursery-grown plants represent a unique food source. Additionally, the dense native shrub cover at the nursery provides habitat for wildlife. Nursery-grown plants were especially impacted by herbivores during periods of below average rainfall, when plant growth in the vicinity of the nursery was reduced.

Based on numerous sightings and the presence of scat in the immediate vicinity of damaged plants, we believe that black-tailed jackrabbits (*Lepus californicus*) and desert cottontails (*Sylvilagus audubonii*) are the main herbivore pests at the nursery. However, we have also observed evidence of damage caused by deer mice (*Peromyscus maniculatus*) and birds. Species that were especially susceptible to browsing by wildlife are listed in Table 2. Species shown in bold were especially well adapted to the nursery site conditions and easy to cultivate, with the exception of their susceptibility to herbivory. For the species not shown in bold, we do not claim that damage from herbivory was our main limitation in successfully cultivating them. Rather, limited seed supply, dry growing conditions, or our limited experience with cultivating the species were more significant factors than browsing by herbivores.

Table 2. Species that were browsed heavily by wildlife during one or more growing seasons while in cultivation at the nursery.

Annuals	Perennials
Achyrachaena mollis	***Asclepias fascicularis***
Daucus pusillus	*Eastwoodia elegans*
Deschampsia danthonioides	*Eriogonum fasciculatum*
Epilobium brachycarpum	***Lotus scoparius***
Eremalche parryi	*Nassella cernua*
Lepidium dictyotum	*Poa secunda*
Lupinus succulentus	*Sesuvium verrucosum*
Malacothrix coulteri	*Sporobolus airoides*
Monolopia major	
Monolopia stricta	
Uropappus lindleyi	

In addition to the browsing of the species listed above, we also observed significant damage to the branches of three shrub species, *Artemisia californica, Atriplex spinifera*, and *Salvia mellifera*. We presume that rabbits gnawed the woody material in order to sharpen their teeth. We also believe (based on the presence of slanted cuts) that rabbits clipped stems of *Mentzelia laevicaulis*, a perennial herb, and left them on the ground uneaten. It also seemed that animals uprooted and killed several *M. laevicaulis* rosettes but did not eat them.

HERBIVORE EXCLOSURES

We built several fenced exclosures at the nursery, to protect transplanted seedlings and select species that are susceptible to herbivory. Initially, we constructed a few 100-150 m^2 exclosures, using chicken wire and 1-meter tall metal t-stakes. The height of the fencing was sufficient to prevent rabbits from jumping over the top and we buried the fencing several centimeters belowground, to prevent rabbits from digging underneath the fence. During 2007, we built some additional exclosures out of 1.5-meter tall welded wire and 1.5-meter tall metal t-stakes, and buried the fencing at least 0.25 meters belowground. Because it is difficult to dig in clay soils when they are dry, we used a gas-powered walk behind trencher to dig trenches for fence installation. Although the mesh size of welded wire is unfavorably much larger than that of chicken wire, the welded wire is more sturdy and resistant to damage than chicken wire. The largest welded wire exclosure that we built was approximately 2500 m^2. In hindsight, we should have cleared the fenced-in area of mammals and mammal burrows before the fence was completed. Following fence construction, we observed rabbit droppings and damage to plants within the exclosure and concluded that there were mammals living within the exclosure.

We anticipated that the welded wire exclosures would restrict rabbit access, with the possible exception of juvenile cottontails. However, we observed evidence that deer mice entered the welded wire exclosures and caused damage to plants. During the 2007-08 growing season, we transplanted numerous robust *Nassella cernua* individuals into an exclosure at a time when surrounding vegetation was minimal due to low seasonal rainfall. Within a few days, all of the transplants had been browsed to ground level. We later discovered some of the harvested grass in a nearby mouse den, presumably being used as nesting material. Also during the 2007-08 growing season, we transplanted *L. succulentus* seedlings inside an exclosure, covered the seedlings with floating row cover, and anchored the row cover to the ground with stakes. However, based on the presence of scat, a deer mouse (*Peromyscus maniculatus*) entered the exclosure, squeezed under the row cover and ate several of the seedlings.

We also suspect that birds have caused damage to *L. succulentus* plants. Because *L. succulentus* is a favored browse of rabbits, we began transplanting the species into herbivore exclosures. Nevertheless, the plants sustained damage and we observed bird droppings near the damaged plants. In the year that we suspected damage from birds, many stems with immature fruits had been clipped off plants and left on the ground uneaten. A list of bird species that we have observed at the nursery is included in Appendix B.

In summary, the successful exclusion of rabbits from most of the fenced exclosures helped to greatly reduce browsing damage to plants. However, it would have been ideal to use fencing material with a mesh size small enough to exclude small mammals such as deer mice. In dry years when the herbivore pressure on nursery-grown plants was increased, the exclosures did not adequately protect plants from browsing by small mammals.

IRRIGATION

Because adaptation to low-moisture growing conditions would be an essential trait for seed stock to be used in the restoration of the retired farmland, we did not water nursery-grown plants on a regular basis. We wanted to avoid selecting for individuals that require moist growing conditions. However, we occasionally irrigated the nursery during periods of below average rainfall. Such minimal precipitation was received during some growing seasons that in the absence of irrigation, there would have been almost no germination and growth of the planted natives. On average, we irrigated the nursery two to four times per growing season.

Because the nursery is located within a matrix of agricultural fields, the infrastructure for water delivery was already in place (Figure 10). We established an account with Westlands Water District and each winter would request water for the upcoming 'water year'. A water year begins in March and extends through February of the following calendar year. When we needed to irrigate the nursery, we would place a water order with Westlands Water District over the phone, 24 hours in advance.

We typically watered the nursery through flood irrigation, but we occasionally used sprinkler irrigation. In order to flood irrigate the nursery, we assembled a sequence of gated irrigation pipes in a north-south direction at the western edge of the planted beds. Irrigation water would then travel from west to east through the furrows between the planting beds (Figure 11). The duration of each flood irrigation event ranged from 12 to 48 hours, with water typically flowing at the rate of 1 cubic foot per second (cfs). One flood irrigation event would typically use two to four acre-feet of water.

A significant drawback of flood irrigation is that a large volume of water would flow into the deep cracks in the soil and then travel below the soil surface, rather than traveling down the furrows between the mounded planting beds. In addition, flood irrigation resulted in a flush of weed growth in both the planting beds and the furrows, thereby increasing the need for weed control.

Sprinkler irrigation was practical when only select areas of the nursery were in need of water. Sprinkler irrigation resulted in less vigorous weed growth than flood irrigation and allowed for more efficient water use, because water was not diverted as sub-surface flow.

During fall 2007, we planted cool season annuals in a separate area of the nursery from the warm season annuals. The segregated planting design allowed for the two groups of annual species with different phenological patterns to be watered independently of each other. Had winter or spring rainfall been minimal, we may have wanted to selectively irrigate the cool season or warm season species, respectively, in order to promote germination. In order to minimize the need for weed control, it was ideal to irrigate as small of an area as possible.

In comparison to flood and sprinkler irrigation, drip irrigation would have allowed for even more efficient water use and a greater reduction in weed growth. We considered installing a drip irrigation system, but due to the remote location of the nursery we had concerns about the potential for vandalism and the labor required for regular maintenance, such as the flushing of filters, drip tape, etc. Additionally, we anticipated that the resident mammal population would damage the tubing and other system components.

Figure 10. The nursery site is located within Westlands Water District. This "turnout" is part of the Westlands water distribution system. To irrigate the nursery, irrigation pipe was connected to the turnout and a water order was placed with Westlands Water District.

Figure 11. Flood irrigation of the field nursery during May 2007. Looking east across the nursery, Mt. Diablo milkvetch *(Astragalus oxyphysus*) is in flower on the right.

WEED MANAGEMENT

Following the cessation of agricultural production and associated weed suppression efforts, fallowed or retired agricultural lands quickly become dominated by introduced weedy species. Various restoration trials conducted in the region have indicated that weed control will be an essential component of any attempt to re-establish native vegetation on retired farmlands (USDI 2005; Ritter and Lair 2006).

Weed management was a necessary aspect of nursery operations. We used a combination of non-chemical (e.g., disking, hand-pulling, and flaming) and chemical methods to control weed growth at the nursery. Our weed control efforts at the nursery likely exerted some selective pressure on the cultivated plants, by reducing competition from weed species. Though competitive ability against weeds would be an ideal trait for nursery-produced seed stock to have, the absence of weed control at the nursery would have made it virtually impossible to successfully cultivate native species. The dominant weed species at the nursery grow so aggressively that they would have significantly hindered native plant growth (Figure 12). In addition, our efficiency in harvesting and processing seed would have been significantly reduced if we had allowed weeds to grow intermixed with the natives.

Figure 12. During years with above average precipitation, black mustard (*Brassica nigra*), the yellow-flowered plant, grew vigorously at the nursery, and outcompeted most of the seeded native species. Great Valley phacelia (*Phacelia ciliata*), the purple-flowered plant, was one native species that had good competitive ability against black mustard.

The most prevalent weed species that we observed at the nursery included *Amaranthus albus*, *Atriplex argentea*[F], *A. rosea*, *Brassica nigra*, *Chenopodium album*, *C. murale*, *Erodium cicutarium*, *Phalaris minor*, *Portulaca oleracea*, *Salsola tragus*, and *Sisymbrium irio*. Two native species that were planted during the first and second

[F] *A. argentea* is native to California but is weedy and aggressive in nature; seeds of *A. argentea* were never planted at the nursery.

growing seasons, *Amsinckia menziesii* and *Helianthus annuus,* spread throughout the nursery and competed aggressively with other native species. By the third growing season, we had ceased planting the two species. Two native species that were regularly sown at the nursery, *Heliotropium currassavicum* and *Phacelia ciliata,* grew aggressively as volunteers and were removed by hand pulling when they encroached upon other cultivated native species.

In addition to weeds growing on the nursery site, various species of broadleaf annual 'tumbleweeds' (*Salsola tragus, Atripex argentea*, and *A. rosea*) that are common on fallowed lands adjacent to the nursery were also problematic. As the plants senesce, they break off from their base and distribute their seeds while being blown across the landscape. In order to prevent numerous tumbleweeds from entering the nursery, we constructed a 2.4-meter tall north and west-facing perimeter fence. Tumbleweeds would accumulate against the fence by the hundreds and had to be removed at least twice a year (Figure 13).

Figure 13. A north and west-facing perimeter fence effectively prevented numerous tumbleweeds from entering the nursery. Tumbleweeds that accumulated against the fence had to be removed a few times a year.

NON-CHEMICAL WEED CONTROL

Disking

There are some areas within the nursery perimeter fence that were used for vehicle access or that otherwise remained uncultivated. When weeds germinated densely (Figure 14), we would disk the area before the plants could produce seed.

Pre-irrigation

On a few occasions, we pre-irrigated the nursery before the onset of winter rainfall, in order to stimulate weed germination. We suppressed the weed growth by disking, and then seeded the native species. The objective of this technique is to deplete the amount of weed seeds in the soil seed bank, thereby reducing weed germination later in the growing season, and providing the seeded species with a competitive advantage (Lanini et al. 2003).

Hand-Pulling

Because we could not utilize any form of chemical weed control on the planting beds after the natives had germinated, a substantial amount of labor was devoted to hand pulling of weeds from the planting beds. We were very fortunate to employ a contracted labor crew that quickly learned to identify native versus weedy species, even at the seedling stage. Following average to above average amounts of rainfall or a flood irrigation event, 100-150 person-days would typically be required (five people working full-time over a four to six week period) to hand pull the resulting flush of weeds. When rainfall received was below average and the nursery was not irrigated, 5-10 person-days a month of hand pulling was typically sufficient to remove weeds growing in the planting beds.

Flaming

We frequently used an agricultural flamer for weed control before sowing seeds of native species, or in areas of the nursery where natives had not been planted (Figure 15). The flamer was particularly effective at killing young plants, less than 5 cm in diameter. The flamer was less effective at killing mature plants; sometimes the foliage would be destroyed but the stems would persist. Raking the weed-infested area (to remove foliage) before flaming helped to increase the effectiveness of the flamer.

Additional Methods

On a few occasions during winter and early spring, we used the tractor and an attached lister implement to scrape weed seedlings out of the furrows that were located between the annual planting beds. Because the natives had already been sown, the lister had to be raised high enough so that it would not disturb the surface of the planting beds. This method could only be used when plants growing on the surface of the beds were less than a few centimeters tall.

We utilized the soil solarization method to a limited extent during one growing season. This method entails covering the planting beds with plastic sheeting that will trap the sun's heat, thereby killing weed seeds, pathogens, and insects in the soil. This method appeared effective at reducing weed growth, but we did not implement it in following years.

A weed management technique that we researched but did not implement is nighttime tillage, also referred to as photo-control (Ascard 1994; Juroszek and Gerhards 2004).

Figure 14. Looking northeast across an uncultivated portion of the nursery site during February 2009. Virtually all of the green growth is black mustard (*Brassica nigra*) seedlings. The area was disked before the plants produced seed.

Figure 15. An agricultural flamer was very effective at controlling weeds that were in the seedling stage.

CHEMICAL WEED CONTROL

Pre-emergent Herbicide

During the fall of a few growing seasons, we applied pre-emergent herbicide (e.g., Gallery 75 Dry Flowable or Goal 2XL) to the furrows between the annual species' planting beds, which helped to reduce the amount of labor needed for hand pulling of weeds. Even if the natives had not yet been planted, we did not apply the product to the surface of the planting beds, because we wanted to minimize risk to the native seeds that would be sown in following weeks.

For maximum efficacy, pre-emergent herbicides typically need to be incorporated into the soil by a minimum amount of rainfall within a certain number of days following application. In some instances, the efficacy of the herbicides may have been reduced due to minimal rainfall received in the weeks following application.

Activated Charcoal

One particularly promising approach to chemical weed control and native plant establishment entails using activated charcoal to protect native seeds from the effects of pre-emergent herbicides (Lair et al. 2006; Ritter and Lair 2006). This method facilitates the establishment of native species by providing them with a competitive advantage over weedy species. We did not utilize this weed control method at the nursery. However, this method could potentially be very useful in efforts to restore native vegetation in disturbed areas that are dominated by non-native weedy species.

Post-emergent Herbicide

We frequently applied Roundup, a post-emergent herbicide, to the planting beds before the natives had germinated. In some instances, we would pre-irrigate the nursery, control the flush of weed growth with Roundup, and then plant the native seeds. However, we sometimes planted the natives, irrigated the nursery, and then applied Roundup. The weeds would emerge almost immediately following irrigation, whereas native species emergence would be slightly delayed. Therefore, a short window of opportunity existed within which Roundup could be applied to control the weeds, without harming the natives.

We also frequently applied Roundup in areas of the nursery where weed growth became dense, yet disking was not feasible. Over the duration of the project, we used three different types of Roundup: Original, Ultramax, and Weathermax, and found each of them to be effective.

Pesticide Permitting and Regulations

An individual with a Qualified Applicator License from the California Department of Pesticide Regulation (CDPR) supervised pesticide application at the nursery and trained ESRP staff in pesticide application and safety. We obtained a non-certified permit and an Operator Identification Number from the Fresno County Department of Agriculture, and consulted with the Department to determine which products were appropriate to use at the nursery. Following any pesticide application at the nursery, we submitted a pesticide use report to the County Agricultural Commissioner within a month's time.

PEST CONTROL

Nursery-grown plants occasionally incurred damage from insect and fungal pests.

SEED WEEVILS

During several growing seasons, the fruits (pods) of *Astragalus lentiginosus* and *A. oxyphysus* became heavily infested by an insect identified as *Acanthoscelides* spp. (subfamily Bruchinae). Insects of this genus are commonly referred to as seed weevils, and they infest a variety of leguminous plant hosts. The weevil larvae live in and feed on maturing or stored seeds, rendering infested seeds unviable (Figure 16). Because seeds of *Astragalus* species are contained in pods, the degree of infestation was not apparent until pods of the two species had already been collected and transported to our seed processing facility. We eventually learned that small exit holes are visible on the fruits, if one knows to look for them. At the seed processing facility, we attempted to control the insects through a combination of fumigation (with an over the counter flea fogger product), freezing of processed seed lots, and vacuum removal during seed processing. Admittedly, we had some concerns about the effect of freezing on seed germinability. In some instances, we believed that we had successfully eradicated the insects during seed processing, but later observed insects in stored seed lots. Therefore, stored seed lots of *Astragalus* and other legume species should be periodically checked for infestation. In order to minimize seed damage and reduce the amount of effort required for seed processing, it would have been ideal to find a way to control the insect infestations in the field.

The Great Basin Native Plant Selection and Increase Project has also reported problems with seed weevil infestations of cultivated *Astragalus* species:
www.nsl.fs.fed.us/Forb_seed_predators.ppt

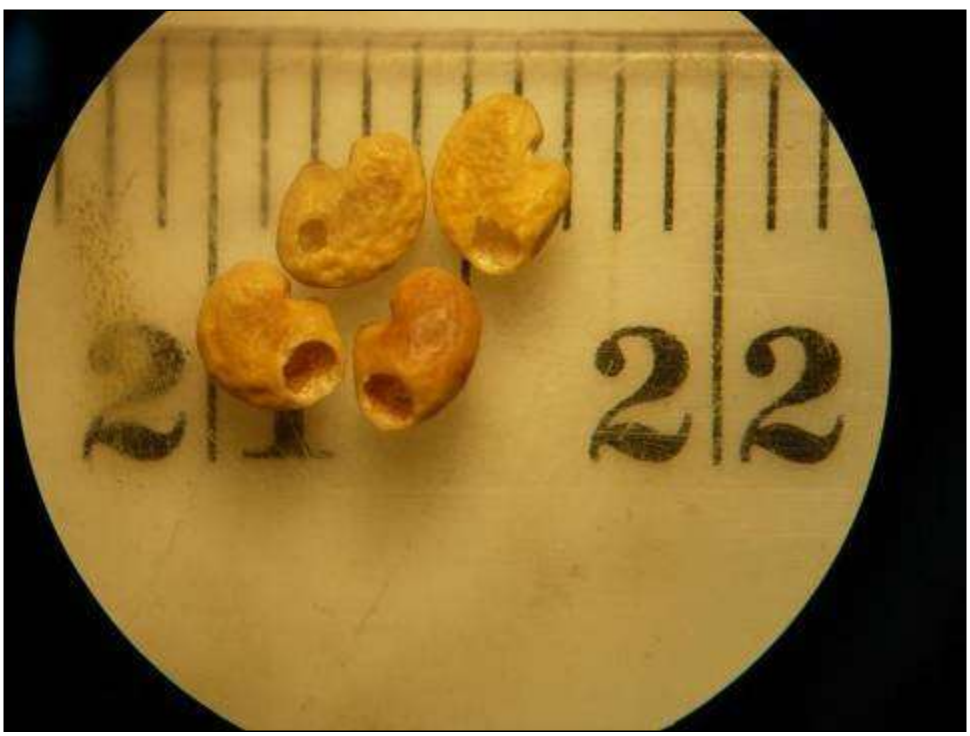

Figure 16. While in cultivation at the nursery, the seeds of Mt. Diablo milk-vetch (*Astragalus oxyphysus*) became infested by insects known as seed weevils. The weevil larvae live in and feed on growing or stored seeds, rendering infested seeds unviable. Scale is 1 cm.

RUST

Several *Astragalus oxyphysus* individuals established in the nursery became infected with a rust fungus that was identified as *Uromyces punctatu*s (Meadowview Labs, Sacramento). The fungus only infects plants of the *Astragalus* genus, and therefore it could not infect the majority of other species growing at the nursery and in the surrounding area. Because the rust is an obligate parasite, it will not kill its plant host, but has the potential to reduce plant productivity and seed set. Though the rust is not seed-transmitted, we were advised to treat all *A. oxyphysus* seeds with fungicide before using them in any research or restoration trials, in order to prevent spore dispersal.

APHIDS

On a few occasions, we observed oleander aphids (*Aphis nerii*) on *Asclepias fascicularis* (Figure 17). We did not attempt to control the insects with pesticide.

Figure 17. Oleander aphids (*Neris aphii*) would occasionally infest nursery-grown narrow-leaved milkweed plants (*Asclepias fascicularis*).

FALSE CHINCH BUGS

False chinch bug infestations (*Nysius raphanus*) were a recurring problem at the native plant nursery and on surrounding retired lands (Figure 18; Figure 19). Cruciferous plants, including the non-native black mustard (*Brassica nigra*) and London rocket (*Sisymbrium irio*) are the primary hosts of the false chinch bug; both of the species are abundant at the nursery site and in the surrounding area. False chinch bugs are also a known pest of grape[G] and cotton crops[H].

During the most severe infestations, false chinch bugs caused damage to almost every species growing at the nursery, native and non-native. The insects would congregrate on plant stems and foliage at high densities, forming a dark gray mass. We also frequently observed the insects crawling on the ground at high densities. It was clear that some plant species were highly preferable and were the first to be attacked. Other less preferable species would not be broadly attacked until the more preferable species had been defoliated and/or killed. We observed that the palatability of a species would vary within the same genus. For example, *Atriplex phyllostegia* (leafcover saltbush) was one of the earliest species to be attacked, whereas *Atriplex rosea* and *A. argentea* (tumbling saltbushes) were some of the last species to be attacked.

Figure 18. A false chinch bug (*Nysius raphanus*) infestation on leafcover saltweed (*Atriplex phyllostegia*) during June 2004.

[G] http://www.ipm.ucdavis.edu/PMG/r302301111.html

[H] http://www.ipm.ucdavis.edu/PMG/r114302411.html

Figure 19. A false chinch bug (*Nysius raphanus*) infestation on iodinebush (*Allenrolfea occidentalis*) during November 2008.

False chinch bug outbreaks most often occurred during June and July. Constant monitoring (i.e., weekly site visits) during the dry season was necessary to adequately detect false chinch bug presence and levels of infestation. This frequent scouting helped to initiate control measures before extensive damage occurred. We observed on a few occasions that false chinch bugs appeared at the nursery following an irrigation event. According to the University of Nebraska-Lincoln[l], adult and nymph insects spend the winter under plant debris and the insects' eggs are laid in loose soil or soil cracks. It is possible that the application of irrigation water caused the adults to emerge or caused the eggs to hatch.

We used Wisdom™ Flowable and Malathion® 8 pesticides to control false chinch bugs, and we found both products to be very effective. We used 15.14-liter (4-gallon) capacity backpack sprayers or 3.79-liter (1-gallon) capacity hand-held sprayers to apply the pesticides. More than one application within a week's time was often necessary, in order to completely suppress the insect outbreaks.

SEED PROCESSING

Beginning in 2003, we conducted seed processing work in an approximately 140 square meter (1500 sq ft) rented warehouse space located in Fresno, California (Figure 20). We would transport harvested plant material to the warehouse and spread it out on tarpaulins to air dry, indoors. We typically set up a few electric fans to facilitate drying and turned the plant material at least once a day.

[l] http://panhandle.unl.edu/web/potato/false_chinch_bug

Figure 20. Iodinebush (*Allenrolfea occidentalis*) plant material air-drying on tarpaulins in the seed processing facility.

Cleaning seed lots before storing them decreases bulk, reduces disease risk (Terry and Bertenshaw 2008), and typically removes hollow, broken, or underdeveloped seeds (Wall and Macdonald 2009). The ease of removing chaff (e.g., pieces of branches, stems, leaves, fruits, and floral structures) from a seed lot varies with the species. With the exception of large-seeded species such as *Isomeris arborea* and *Lupinus succulentus*, it was virtually impossible to remove every chaff particle from a seed lot. When a seed lot was designated for a restoration trial or for seed archiving (long-term storage), we cleaned it to a high level of purity. When using any kind of mechanical seeder, it is easier to calibrate the equipment for a clean seed lot, and seed will pass through the equipment more easily. When a seed lot was intended for replanting in the nursery, we cleaned it to a moderate level of purity (i.e., separated seed from chaff until it became labor intensive and time-consuming to remove additional chaff).

The primary pieces of equipment that we used were a hammermill, a Wall Mount Air Separator (Seed Tech Systems) also known as a winnower or aspirator, a Clipper Office Tester (A.T. Ferrell Company, Inc.), and a Clipper Eclipse (A.T. Ferrell Company, Inc.). We found an air compressor to be invaluable for cleaning out machinery after processing each seed lot.

None of the species for which we collected and processed seed had fleshy fruits, e.g., berries, drupes, or pomes. Methods for processing such fruits would be very different from the methods described here.

Our first step in cleaning any seed lot was to break up the plant material and separate seeds from fruits. This process is called threshing and we would typically use either the hammermill or a large (approximately 0.6 square meter) screen mounted on a wooden frame.

HAMMERMILL

Hammermills are available in a variety of sizes and are used for numerous purposes other than seed processing. We purchased a hammermill from a private seller on eBay (Figure 21; Figure 22), and then made a few modifications such as constructing a hood over the moving parts for safety purposes and constructing bins to collect the seed as it passed through the hammermill. Our hammermill did not come with screens, so we had two different sized screens custom made by a local company. The hammer mill quickly reduced raw plant material into a coarse but uniform mixture of seeds and chaff. In order to completely remove fruits from branches and stems or to release seeds from fruits, we would run some seed lots through the hammermill more than once. Hammermilling serves to greatly reduce the volume of harvested plant material. Plant material that was air-drying on tarps in the warehouse would initially occupy several square meters of floor space. However, after a seed lot was hammermilled, the plant material would fit into a few large bins.

Figure 21. For the majority of the seed lots, a hammermill was used to reduce harvested plant material into a coarse but uniform mixture of seeds and chaff (e.g., pieces of branches, stems, leaves, fruits, and floral structures).

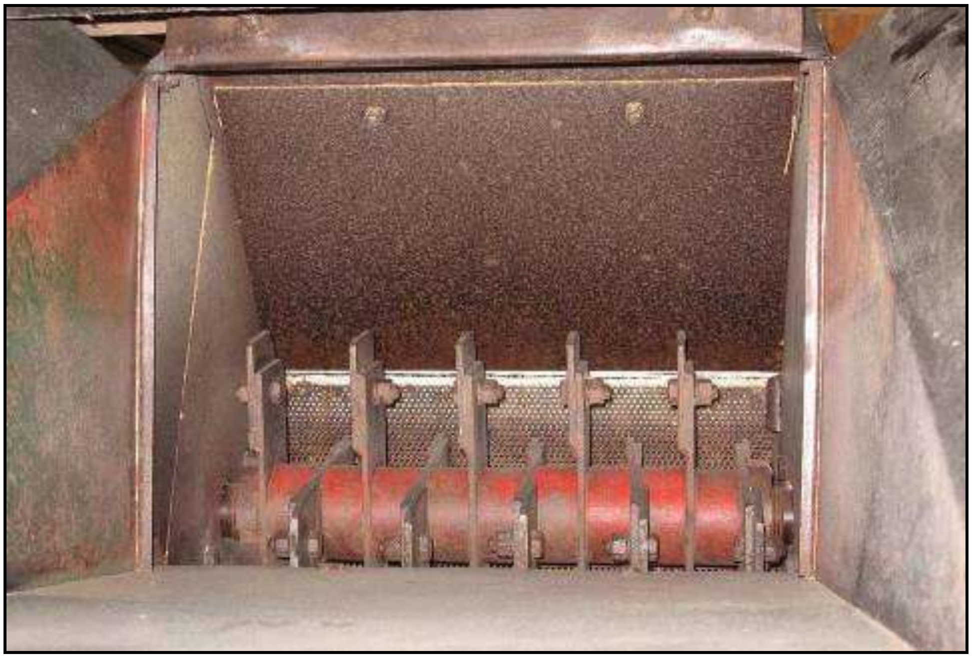

Figure 22. A view of the hammers that rotate within the machine. Raw plant material that was fed into the machine would become ground up by the rotating hammers, and then pass through the screen into a collection bin below.

We used the hammermill to process the majority of our seed lots, but some seed lots were not well suited for the hammermill. Any seed lot smaller than 0.025 cubic meters was not likely to be broken up by the rotating hammers. We did not find the hammermill to be very effective for processing species such as *Allenrolfea occidentalis, Frankenia salina,* and *Hutchinsia procumbens* that have very small fruits and seeds (less than 1 mm in diameter). Fluffy seeded species of the family Asteraceae (e.g., *Isocoma acradenia, Lepidospartum squamatum*) and the large capsules (fruits) of *Astragalus oxyphysus* are lightweight and therefore tend to float or bounce around inside the hammermill rather than moving through it. This problem could be remedied somewhat by blowing air into the hammermill, using the nozzle of an air compressor.

Coarse Screening

As an alternative to the hammermill, we would gently rub plant material over a screen that was mounted on a wooden frame, in order to dislodge fruits from stems and to break open fruits. We would select a screen with mesh size that was a little larger than the seed, so that seeds and small chaff particles would pass through the screen and into a bin placed below, while stems, branches, and large chaff particles remained on top of the screen. To remove a greater portion of chaff, we would next run the broken up plant material through an air screen cleaner.

Air Screen Cleaners

After we had threshed a seed lot, we would typically run it through an air screen cleaner to separate seeds from chaff. For relatively small seed lots (less than 0.05 cubic meters after hammermilling), we used a Clipper Office Tester[J]. For larger seed lots (more than 0.05 cubic meters after hammermilling), we used a Clipper Eclipse[K]. Both pieces of equipment use vibrating screens and an air stream to separate seed from various components of chaff, based on size and density. The Office Tester has two screens, whereas the Eclipse has three screens. Wire mesh or perforated metal screens of various sizes can be purchased for either piece of equipment and the airflow is adjustable. A Clipper seed gauge (Figure 23) is extremely helpful for selecting the appropriate screen sizes for a given seed lot, but the gauge must be purchased separately from either piece of equipment. If a Clipper seed gauge is not available, one could substitute a gauge that is used for sizing screws and bolts. This type of gauge is commonly available at hardware stores.

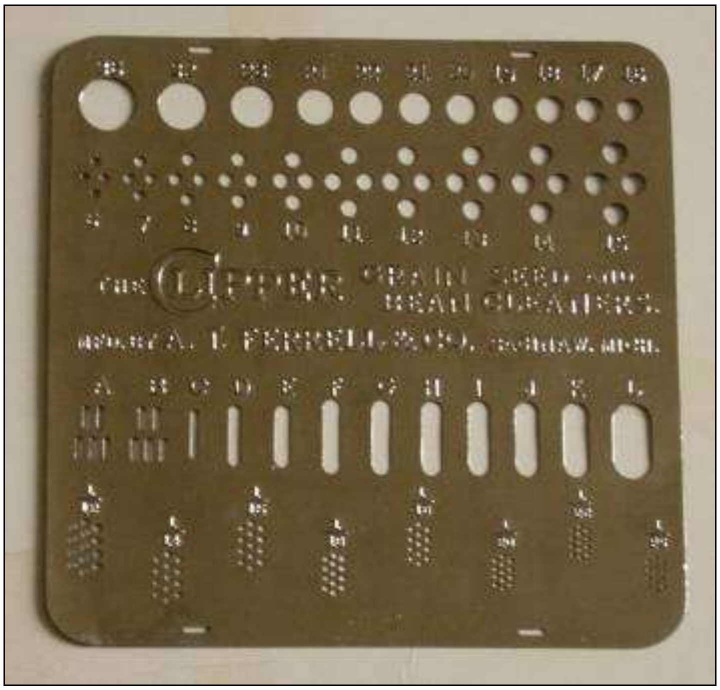

Figure 23. When cleaning a seed lot with either the Clipper Office Tester or the Clipper Eclipse, a Clipper seed gauge was very helpful in selecting the appropriate screen size.

Cleaning seed lots with air screen cleaners can potentially result in selection for uniformity of seed size. The person who is cleaning seed will likely select the screen size based on the average seed size of the seed lot. As a seed lot is run through either air screen cleaner, the seed and various chaff components are separated into multiple fractions based on size and density and will exit the machine out of different chutes. The fraction from one of the chutes will contain the majority of the seed and a low proportion of chaff, but the other fractions should be examined for the presence of seed. Seeds that are above average in size could potentially be present in the fraction that contains larger chaff particles whereas seeds that are below average in size could potentially be present in one of the fractions that contain fine chaff particles. If the person cleaning seed were

[J] http://www.clipperseparation.com/pdf/officeTester.pdf

[K] http://www.clipperseparation.com/pdf/eclipse324.pdf to retain only the fraction that contained the most seed, seeds that are above or below average in size would potentially be excluded from the final processed seed lot. In order to prevent shifts in genetic composition and maintain genetic variability, it is ideal to capture a range of seed sizes (Meyer and Monsen 1992). If a fraction contained some seed but also contained a significant amount of chaff, we would run the fraction through the cleaner a second or even third time, and adjust the screen size if needed.

It can be difficult to process ‘fluffy seed’ of the family Asteraceae with an air screen cleaner. The presence of an attached pappus that is wider in diameter than the seed will cause the seed to lodge in the screen, rather than passing through (Figure 24). If a screen is selected to accommodate the diameter of the pappus, the perforations in the screen will be so large that a significant amount of chaff will pass through the screen along with the seed.

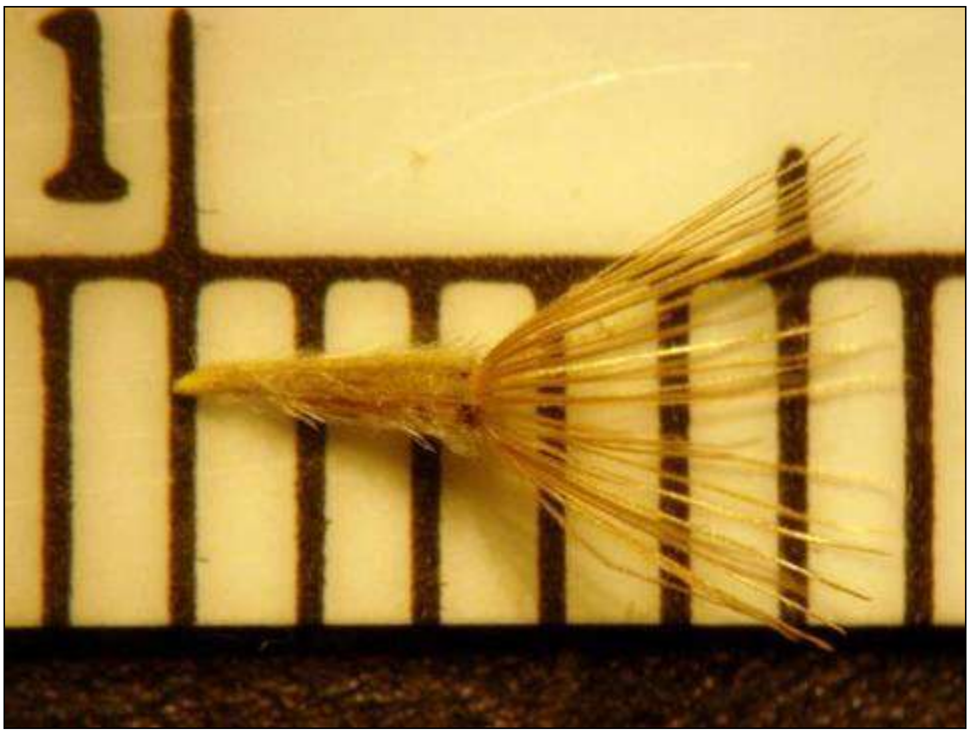

Figure 24. Valley lessingia (*Lessingia glandulifera*) seeds have an attached pappus that makes it difficult to separate them from chaff using a screen or sieve.

AIR SEPARATOR

We used an STS-WM2 Wall Mount Air Separator[L] to separate seeds from chaff, either in addition to using an air screen cleaner or in substitution of one. The Wall Mount Air Separator, hereinafter referred to as a winnower, was developed to separate out immature or less viable seed based on their lower density, in order to improve the quality (germination rate) of a seed lot (Seed Tech Systems, LLC.). The feed rate and the force of the air stream can be adjusted for each seed lot. A canister vacuum originally powered the winnower, but we replaced the canister model with a Delta single-stage dust collector,

[L] http://www.seedtechsystems.com/wallmount/

in order to gain more power (Figure 25). We used the winnower when seeds and chaff particles were similar in size yet had different densities. We would typically use it to remove lightweight pieces of chaff from a heavier seed fraction. Alternatively, if the seeds were lower in density than the chaff, we would use a reverse winnow process. Reverse winnowing works well for wind-dispersed seeds of the family Asteraceae. Before reverse winnowing, one must make sure that the vacuum receptacle is free of dust and chaff from previous seed lots.

Figure 25. This Delta dust collector was used in conjunction with a Wall Mount air separator, in substitution of the canister vacuum that originally powered the air separator.

SIEVES

For relatively small seed lots (less than 0.05 cubic meters after hammermilling), we found wire mesh sieves to be very useful for separating seed from chaff. In some instances, a single sieve would be highly effective at separating seed from the majority of chaff. In other instances, we would stack sieves of various mesh sizes on top of one another to separate out various sized chaff particles. We used sieves either in addition to or in substitution of the Clipper Office Tester. In the same way as the air screen cleaners, cleaning seed lots with mesh sieves can potentially result in selection for uniformity of seed size. When cleaning a seed lot with sieves, an effort should be made to retain seeds that are above or below average in size.

BLENDER

We have used a household blender on pulse mode to break open the fruits of some species (*Astragalus oxyphysus, Clarkia purpurea, Frankenia salina, Isomeris arborea*). In order to prevent damage to the seeds, the blender blade needs to first be coated with a plastic dip (Thomas 2003). We found this method to be effective for processing a small volume of plant material, but it would not be ideal for processing a large volume of material.

DUST ABATEMENT

Due to the significant amount of dust produced during seed processing, we installed a dust removal system at the warehouse (Figure 26). We also hung a lightweight, portable air cleaner directly over the Clipper Office Tester. Though the dust removal system substantially reduced the amount of accumulated dust in the warehouse space, it was still necessary for staff to wear disposable particulate respirator masks over the nose and mouth while processing seed. The warehouse space had two large roller shutter doors that could be opened for ventilation, and we used several box fans to circulate the air.

Figure 26. Dust removal system. a. The dust removal system included a hood that attached directly to the Clipper Eclipse seed cleaning equipment. The dust moved through the ductwork and was collected in a receptacle located outside of the building. b. The dust collection vacuum and receptacle were stored outside of the building due to the level of noise that the vacuum produced.

RESOURCES

Sources that provide an excellent summary of seed processing techniques include:

- Young, J.A., and C.G. Young. 1986. Collecting, Processing, and Germinating Seeds of Wildland Plants. Timber Press, Inc., Portland, OR. 236 pp.
- Cleaning seed collections for long-term conservation by the Millennium Seed Bank Project at the Royal Botanic Gardens, Kew:
- Processing seeds of California native plants for conservation, storage, and restoration by the Rancho Santa Ana Botanic Garden (see link to download .pdf at lower left hand corner of page)

SEED ARCHIVING

In the final year of the program, we reached the consensus that representative seed stocks from nursery propagation, as well as from local collecting activities, were important resources that should be either made available for additional research or for preservation.

We submitted 42 seed lots (of 36 species) to the National Center for Genetic Resources Preservation in Fort Collins, Colorado, for long-term storage. Twenty-three of the seed lots resulted from nursery propagation, and 19 of the seed lots were wild-collected. We do not have ownership over the seed lots that we submitted; they will either be maintained in storage or distributed to interested parties at the discretion of NCGRP.

RECORD KEEPING

Once we collected a seed lot either from the wild or from the nursery, we assigned it a Seed Lot ID. A Seed Lot ID for a wild seed collection included the year in which the seed lot was collected from the wild, a unique 4-digit serial number[M], and the letter code 'W' designating that the collection was from the wild, e.g., **2006-0001-W**.

If we planted the **2006-0001-W** seed lot at the nursery and harvested seed from the nursery-grown plants during 2007, we would assign the harvested seed lot a Seed Lot ID that included: 1) the year in which the seed was harvested from the nursery (**2007**); 2) the year and serial number of the original wild seed collection (**2006-0001**); and, 3) the code of '**N1**' to indicate that we had cultivated the seed lot in the nursery for one generation. Therefore, the Seed Lot ID would be **2007-2006-0001-N1**.

If we planted the **2007-2006-0001-N1** seed lot at the nursery and harvested seed from the nursery-grown plants during 2008, the Seed Lot ID would be **2008-2006-0001-N2**. The 'N2' code indicates that the wild seed lot has been cultivated in the nursery for two generations. We followed the same convention for 'N3' and 'N4' seed lots that had been cultivated in the nursery for three and four generations, respectively. Under this cataloging system, the serial number of the original wild seed collection was always reflected in the Seed Lot ID of each nursery-produced seed lot.

In order to minimize the risk of genetic shifts (Knapp and Rice 1994), we did not replant nursery-produced seed for more than four successive generations. A conservative guideline when operating a seed production program is to plant only wild collected seed,

[M] During each calendar year, we would begin with serial number '0001' and then assign serial numbers sequentially, using each serial number only once per calendar year.

rather than replanting seed that has resulted from previous seed production efforts (Knapp and Rice 1994). A less conservative approach would entail using a new wild seed collection every few generations (Smith et al. 2007).

Throughout the duration of the nursery project, we maintained a comprehensive database of wild seed collection activities and planting, harvesting, and processing activities for each seed lot cultivated at the nursery. Among several other fields, each database record for each type of activity contained a field for the Seed Lot ID. Therefore, we could query the database using a Seed Lot ID and locate all records for a particular seed lot.

SEED STORAGE

According to Young and Young (1986), the two most important factors influencing seed longevity are seed moisture content and seed temperature. Suggested rules-of-thumb regarding seed storage conditions are: 1) Each 1 percent reduction in seed moisture doubles the life of the seeds, 2) Each 10°F reduction in seed temperature doubles the life of the seeds. The first rule applies to seeds with a moisture content ranging from approximately 5-14%. The second rule is applicable down to at least 0°C (32°F). While in storage, the moisture content of seeds will change to remain in equilibrium with the ambient relative humidity (Young and Young 1986)

For the duration of the nursery project, processed seed lots were stored in the non-climate controlled warehouse space that also functioned as a seed processing facility. Budgetary restrictions did not allow for climate-controlled seed storage. During the summer months, daily maximum air temperature in the warehouse ranged from 27 to 40°C (80 to 104°F), and average relative humidity in Fresno is 40-48% (CIMIS 2009). During the winter monsoonal period, the daily minimum air temperatures in the warehouse ranged from 2 to 15°C (35 to 59°F), and average relative humidity in Fresno is 68-81% (CIMIS 2009).

Those conditions were not ideal for maintaining high seed viability over time, but we did not intend to store the seed for more than a few years. Seed longevity of California native plant species is highly variable (Emery 1988) and the shelf life for most of the species that we cultivated is unknown or the information is not readily available.

Scientific literature that provides data on seed longevity of some wildland shrub and forb species include:

- Kay, B.L., C.C. Pergler, and W.L. Graves. 1984. Storage of seed of Mojave desert shrubs. Journal of Seed Technology 9: 20-28.
- Stevens, R., K.R. Jorgensen, and J.N. Davis. 1981. Viability of seed from thirty-two shrub and forb species through fifteen years of warehouse storage. The Great Basin Naturalist 41:274-277.

SEED TESTING

It would have been ideal to have each seed lot professionally tested for germination and viability following seed processing and at regular intervals, in order to monitor changes in seed viability over time. However, routine seed testing is costly and we did not have funding available for the endeavor. Before using our seed lots in controlled research trials, we had them tested for purity and germination, so that seeding rates could be determined based on pure live seed (PLS) values.

State Seed Law Requirements

Because we utilized nursery-produced seed stock solely for "in house" restoration activities within the Land Retirement Program, the nursery was exempt from California state seed law requirements for standardized seed label testing (i.e., purity, germination, weed and crop seed content, etc.). If we had intended to sell any nursery-produced seed commercially or supply seed to any program outside of the Land Retirement Program, we would have been required to have each seed lot tested for purity, germination, and presence of noxious weed seed and then labeled accordingly.

The California Seed Law and Seed Inspection Regulations is available at: http://www.cdfa.ca.gov/phpps/pe/Nursery/pdfs/SeedLaw2009.pdf

CONCLUSIONS

When we initiated the seed production program, information on propagation, harvesting, and seed processing was scarce for a majority of the targeted native species. Additionally, we did not know whether the targeted native species could be propagated in a field setting, particularly under the disturbed site conditions characteristic of the retired agricultural lands.

Many of the planted species germinated readily, grew vigorously, and reliably produced seed, albeit with the aid of weed control and occasional irrigation. We produced approximately 545 kilograms (1200 pounds) of seed[N] per growing season. The nursery served as an informal 'laboratory' that we could use to develop planting and seed harvesting methods for numerous species. Because the nursery represents a unique collection of San Joaquin Valley native species, it also served as a valuable setting for outreach activities.

We successfully cultivated and harvested seed from 49 species (29 annuals, 20 perennials) during two or more growing seasons (Appendix A). Based on our success with cultivating these species, we recommend them for further seed production efforts in the Tranquillity area. For the species that we were less successful in cultivating, we do not recommend against utilizing them in future seed production efforts. Our limited success with cultivating them could be attributed to factors such as low initial seed viability, decrease in seed viability while in storage, or limited seed supply, rather than any inherent characteristics of the species.

Though many species appeared to be well adapted to the nursery site conditions, we are cautious in recommending species for use in local restoration activities based on their performance at the nursery. In several instances, species that performed well in the nursery (e.g., *Frankenia salina, Heliotropium curassavicum, Lasthenia chrysantha)* did not perform well when utilized in local restoration trials. Though the site conditions (e.g., highly modified soil structure, elevated soil salinity, fine-textured soils, and low

[N] This weight estimate represents seed plus some inert matter (chaff) that could not be removed during seed processing, rather than pure live seed.

annual precipitation) at the nursery are similar to those of the retired agricultural lands, species in cultivation at the nursery benefited significantly from weed control and occasional irrigation. The growing conditions at a restoration site are more challenging (i.e., significantly less weed control, and little to no irrigation) than the conditions at the nursery, and they have limited the success of native species establishment (Ritter and Lair 2006).

Some plant species that are native to the San Joaquin Valley have become "weedy" in nature (e.g., *Atriplex argentea, Amsinckia menziesii, Cressa truxillensis, Datura wrightii, Eremocarpus setigerus, Helianthus annuus, Iva axillaris,* and *Malvella leprosa*), and they commonly grow in disturbed areas such as road margins, vacant lots, and fallowed agricultural fields, along with non-native weedy species. Based on our experience at the nursery and in local restoration trials, we do not recommend these species for use in the restoration of native plant communities in the San Joaquin Valley, due to their aggressive nature and tendency to outcompete other native plant species.

Challenges Encountered

The nursery site and surrounding retired agricultural lands are dominated by non-native weedy species. The weeds at the nursery would germinate so densely and grow so aggressively that weed control was a necessary aspect of nursery operations and management. We controlled weed growth at the nursery through a combination of mechanical (e.g., tilling, hand-pulling, flaming) and chemical (e.g., pre- and post-emergent herbicides) methods.

The nursery site has a semi-arid climate, with average annual rainfall of 22.03 cm (8.67 in). However, precipitation is highly variable both spatially and temporally, with pronounced differences in both year-to-year and within-year precipitation. Such minimal precipitation was received during some growing seasons that in the absence of irrigation, there would have been almost no germination and growth of the planted natives. However, a significant drawback of irrigating the nursery was that weeds would germinate densely, necessitating weed control efforts. During growing seasons with above average precipitation, the seeded natives would respond favorably, but weeds at the nursery would grow so vigorously that in the absence of weed control, black mustard plants would reach heights of over 1.5 meters.

Herbivorous wildlife including black-tailed jackrabbits, desert cottontails, and deer mice regularly fed on nursery-grown native plants, reducing potential seed harvest. Nursery-grown plants were especially impacted by herbivores during periods of below average rainfall, when plant growth in the vicinity of the nursery was reduced. Planting susceptible species inside of fenced herbivore exclosures helped to greatly reduce browsing by rabbits. Though building an exclosure provided a solution for a relatively small population of nursery-grown plants, it would not likely be a practical approach for a large-scale seed production effort. It would also not likely be feasible to protect species from herbivory, with fenced exclosures, if they have been seeded at a restoration site.

False chinch bug infestations were a recurring problem at the nursery, and negatively affected plant health and survival. During the most severe infestations, false chinch bugs caused damage to almost every species growing at the nursery, native and non-native. Constant monitoring (i.e., weekly site visits) during the dry season was necessary to detect false chinch bug presence and initiate control measures before extensive damage occurred.

SUMMARY OF ACCOMPLISHMENTS

- Identified numerous areas of remnant native habitat within an 80-km radius of the nursery site that can provide a source of local ecotype seed for restoration efforts
- Submitted a manuscript for peer review that describes the scarcity of local native seed sources in the San Joaquin Valley
- Developed seed harvesting and seed processing methods for numerous species
- Maintained a database of all planting, seed harvesting, and seed processing activities
- Produced approximately 545 bulk kilograms of seed per growing season
- Identified a suite of San Joaquin Valley species that can be cultivated in a field setting for the purpose of seed production
- Submitted 42 seed lots (of 36 species) to the National Center for Genetic Resources Preservation, for long-term storage
- Compiled species profiles that describe our planting, seed harvesting, and seed processing methods, summarize our phenological observations, display numerous photos, and describe both the successes and the obstacles that we encountered during our propagation efforts
- Submitted photos of seed, seedling, and mature plant life stages to the CalPhotos database: http://calphotos.berkeley.edu/cgi/photographer_query?seq_num=1602

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APPENDIX A. NATIVE PLANT SPECIES DOCUMENTED DURING 2001-2007 FIELD SURVEYS

During field surveys conducted from 2001-2007, in areas of remnant upland habitat in the western San Joaquin Valley, we documented the occurrence of 158 native plant species. Botanical nomenclature follows the Jepson Online Interchange for California Floristics (University of California, Berkeley, 2008). Due to the absence of diagnostic characteristics (e.g., flowers, fruits) at the time of our surveys, we were unable to identify three of the taxa to the species level. We collected seed from 125 of the species; the 30 species for which we did not collect seed are marked with an asterisk. The 49 species that we successfully cultivated at the field nursery during a minimum of two growing seasons are marked in bold.

Species	Family	Common name	Life form
Achillea millefolium	Asteraceae	common yarrow	perennial herb
Achnatherum hymenoides	Poaceae	Indian ricegrass	perennial herb
Achyrachaena mollis	**Asteraceae**	**blow wives**	**annual herb**
Allenrolfea occidentalis	**Chenopodiaceae**	**iodinebush**	**shrub**
*Ambrosia acanthicarpa**	Asteraceae	annual burrweed	annual herb
Amsinckia menziesii	Boraginaceae	Menzie's fiddleneck	annual herb
Amsinckia vernicosa	**Boraginaceae**	**green fiddleneck**	**annual herb**
Arida carnosa	Asteraceae	shrubby alkali aster	shrub
Artemisia californica	Asteraceae	California sagebrush	shrub
*Artemisia douglasiana**	Asteraceae	mugwort	perennial herb
Artemisia tridentata	Asteraceae	common sagebrush	shrub
Asclepias fascicularis	**Apocynaceae**	**narrow-leaved milkweed**	**annual or perennial herb**
Astragalus asymmetricus	Fabaceae	San Joaquin milkvetch	perennial herb
Astragalus lentiginosus	**Fabaceae**	**freckled milk-vetch**	**annual or perennial herb**
Astragalus oxyphysus	**Fabaceae**	**Mt. Diablo milkvetch**	**sub-woody perennial**
*Atriplex argentea**	Chenopodiaceae	silverscale saltbush	annual or perennial herb
*Atriplex cordulata**	Chenopodiaceae	heartscale	annual herb
Atriplex coronata	**Chenopodiaceae**	**crownscale**	**annual herb**
Atriplex fruticulosa	Chenopodiaceae	valley saltbush	perennial herb
*Atriplex lentiformis**	Chenopodiaceae	big saltbush	shrub
Atriplex minuscula	Chenopodiaceae	lesser saltscale	annual herb
Atriplex phyllostegia	Chenopodiaceae	leafcover saltweed	annual herb
Atriplex polycarpa	**Chenopodiaceae**	**allscale saltbush**	**shrub**
Atriplex spinifera	**Chenopodiaceae**	**spinescale saltbush**	**shrub**
Atriplex subtilis	Chenopodiaceae	deltoid-bract saltbush	annual herb
Atriplex vallicola	**Chenopodiaceae**	**Lost Hills crownscale**	**annual herb**
Baccharis salicifolia	Asteraceae	mule-fat	shrub
Benitoa occidentalis	Asteraceae	western lessingia	annual herb
Blepharizonia plumosa	Asteraceae	big tarweed	annual herb
Blepharizonia plumosa	Asteraceae	big tarweed	annual herb
Brassicaceae sp.*	Brassicaceae		annual herb
*Bromus carinatus**	Poaceae	California brome	perennial herb
Calandrinia ciliata	Portulacaceae	redmaids	annual herb

Species	Family	Common name	Life form
*Calochortus clavatus**	Liliaceae	clubhair mariposa lily	perennial herb
Camissonia boothii	Onagraceae	Booth's evening-primrose	annual herb
*Camissonia campestris**	Onagraceae	field suncup	annual herb
Camissonia hirtella	Onagraceae	hairy sun-cups	annual herb
Camissonia strigulosa	Onagraceae	sandysoil suncup	annual herb
*Castilleja attenuata**	Scrophulariaceae	valley tassels	annual herb
Castilleja exserta	**Scrophulariaceae**	**purple owl's clover**	**annual herb**
*Castilleja foliolosa**	Scrophulariaceae	Texas Indian paintbrush	perennial herb
Ceanothus sp.*	Rhamnaceae		shrub
Centromadia fitchii	**Asteraceae**	**Fitch's spikeweed**	**annual herb**
Centromadia pungens	**Asteraceae**	**common spikeweed**	**annual herb**
Chaenactis glabriuscula	Asteraceae	yellow pincushion	annual herb
*Chaenactis xantiana**	Asteraceae	Xantus pincushion	annual herb
Chaenactis glabriuscula	Asteraceae	yellow pincushion	annual herb
*Chaenactis xantiana**	Asteraceae	Xantus pincushion	annual herb
Chamaesyce ocellata	Euphorbiaceae	Contura creek spurge	annual herb
Clarkia purpurea	**Onagraceae**	**purple clarkia**	**annual herb**
Clarkia tembloriensis	Onagraceae	Temblor Range clarkia	annual herb
*Clarkia unguiculata**	Onagraceae	elegant clarkia	annual herb
Claytonia perfoliata	Portulacaceae	miner's lettuce	annual herb
*Cordylanthus palmatus**	Scrophulariaceae	palmate-bracted bird's-beak	annual herb
Cressa truxillensis	Convolvulaceae	alkali weed	perennial herb
*Datura wrightii**	Solanaceae	jimsonweed	perennial herb
Daucus pusillus	**Apiaceae**	**American wild carrot**	**annual herb**
Deinandra kelloggii	**Asteraceae**	**Kellogg's tarweed**	**annual herb**
Delphinium gypsophilum	Ranunculaceae	Pinoche Creek larkspur	perennial herb
Delphinium gypsophilum	Ranunculaceae	Pinoche Creek larkspur	perennial herb
Deschampsia danthonioides	Poaceae	annual hairgrass	annual herb
Dichelostemma capitatum	Themidaceae	bluedicks	perennial herb
Distichlis spicata	Poaceae	saltgrass	perennial herb
Eastwoodia elegans	**Asteraceae**	**yellow mock aster**	**shrub**
Ephedra californica	Ephedraceae	California Ephedra	shrub
Epilobium brachycarpum	Onagraceae	tall Annual willowherb	annual herb
Eremalche parryi	**Malvaceae**	**Parry's mallow**	**annual herb**
Eremocarpus setigerus	Euphorbiaceae	doveweed	annual herb
Ericameria linearifolia	Asteraceae	narrowleaf goldenbush	shrub
Eriodictyon californicum	Boraginaceae	California yerba santa	shrub
Eriodictyon tomentosum	Boraginaceae	woolly yerba santa	shrub
Eriogonum angulosum	Polygonaceae	angled-stem buckwheat	annual herb
Eriogonum fasciculatum	**Polygonaceae**	**California buckwheat**	**shrub**
Eriogonum gracile	Polygonaceae	slender woolly buckwheat	annual herb
Eriogonum gracillimum	**Polygonaceae**	**slender-stemmed buckwheat**	**annual herb**
*Eriogonum inflatum**	Polygonaceae	desert trumpet	perennial herb
Eriogonum vestitum	Polygonaceae	Idria buckwheat	annual herb
Eschscholzia californica	Papaveraceae	California poppy	annual herb
Eucrypta chrysanthemifolia	Boraginaceae	spotted hideseed	annual herb

Species	Family	Common name	Life form
Frankenia salina	**Frankeniaceae**	**alkali heath**	**perennial herb**
Gilia tricolor	Polemoniaceae	bird's-eye gilia	annual herb
Grindelia camporum	**Asteraceae**	**gumplant**	**perennial herb**
Guillenia lasiophylla	**Brassicaceae**	**California mustard**	**annual herb**
Gutierrezia californica	**Asteraceae**	**California matchweed**	**perennial herb**
Helianthus annuus	Asteraceae	hairy-leaved sunflower	annual herb
Heliotropium curassavicum	**Boraginaceae**	**seaside heliotrope**	**perennial herb**
*Heteromeles arbutifolia**	Rosaceae	toyon	shrub
Heterotheca grandiflora	Asteraceae	telegraph weed	annual/perennial herb
Holocarpha obconica	**Asteraceae**	**San Joaquin tarweed**	**annual herb**
Holocarpha virgata	Asteraceae	pitgland tarweed	annual herb
Hordeum depressum	Poaceae	alkali barley	annual herb
Hutchinsia procumbens	Brassicaceae	prostrate Hutchinsia	annual herb
Isocoma acradenia	**Asteraceae**	**goldenbush**	**shrub**
Isomeris arborea	**Brassicaceae**	**bladderpod**	**shrub**
Iva axillaris	Asteraceae	povertyweed	perennial herb
Kochia californica	Chenopodiaceae	rusty molly	perennial herb
Lasthenia californica	Asteraceae	California goldfields	annual herb
Lasthenia chrysantha	**Asteraceae**	**alkali goldfields**	**annual herb**
Layia munzii	Asteraceae	Munz's tidytip	annual herb
Layia platyglossa	Asteraceae	common tidy-tips	annual herb
Lepidium dictyotum	**Brassicaceae**	**alkali pepperweed**	**annual herb**
Lepidium jaredii	Brassicaceae	Jared's pepperweed	annual herb
*Lepidium nitidum**	Brassicaceae	shining peppergrass	annual herb
*Lepidium virginicum**	Brassicaceae	Virginia pepperweed	annual/perennial herb
Lepidospartum squamatum	Asteraceae	California broomsage	shrub
Lessingia glandulifera	**Asteraceae**	**valley lessingia**	**annual herb**
Lomatium utriculatum	Apiaceae	bladder parsnip	perennial herb
*Lotus purshianus**	Fabaceae	Spanish Lotus	annual herb
Lotus scoparius	Fabaceae	deerweed	perennial herb
*Lotus wrangelianus**	Fabaceae	calf lotus	annual herb
Lupinus albifrons	Fabaceae	silver bush lupine	shrub
Lupinus bicolor	Fabaceae	bicolored lupine	annual/perennial herb
Lupinus microcarpus* var. *densiflorus	**Fabaceae**	**dense-flowered chick lupine**	**annual herb**
Lupinus stiversii	Fabaceae	harlequin lupine	annual herb
Lupinus succulentus	**Fabaceae**	**arroyo lupine**	**annual herb**
Madia elegans	**Asteraceae**	**common madia**	**annual herb**
Madia radiata	Asteraceae	golden madia	annual herb
Malacothamnus aboriginum	Malvaceae	gray bushmallow	shrub
Malacothrix coulteri	**Asteraceae**	**snake's head**	**annual herb**
Malacothrix floccifera	Asteraceae	woolly dandelion	annual herb
*Malvella leprosa**	Malvaceae	alkali mallow	perennial herb
Mentzelia affinis	Loasaceae	yellow blazing star	annual herb
Mentzelia laevicaulis	**Loasaceae**	**smooth-stem blazing star**	**perennial herb**
Microseris sp.*	Asteraceae		
*Monolepis nuttalliana**	Chenopodiaceae	Nuttall's povertyweed	annual herb

Species	Family	Common name	Life form
Monolopia lanceolata	Asteraceae	common monolopia	annual herb
Monolopia major	Asteraceae	cupped monolopia	annual herb
Monolopia stricta	**Asteraceae**	**Crum's monolopia**	**annual herb**
*Muilla maritima**	Themidaceae	common muilla	perennial herb
Nassella cernua	Poaceae	nodding needlegrass	perennial herb
Nicotiana attenuata	Solanaceae	coyote tobacco	annual herb
Nitrophila occidentalis	Chenopodiaceae	boraxweed	perennial herb
Oenothera deltoides	**Onagraceae**	**desert lantern**	**annual herb**
Oenothera elata	Onagraceae	Hooker's evening primrose	biennial/perennial herb
*Pectocarya penicillata**	Boraginaceae	winged combseed	annual herb
Phacelia ciliata	**Boraginaceae**	**Great Valley phacelia**	**annual herb**
Phacelia tanacetifolia	**Boraginaceae**	**tansy-leafed phacelia**	**annual herb**
*Pholistoma membranaceum**	Boraginaceae	white fiesta flower	annual herb
Plagiobothrys nothofulvus	Boraginaceae	rusty popcornflower	annual herb
Plantago ovata	Plantaginaceae	woolly Plantain	annual herb
Platystemon californicus	Papaveraceae	creamcups	annual herb
Poa secunda	**Poaceae**	**one-sided blue grass**	**perennial herb**
Salicornia subterminalis	Chenopodiaceae	Parish's glasswort	perennial herb
Salvia columbariae	**Lamiaceae**	**chia**	**annual herb**
Salvia mellifera	Lamiaceae	black sage	shrub
Sambucus mexicana	Adoxaceae	blue elderberry	tree or shrub
Sesuvium verrucosum	**Aizoaceae**	**western sea-purslane**	**perennial herb**
*Solanum umbelliferum**	Solanaceae	bluewitch nightshade	shrub
Spergularia atrosperma	Caryophyllaceae	blackseed sandspurry	annual herb
Spergularia macrotheca	Caryophyllaceae	sticky sand-spurry	perennial herb
Spergularia marina	Caryophyllaceae	salt marsh sand spurrey	annual herb
Sporobolus airoides	**Poaceae**	**alkali sacaton**	**perennial herb**
Stachys pycnantha	Lamiaceae	shortspike hedgenettle	perennial herb
Stephanomeria pauciflora	**Asteraceae**	**brownplume wirelettuce**	**perennial herb**
Stephanomeria virgata	Asteraceae	tall Stephanomeria	annual herb
Suaeda nigra	**Chenopodiaceae**	**bush seepweed**	**sub-woody perennial**
Trichostema lanceolatum	**Lamiaceae**	**vinegarweed**	**annual herb**
Trichostema ovatum	**Lamiaceae**	**San Joaquin bluecurls**	**annual herb**
Uropappus lindleyi	Asteraceae	silver puffs	annual herb
Vulpia microstachys	Poaceae	small fescue	annual herb
Wislizenia refracta	**Brassicaceae**	**jackass clover**	**annual/perennial herb**
*Xanthium strumarium**	Asteraceae	cocklebur	annual herb

APPENDIX B. BIRD SPECIES OBSERVED AT THE NATIVE PLANT NURSERY NEAR TRANQUILLITY, CA.

All of the observations were incidental; focused avian surveys were not conducted at the nursery.

Common Name	**Scientific Name**
American crow	*Corvus brachyrhynchos*
American kestrel	*Falco sparverius*
Anna’s hummingbird	*Calypte anna*
Brewer’s blackbird	*Euphagus cyanocephalus*
Burrowing owl	*Athene cunicularia*
Ferruginous hawk	*Buteo regalis*
Horned lark	*Eremophila alpestris*
Killdeer	*Charadrius vociferus*
Loggerhead shrike	*Lanius ludovicianus*
Northern harrier	*Circus cyaneus*
Prairie falcon	*Falco mexicanus*
Red-tailed hawk	*Buteo jamaicensis*
Red-winged blackbird	*Agelaius phoeniceus*
Sandhill crane	*Grus canadensis*
Savannah sparrow	*Passerculus sandwichensis*
Says phoebe	*Sayornis saya*
Swainson’s hawk	*Buteo swainsoni*
Tree swallow	*Tachycineta bicolor*
Turkey vulture	*Cathartes aura*
Western kingbird	*Tyrannus verticalis*
Western meadowlark	*Sturnella neglecta*