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Seed Collection and Germination Strategies for Common Wetland and Coastal Sage Scrub Species in Southern California

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Abstract.—There is a need for a consolidated source of information on native vegetation seed collection and germination strategies in southern California. Published literature on these methods is often experimental, species-specific, and widely scattered throughout online and print media. Planting and restoration strategies may need to be site-specific; however, similar methodological approaches are often utilized allowing for the development of general strategies for seed collection, storage, and germination methods. A better understanding of species-specific seed attributes and growth processes will help restoration ecologists collect high-quality, viable seed, thereby increasing the potential success of the restored vegetation community by reducing plant mortality, project costs, and effort. This paper synthesizes seed collection and germination strategies for native vegetation common to southern California estuarine wetland, coastal dune, and coastal sage scrub systems.

Current estimates affirm that over 70% of coastal wetlands in the Southern California Bight have been lost since the 1800's, with estimates increasing to over 95% for highly urbanized areas, such as Los Angeles County (Stein et al. 2014). The magnitude of these losses and the continued degradation of coastal wetland systems, and adjacent upland and coastal sage scrub habitats, threatens the ecological integrity and sustainability of these habitat types and their watersheds. To address these issues, a number of restoration and mitigation projects aimed at restoring lost ecosystem services, increasing biodiversity, boosting resilience, and in the case of mitigation, creating new wetland habitat, are currently in the planning process in southern California (Noss 2000, Zedler 2000). The majority of wetland restoration or mitigation projects develop a site-specific framework of protocols and management strategies outlining a planting and re-vegetation strategy.

Planting strategies designed to establish self-sustaining plant communities identify both the species to be included in the restoration and the source of plant material (i.e. nursery stock or local seeds) (Zedler 2001). Restoration plant palettes should be designed to mimic reference or historic site diversity and be composed of an appropriately broad range of species (Zedler 2001, Johnston et al. 2012). Because of their unique location in the landscape as the connecting habitat between marine, terrestrial, and freshwater ecosystems, coastal wetland complexes naturally support a variety of salt marsh, brackish, and freshwater plant species (Lichvar et al. 2014). Species from each of these habitat types should be incorporated into an appropriate plant palette. Evidence also suggests that the wetland-upland ecotone should be considered an extension of wetland habitat for conservation and restoration purposes (James and Zedler 2000, Wasson and Woolfolk 2011). Thus, coastal sage scrub, dune, and transitional species commonly found in the wetland-upland ecotone should be considered in wetland restoration re-vegetation strategies.

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Once a restoration plant palette has been developed, species-specific plant material (e.g. seeds and seedlings) acquisition and propagation methods must be determined. While plant material can be obtained from local nurseries, collection and propagation of native seed from local sites is considered the most cost-effective and ecologically-sound method of sourcing germplasm for restoration and mitigation projects (Zedler 2001, Broadhurst et al. 2008). Site-specific or nearest neighbor collections are preferred to distant collections and use of nursery stock, as locally-collected individuals are better adapted to community environmental conditions, maintain local genetic integrity, ensure persistence of local eco-types, prevent unintended gene flow, may improve the long-term sustainability of the site, and may enrich the diversity of the wetland plant community (Guerrant 1996, Montalvo et al. 1997, Bowler 2000, Zedler 2001, Mitsch and Gosselink 2010, Vander Mijnsbrugge et al. 2010). Non-local genotypes may be maladapted to local site conditions, leading to improper establishment, or negative impacts to plant and animal communities through competition or species hybridization (Bischoff et al. 2006, Vander Mijnsbrugge et al. 2010). The retention of local eco-types and genetic information is gaining importance in the field of restoration biology, reflected by the recent inclusion of required onsite and/or near neighbor collections by regulatory agencies overseeing restoration and mitigation work (Bowler 2000). It is also important to note that making collections in many nature preserves requires permits and/or express permission from the regulating agency.

A number of techniques exist to propagate plant material for wetland, coastal sage scrub, and dune species. Seeds are often the primary means of reintroducing native plant species to restoration sites in a number of habitat types (Montalvo et al. 2002, Merritt and Dixon 2011). Restoration sites may be seeded using a variety of techniques (e.g. broadcast seeding, drilling, imprinting, or hydroseeding) or collected, cultivated in a greenhouse, and transplanted to the site (Bowler 2000, Montalvo et al. 2002, Merritt and Dixon 2011). Simple seeding experiments generally are performed with limited success, especially at lower elevations or within tidal wetland habitats, as seeds often fail to germinate or float away with rising tides (Broome et al. 1988, Zedler 2001). Techniques like hydroseeding that involve mixing seed with water and either mulch, soil, or organic matter prior to application, tend to work well for many wetland and coastal sage scrub species [e.g. *Salvia mellifera* (black sage) and *Eriogonum fasciculatum* (California buckwheat)] and may enhance seedling establishment (Zedler 2001, Montalvo et al. 2002, Montalvo and Beyers 2010).

Transplanting greenhouse-grown seedlings is an effective re-vegetation strategy that may increase the potential establishment success when compared to direct seeding for some species. In one experiment, survivorship of 2-4 month old marsh seedling transplants was over 95% for all but one treatment, much higher than the success rate of direct seeding (Zedler 2001). Seedlings of a variety of halophytic marsh species including *Suaeda esteroa*, estuary seablite, and *Salicornia bigelovii*, dwarf pickleweed, and a variety of coastal sage scrub species like *Atriplex canescens*, four-wing salt bush, have been successfully grown in greenhouses and transplanted for restoration purposes (Zedler 2001, Francis 2009). While use of seeds and seedlings has been successful for many species [e.g. *Achillea millefolium* (common yarrow) and *Astragalus tener* var. *titi* (coastal dunes milk vetch)], effective propagation techniques are species-specific and other species, like *Batis maritime*, saltwort, do not readily grow from seed and require use of alternate methods (Zedler 2001).

Other common approaches to generate plant stock include use of cuttings, root division, and direct transplantation of seedlings or mature plants to the site of interest (Zedler 2001, Baskin and Baskin 2014). Direct transplantation of coastal sage scrub seedlings [e.g. *Artemisia californica* (California sagebrush), *Salvia mellifera, Encelia californica* (California brittlebush), and *Eriogonum fasciculatum*] and mature plants salvaged from donor sites have been used with

great success in mitigation efforts (Bowler et al. 1994, Bowler 2000). Similarly, use of transplants, sod, and small plugs of wetland soil, have been effective in introducing a number of wetland species, including *Spartina foliosa*, California cordgrass, to sites (Trnka 1998, Zedler 2001, Mitsch and Gosselink 2010). Use of cuttings is documented to work well for other species; cuttings of *Salicornia pacifica*, common pickleweed, for example, have been successfully propagated by Tree of Life Nursery in San Juan Capistrano, California. While each of these approaches has merit, the discussion in the remainder of this paper (and the accompanying appendices) focuses on the use of seeds and greenhouse-grown seedlings to target a data gap in peer-reviewed literature.

While general techniques for successfully establishing common wetland and coastal sage scrub species described in the preceding paragraphs are understood (Broome et al. 1988), the field of restoration biology is still developing and could benefit greatly from additional research. More specifically, the field could benefit from research regarding species-specific collection and propagation techniques because cultivation and planting strategies are often species-specific, highly variable, proprietary, or experimental. Information for many native species of interest does not exist, or is not publically available, forcing restoration managers and ecologists to rely on general information about the genus or costly and time-intensive exploratory studies (Dreesen and Harrington 1997). Publically available sources are scattered throughout a variety of peer-reviewed and non-peer-reviewed resources. With over a dozen wetlands in southern California considered candidates for large-scale wetland restoration projects, a compilation of literature summarizing re-vegetation strategies for the region is needed (SCCWRP 2001). This paper synthesizes basic seed characteristics, as well as collection and germination strategies for vegetation species common to estuarine wetland and adjacent upland habitat types, specifically coastal salt marsh and coastal sage scrub habitats in southern California.

Materials and Methods

Common seed collection, germination, and propagation techniques are described in the text of this paper. General species information (e.g. scientific name, common name, and habitat type) is included in Appendix I. Detailed species-specific data and recommendations are included in Appendix II, which summarizes available information for 66 native plant species commonly used in southern California coastal restoration projects. Species-specific details were compiled using available literature. While the majority is derived from peer-reviewed publications, some non-peer reviewed literature was included to fill data gaps in published information. As many data gaps exist, and gray literature was used throughout the article text and the accompanying appendices, the authors have chosen not to distinguish gray literature with footnotes and this was approved by the editors. Instead, these sources are listed, with all peer-reviewed sources, in the Literature Cited section. In instances where duplicate information was identified, the source with the most extensive experimental results was cited. Field observations from the Ballona Wetland Ecological Reserve, Los Angeles, CA, were used to determine some seed collection windows. Appendix II is not intended to be comprehensive; instead, it focuses on common coastal wetland and upland species in southern California for which there was available literature. Priority was given to information specific to southern California coastal habitats, but species-specific information from other geographic areas was included as needed for completeness. Implementation of specific methods may vary slightly by site or project. A number of resources exist that provide general species profiles of the plants described in Appendices I and II. Three websites in particular, S&S Seeds (http://www.ssseeds.com), the Theodore Payne Foundation (http://theodorepayne.org), and Tree of Life Nursery

Table 1. Suggested field, lab, and greenhouse equipment for seed collection, cleaning, and germination.

Field equipment	Lab/greenhouse equipment
Collecting bins/paper bags	Sieves of varying sizes (500 um–2 mm)
Ziploc bags	Paper envelopes
Pens/pencils/markers	Freezer
Paper clips/binder clips	Refrigerator
Field data collection sheet	Oven
Clipboard	Growing medium*
Background documentation (recommended)	Sterile petri dishes*
Mesh screens/sieves^{+}	Hydrogen peroxide (H_2O_2)*
Tarp(s)$^{+}$	Nail clippers*
Gloves^{+}	Mothballs*
Gardening shears^{+}	Ethylene (ethephon or sliced apple)*
Jepson manual^{+}	

* = species specific
$^{+}$ = optional

(http://www.californianativeplants.com), are recommended for supplemental information relating to life history and planting recommendations.

Materials

Equipment and supplies needed for seed collection, cleaning, and germination are highly variable based on the specific vegetation species. Recommended field, laboratory, and greenhouse equipment are listed in Table 1. In addition to the field equipment listed, available background information (e.g. reports, vegetation maps, taxonomic keys) should be brought into the field to aid correct taxonomic identification of species.

Seed Collection

Seeds should be collected within seed zones, geographic zones in which genetic exchange naturally occurs. Practitioners are advised to use life history traits, landscape context, and available genetic studies to correctly determine seed zones (Krauss and He 2006). It is important to note that due to extensive urbanization and fragmentation in southern California, historic areas of seed exchange have been diminished. In addition to considering provenance of seeds, care should be taken to ensure that seed collections contain sufficient genetic diversity (Vander Mijnsbrugge et al. 2010) as diversity safeguards against disease, environmental fluctuations, and inbreeding depressions (Smith et al. 2007). To maximize the range of genetic diversity represented in the collection, seed should be collected from 10-50 individuals per population (Lippitt et al. 1994, Vander Mijnsbrugge et al. 2010). Local adaptations and site-specific variability should also be taken into consideration, but site-specific recommendations are outside the scope of this product. When collecting seeds, less intense and more frequent seed harvests are preferable to infrequent and intense harvests (Wall 2009). Negative impacts on the seed source population must be considered (Krauss and He 2006). A general safe harvesting recommendation is to take no more than 5% of seed from a given species and geographic area (Zedler 2001).

Once plant identity has been confirmed, carefully examine the seeds to assess maturity. Avoid collection of immature seed, as premature collection may result in low seed viability (Bonner and Karrfalt 2008, Baskin and Baskin 2014). In general, it is good practice to begin collecting seeds around the time that natural dispersal begins (Baskin and Baskin 2014). Seeds are considered ripe if seed capsules are dry and tan or brown in color, rather than yellow or green (Lippitt

Table 2. General seed collection method based on plant anatomy (Wall 2009).

Fruit/seed type	Collection techniques
Moist fruits/berries	Hand-pluck fruits.
Dehiscent species	Collect entire inflorescences prior to dispersal. Alternatively, secure cloth bags around ripening stalks to capture dispersed seed.
Inflorescences	Strip inflorescences.
Seed heads	Shake ripe seed directly onto a tarp or collection bag underneath the target plant.
Seed clusters	Remove entire seed cluster from plant.

et al. 1994, Bonner and Karrfalt 2008, Baskin and Baskin 2014). Frequent visits to collection sites are suggested to repeatedly assess seed stage within the recommended collection time window. For species with insufficient published seed collection data or information, e.g. *Artemisia douglasiana*, detailed field notes are essential to pinpoint the ideal collection window and successfully collect seeds.

Once the seeds of target species are deemed ripe, the collection process can begin. Collection/isolation of seed varies based on plant anatomy. Observe the plant and note if the species has berries or dry fruits, dehiscent or indehiscent seeds, and note if seeds are in seed heads or seed clusters as collection methods vary for each category (Table 2). Additionally, if a species is known to be dioecious [e.g. *Croton californicus* (California croton)*, Baccharis* spp.*, Salix* spp.], care should be taken to ensure that sufficient seed quantities are collected from both male and female plants (Clarke et al. 2007). Vouchering specimens from collected seeds is a good practice and should be considered during the planning phase.

Seed Cleaning

Seed cleaning removes floral parts, seed coats, pods, fleshy fruit material, and other debris from seeds (Jorgensen and Stevens 2004). Machinery, including aspirators, hammermills, fanning mills, and blowers, exists to aid large-scale seed enterprises. Hammermills, fanning mills, and blowers help isolate seed and remove chaff and floral parts (Shaw 1975, Jorgensen and Stevens 2004). Although seed cleaning machinery is useful, cleaning for small-scale projects can be efficiently performed by hand (Bonner and Karrfalt 2008). To isolate seeds and remove excess chaff, remove seeds from branches and large floral parts. Then, rub remaining seeds and floral parts over a sieve. Once seeds are isolated from chaff, only retain seeds that look healthy and ripe (i.e. dark brown/tan in color, fully-formed). For some species, chaff does not present a huge problem, and it may be more efficient to seed with some chaff. Discard seeds that appear sickly or deformed. If the seed is contained in a capsule, gently crush the capsule by hand or with a rolling pin. Removal of woody capsules, as seen in *Abronia* spp., may also be aided with the use of generic nail clippers (P.M. Drennan, personal communication).

Seed Storage

For the greatest germination yield, storage time should be minimized, and use of newer seeds should be prioritized. While native seed longevity varies by genus and species, a number of seeds are known to be short-lived. For example, seeds of *Lycium californicum,* California box-thorn, are viable for up to one year at most. While seeds of other species [e.g. *Atriplex* spp.*, Astragalus* spp., and *Lupinus chamissonis* (dune bush lupine)] will remain viable for much longer (i.e. 4-10 years), the germination rate of seeds in long-term storage will likely decline over time. In addition to reducing germination rate, long-term storage will often induce seed coat or embryo dormancy, and stored seeds may need to be treated prior to planting. For example, the hard seed coat of *Astragalus tener* var. *titi* seeds may require scarification,

or mechanical scraping with sandpaper, a file, or a knife, to initiate germination if stored for an extended period of time (Baskin and Baskin 2014, USFWS n.d.)

The longevity of certain seeds can be increased if best management practices for storage are followed for the species and/or general seed storage procedures are applied. Most dry seeds should be stored at low temperatures, 10-15.6°C (50-60°F), and low humidity, less than 40% relative humidity (Jorgensen and Stevens 2004, Recon Native Plants Inc. 2015). Substandard storage in conditions with fluctuating temperatures or high humidity may result in significant seed loss (Merritt and Dixon 2011).

Germination Considerations

Successful propagation of southern California coastal plant species requires a thorough understanding of seed germination ecology. Seed germination is dependent upon a number of evolutionary and ecological factors which generally must be observed, and often replicated, in the laboratory or greenhouse to successfully grow propagules. These, often species-specific, factors include, but are not limited to: germination timing/seasonality, environmental conditions, such as temperature, soil texture, soil moisture, soil salinity, light availability, presence of smoke, and seed age, and dormancy state, both at the time of maturation and dispersal (Baskin and Baskin 2014).

Germination Timing

Seeds are adapted to germinate under favorable environmental conditions (Deberry and Perry 2000). An understanding of natural germination timing is helpful in determining the environmental conditions that best promote germination of a particular species in the greenhouse or laboratory. This is particularly true, as in both the greenhouse and laboratory, environmental conditions can be manipulated to mimic natural seasonal variation. Temperature, moisture, and light are generally controlled for this purpose (see 'Temperature' and 'Light' sections below) (Noe and Zedler 2001).

Temperature

Understanding germination timing under natural conditions will often indicate what range of temperatures best promote germination. Temperature influences germination directly through regulation of enzymatic reactions, or indirectly by controlling the synthesis of hormones that alter seed dormancy. While temperature is an important determinant in the regulation of both germination and dormancy, response to temperature in freshwater wetland species seems to be dependent on habitat, not phylogenetic relatedness. Temperature interplays with other environmental conditions to promote germination (Brändel 2006). Further, the germination rate of certain species is enhanced with simulated temperature fluctuations, rather than constant temperatures. While response to fluctuating temperatures depends both on specific species and habitat, a few generalities exist. Both small-seeded species and forbs tend to respond well to fluctuating temperatures while larger-seeded and graminoid species do not show as marked a preference for temperature fluctuations (Liu et al. 2013).

Soil Texture

To grow seedlings, clean, viable seeds should be planted in mixtures of sand, top soil, and peat moss or vermiculite (Broome et al. 1988). To achieve the greatest germination rate, the exact composition of the mixture should be tailored to the individual plant species of interest. Life history and preferred habitat of the species should be considered when determining optimal

soil conditions. For instance, *Abronia maritima,* which naturally occurs on sandy dunes, should be sown in soil consisting largely of sand, or other coarse grains.

Soil Moisture

Soil moisture must also be considered when sowing seeds (Noe and Zedler 2000, Noe and Zedler 2001). Most mature seeds must imbibe in the early stages of germination to activate enzymes (Deberry and Perry 2000). After seeds imbibe, sufficient, and relatively constant soil moisture is needed to ensure proper germination (Bonner and Karrfalt 2008). Most species in southern California salt marsh systems germinate well in moist soil at low salinity (Zedler 2001). Experiments suggest that *Distichlis spicata* grows best with a fluctuating inundation regime, where inundation was varied over time, but the soil surface was never completely dry (Elsey-Quirk et al. 2009). Germination of other high marsh plant species is highest with 41-51% soil moisture (Zedler 2001).

It is important to note that while seeds of wetland species are adapted to wet conditions with limited oxygen, coastal sage scrub and upland transition species are more sensitive to inundation. For these species, excessive exposure to water can be problematic, causing seeds to become waterlogged (Fenner 1992, Deberry and Perry 2000). Following germination, water regimes, that specify both the quantity and frequency of water application, both in the greenhouse and in natural environments, may influence growth rates and should be carefully considered.

Soil Salinity

Another major factor that influences germination is soil salinity (Noe and Zedler 2000, Noe and Zedler 2001). Certain halophytic species, like *Salicornia bigelovii,* germinate to higher percentages under somewhat saline conditions (0.05-0.09 M). In general, although halophytes are salt-tolerant, high percentages of halophyte seeds will germinate in distilled water. Results of salinity experiments suggest that seeds will often germinate to higher percentages in distilled water, as seeds tend to be sensitive to salt concentrations, and exposure to excessive salt can drastically decrease germination yields. Still, much variation exists in the germination of halophyte species in saline environments (Baskin and Baskin 2014).

Light

Light is another environmental factor that affects germination. Exposure to light is often required for germination to occur. Exposure to light has been documented to improve germination rates for certain species [e.g. *Eriogonum fasciculatum* (California buckwheat), *Baccharis salicifolia* (mule fat)] (Zedler 2001, Bonner and Karrfalt 2008). Still, exposure is not always sufficient to ensure the successful occurrence of germination mechanisms. Duration of exposure to light (i.e. day length or photoperiod) also plays an important role in seedling emergence and growth of southern California natives (Sprague 1944, Noe and Zedler 2000, Greiner and Köhl 2014). For instance, long-day conditions (16 hours of light for every 8 hours of darkness) are necessary to successfully culture *Oenothera* species (Greiner and Köhl 2014). Photoperiod may also influence other processes, such as flowering. *Melica imperfecta* and *Stipa lepida* have been shown to flower 10-20 weeks faster with constant light (i.e. 24-hour photoperiod) when compared to an 8-hour photoperiod (Ashby and Hellmers 1959).

Smoke Treatments

Southern California, like most regions with Mediterranean climates, is subject to frequent and intense wildfires, and certain species have adapted to be fire-tolerant (Keeley and

Fotheringham 1998, Crosti et al. 2006). Germination of fire-tolerant species is generally enhanced by exposure to fire or smoke (Crosti et al. 2006, Baskin and Baskin 2014). Smoke-stimulated germination, via exposure to liquid or aerosol components of smoke, may be useful for many coastal sage scrub species. For instances, exposure of *Salvia mellifera* seeds to smoke or other components of fire, like charred wood or potassium nitrate (KNO_3), may help stimulate germination (Montalvo and Beyers 2010).

Other Considerations

In some instances, information regarding the necessary conditions or procedures to promote germination is not readily available for a particular species. In such situations, it is advisable to consult local experts that may have species-specific knowledge. Alternatively, simple tests or experiments manipulating a variety of the environmental factors discussed above may be performed.

Germination Testing

If a seed lot requires germination studies, it is preferable that they are conducted shortly after seed collection, within 7-10 days, to ensure seeds are viable and have not entered seed dormancy. Germination trials can test outcomes of various pre-treatments and/or growing conditions. They are often also used to express the quality of a seed lot (Lippitt et al. 1994). The results of germination trials are typically reported as percentage germination or germination rates. Percentage germination is the percentage of seeds that germinate under the specified set of conditions. Comparing germination rates of a variety of treatments allows easy determination of the most effective combination of germination conditions.

While germination rates are useful, the industry will often use other terms to describe the percentage of seed that will germinate under a given set of conditions. Pure Live Seed (PLS) is a common way to express viability. PLS is calculated by multiplying the percentage of pure seed by the percentage of total viable seed and dividing the product by one hundred (S&S n.d., Showers 2010). Other measures include specification by purity, bulk pounds, or PLS pounds (S&S).

Dormancy Considerations

Seeds for a number of wetland plants are known to be dormant. In these species, seed dormancy must be broken to promote growth and germination (Baskin and Baskin 2014). The process is generally moisture and temperature dependent, but varies both with species and type of dormancy. Three types of dormancy should be considered: physical (or seed coat) dormancy, internal dormancy, and morphophysiological dormancy. Seeds with physical dormancy have seed coats or other structures that are impermeable to water and/or oxygen (Lippitt et al. 1994, Baskin and Baskin 2014). This form of dormancy is generally broken by penetrating/opening the seed coat or specialized structure that excludes water or oxygen. This can be achieved through scarification, cold and warm stratification, or exposure to dry heat, charate, fire, acid, and light. Internal dormancy, caused by a physiological mechanism that inhibits germination, is generally broken through use of warm and/or cold stratification. Morphophysiological dormancy is similar to physiological, but seeds with this type of dormancy also have an underdeveloped embryo. A variety of methods can be used to break morphophysiological dormancy, including: scarification, submersion in hot water [82-93°C (180-200°F)], treatment with dry heat, exposure to fire, acid, mulch treatment, cold stratification, warm stratification, and exposure to light (Emery 1988, McClure 1997, Baskin and Baskin 2014). Common dormancy breaking methods are detailed in Table 3).

Table 3. Detailed methodology for techniques commonly employed to break seed dormancy.

Method	General description
Scarification	Mechanically scar seed coat with sandpaper, knives, files, or clippers. Alternatively soak seed in acid or hot water (Emery 1988, Lippitt 1994, Bonner and Karrfalt 2008).
Hot water treatment	Place seeds into hot water (180-200°F) and leave them to soak as the water cools (Emery 1988, Bonner and Karrfalt 2008).
Dry heat	Expose seeds to 180-212°F heat. Use of an incubator, rather than oven, preferred (Emery 1988).
Charate	Expose seeds to ash from burned plants. This may neutralize germination inhibitors in species that naturally germinate when exposed to fire (Emery 1988, Baskin and Baskin 2014).
Fire	Expose seeds to direct flame. This may be effective as a means to spur germination in species that naturally germinate when exposed to fire (Baskin and Baskin 2014).
Water	Soak seeds in water to leach out water-soluble inhibitors (Baskin and Baskin 2014).
Cold stratification	Store seeds in cold conditions (35-41°F) for 1-3 months to simulate winter conditions (Bonner and Karrfalt 2008, Elsey-Quirk et al. 2009, Baskin and Baskin 2014).
Warm stratification	Store seeds in warm conditions (65°F or higher) (Baskin and Baskin 2014).

Unfortunately, as indicated by the variety of conditions listed above, there is not one prevailing standardized method to break seed dormancy. Again, methods vary based on the life history of the species. Species-specific life histories, available at the growers' websites listed above, can be a good indicator of the required conditions for that species. For example, species that typically germinate in early spring after a cold and/or rainy winter, such as *Platanus racemosa,* western sycamore, often require cold, moist stratification mimicking natural wintering to break dormancy. Other species, such as *Acmispon glaber*, common deerweed, require heat treatment to break dormancy which also correspond with the life history of that species; *A. glaber* does particularly well after wildfire events. However, treating seeds to break dormancy is not enough to guarantee germination. Germination requirements must also be considered. Methods and information should be supplemented by experimentation when necessary.

Mycorrhizae

Establishing functional ecosystems also requires consideration of subsurface components of the system. Many plants have symbiotic relationships with soil-inhabiting microorganisms, yielding root systems that are more effective at extracting water and nutrients from the rhizosphere (i.e. soil profiles influenced by root secretions and soil fauna). The fungus-root system is called mycorrhizae (Gerdemann 1968, Tree of Life Nursery n.d.). Research has shown that mycorrhizae can increase plant growth and are essential in successfully establishing vegetation during restoration and mitigation projects (Reeves et al. 1979, Allen and Allen 1980, Cooke and Lefor 1990). If planting areas are severely disturbed and lack a healthy rhizosphere, steps should be taken to ensure presence of mycorrhizae, or to increase the potential for natural development. As the presence of mycorrhizae is important in establishing many wetland and coastal sage scrub species, container plants are often inoculated prior to planting (Cooke and Lefor 1990, Bowler 2000). Seedlings can be inoculated with a spore suspension or via introduction of small amounts of collected soil from sites with a healthy rhizosphere to a sterile soil (van de Voorde et al. 2012). Starter-cultures are also available commercially.

Discussion

Southern California has lost a significant portion of its coastal ecosystems due to urban development, agriculture, invasive species, and in the case of coastal estuarine wetlands, severely

modified hydrology resulting from both channelization and deposition of fill sediments (Westman 1981). Loss of these ecosystems is concerning because they provide valuable ecosystem services including supporting important fisheries, filtering water, sequestering carbon, and providing habitat for a diversity of plant and animal life, including a number of threatened and endangered species. Wetlands are buffered by transition habitats, and many wetland-associated species also require adjacent upland habitat areas to breed, roost, or to have the highest likelihood of survival. Plant species in Southern California also display a high degree of endemism and the Southern California coast is considered a global biodiversity hotspot (SCCWRP 2001).

Although wetlands in southern California have attained protected status and efforts are being made to restore degraded habitats throughout the Southern California Bight, the increasing human populations along the California coast will continue to impact these coastal ecosystems (Callaway and Zedler 2004). To preserve the spectrum of ecosystem services coastal wetlands and their adjacent upland habitats provide, managers throughout the southern California region need to work collectively to conserve remaining high quality coastal wetland habitat and to restore lower quality, degraded habitats.

Clearly, there is a significant and ongoing regional need for restoration projects to recover lost habitats and preserve the unique communities. Increased reliance on ecological restoration of vegetation assemblages emphasizes the need for sound, scientifically-tested techniques to ensure the successful reestablishment of plant communities. While this document is not comprehensive, and there is still a practical need for land managers to compile detailed site information and evaluate site-specific experiments prior to implementing a restoration scheme, this literature review compiles available seed collection and germination information for the southern California region and provides an initial assessment of published methods for common wetland, dune, and coastal scrub plants. Many unknowns remain in restoration ecology theory, and understanding of the most effective restoration practices remains incomplete. Knowledge gaps regarding the collection and germination requirements of integral species [e.g. *Hazardia squarrosa* (saw-toothed goldenbush)] and other species with limited research available [e.g. *Elymus triticoides* (creeping wild rye)] precluded their inclusion in this review. Planners are encouraged to conduct regular site monitoring and employ adaptive management strategies. In this way, progress can be evaluated and unexpected outcomes and shortcomings can be corrected.

Still, there is a regional need for additional research regarding seed phenology and maturation of southern California species. Although a number of wetland, dune, and coastal sage scrub restorations are planned in southern California, information regarding seed collection and germination for many naturally occurring species is not readily available. Therefore, the field of plant community restoration could benefit greatly from additional research regarding seed phenology and maturation, both in the form of species-specific experimentation and literature and broader-scale, regional or ecosystem-based reviews. Filling in existing knowledge gaps and developing a better understanding of seed processes will help restoration ecologists collect high quality, viable seed, thereby increasing the potential success of the restored vegetation community by reducing seed/seedling mortality, restoration cost and human effort.

Perhaps more importantly, the region could benefit from the development of a coordinated network of restoration ecologists. Compilation of this literature review suggests that information regarding the restoration of wetland plant communities is abundant, but it is dispersed, produced by various sources, and often proprietary. Intentional withholding of information by nurseries or private environmental consulting firms inevitably leads to duplication of efforts by groups working in the southern California region and surely impacts both the overall quality of restored habitats and project efficiency. Engagement and cooperation of existing private industry groups

and public sector regulators with a vested interest in restoring coastal wetland plant communities would be a major victory and a tangible step forward for the threatened coastal ecosystems in the region.

While establishing vegetation in restored wetlands is a vital component to the overall restoration scheme, it is just a small part of the overall restoration process. Restoring wetland ecosystems is complex; plans must incorporate vegetation, hydrology, substrate, and marine and terrestrial animals. To fulfill restoration aims, well-informed, inter-disciplinary approaches that incorporate ecologists, engineers, managers, lawyers, and practitioners from other technical fields are needed (Zedler 2000, Kiehl 2010). Inter-disciplinary approaches will best foster creativity and progress knowledge and understanding in the field of restoration.

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Appendices

Appendix I. Species-specific habitat associations for wetland, coastal sage scrub, and upland transition species common in southern California. This table includes scientific and common names from Jepson eFlora (http://ucjeps.berkeley.edu/, accessed June 4, 2015). Habitat association information is derived from Jepson and further refined with information available from the Manual of California Vegetation (2nd edition), the S & S Seeds Plant Database (www.ssseeds.com/plant-database), and the species-specific literature cited in Appendix II (Baldwin et al. 2012, Sawyer et al. 2009, S&S Seeds, n.d.).

Scientific name	Common name	Low marsh	Mid marsh	High marsh	Salt pan	Low transition	High transition	Grass	Scrub	Fresh water	Salt tolerant
Abronia maritima	Red sand verbena						x				x
Abronia umbellata	Pink sand verbena						x				x
Achillea millefolium	Common yarrow						x	x			x
Acmispon glaber	Deer vetch						x	x	x		x
Ambrosia psilostachya	Western ragweed										
Artemisia californica	California sagebrush								x		
Artemisia douglasiana	Mugwort					x	x				x
Artemisia tridentata	Big sagebrush							x	x		x
Arthrocnemum subterminale	Parish's pickleweed	x	x								x
Astragalus pycnostachyus var. *lanosissimus*	Ventura marsh milk vetch		x	x	x	x					x
Astragalus tener var. *titi*	Coastal dunes milk vetch			x	x	x	x		x		x
Atriplex californica	California orach			x		x	x		x		x
Atriplex canescens	Fourwing saltbush								x		x
Atriplex lentiformis	Big saltbush								x		x
Atriplex prostrata	Fat-hen			x		x					x
Atriplex watsonii	Watson's saltbush			x		x	x				x
Baccharis pilularis	Coyote brush						x		x		
Baccharis salicifolia subs. *salicifolia*	Mule fat								x		
Baccharis sarothroides	Broom baccharis								x		x
Batis maritima	Saltwort		x	x	x	x					x
Cressa truxillensis	Alkali weed										
Croton californicus	California croton						x	x	x		x
Distichlis littoralis	Shore grass			x	x						x
Distichlis spicata	Salt grass		x	x		x					x
Encelia californica	California brittlebush							x	x		
Eriogonum fasciculatum	California buckwheat								x		
Frankenia salina	Alkali heath		x	x	x	x	x				x

Appendix I. Continued.

Scientific name	Common name	Low marsh	Mid marsh	High marsh	Salt pan	Low transition	High transition	Grass	Scrub	Fresh water	Salt tolerant
Grindelia camporum	Valley gum weed								x		x
Hazardia squarrosa	Saw-toothed goldenbush							x	x		x
Heteromeles arbutifolia	Toyon							x	x	x	
Hordeum brachyantherum	Meadow barley					x	x			x	x
Isocoma menziesii	Coastal goldenbush						x	x	x		x
Iva axillaris	Poverty weed										
Jaumea carnosa	Fleshy jaumea	x	x								x
Juncus acutus subs. *leopoldii*	Southwestern spiny rush										
Juncus bufonius	Toad rush			x	x	x					x
Limonium californicum	Western marsh-rosemary		x	x		x					x
Lupinus chamissonis	Dune bush lupine								x		
Lycium californicum	California box-thorn					x	x				x
Melica imperfecta	Little California melica							x	x		
Mimulus aurantiacus	Sticky monkey							x	x		
Oenothera elata	Hookers evening primrose							x			x
Peritoma arborea	Bladderpod								x		x
Phacelia ramosissima	Branching phacelia						x	x	x		x
Plantago erecta	Foothill plantain							x	x		x
Platanus racemosa	Western sycamore								x	x	
Populus fremontii subs. *fremontii*	Fremont cottonwood								x	x	
Potentilla anserina subs. *pacifica*	Pacific silverweed		x	x		x	x				x
Pseudognaphalium californicum	California cudweed										
Rosa californica	California wild rose						x	x	x		x
Salicornia bigelovii	Dwarf pickleweed			x	x						x
Salicornia pacifica	Common pickleweed	x	x								x
Salix exigua subs. exigua	Narrow-leaved willow									x	
Salix lasiolepis	Arroyo willow									x	
Salvia apiana	White sage								x		x
Salvia mellifera	Black sage								x		x
Schoenoplectus acutus var. *occidentalis*	Common tule									x	
Schoenoplectus californicus	Southern bulrush									x	x

Appendix I. Continued.

Scientific name	Common name	Low marsh	Mid marsh	High marsh	Salt pan	Low transition	High transition	Grass	Scrub	Fresh water	Salt tolerant
Spartina foliosa	California Cord grass	x									x
Stipa cernua	Nodding needle grass							x	x		
Stipa lepida	Foothill needle grass							x	x		
Suaeda esteroa	Estuary seablite		x	x							x
Suaeda nigra	Bush seepweed										x
Suaeda taxifolia	Woolly seablite										
Triglochin maritima	Common arrow-grass	x	x	x							x
Vulpia microstachys var. *microstachys*	Small fescue							x	x		x

Appendix II. Detailed, species-specific seed collection, seed germination, and seed storage information for wetland, coastal sage scrub, and upland transition species native to southern California. Information is sorted alphabetically by scientific name.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Abronia maritima (Drennan 2008, Baldwin et al. 2012)	May	Aug	Winged fruit 10-14 mm long. Fruit contains single-seeded achenes.	Plants seed throughout the year, majority of seed production occurs in late spring/summer. Removal of woody capsules aided with the use of generic nail clippers.	In the most successful trials, achenes removed from anthrocarp. Place achenes on filter paper in sterile petri dishes with ethephon or other 10-100 umol ethylene source. Incubate achenes in a chamber with alternating 12 h periods of light (27°C) and dark (20°C). Requires a sandy substrate.	3
Abronia umbellate (Drennan 2008, Baldwin et al. 2012, Center for Plant Conservation 2015,)	May	Aug	Winged fruit 6-13 mm long. Fruit contains single-seeded achenes.	Plants seed throughout the year, majority of seed production occurs in late spring/summer. Removal of woody capsules aided with the use of generic nail clippers.	In the most successful trials, achenes removed from anthrocarp. Some seed lots require cold pre-treatment. Germination requirements may differ year to year. For best results, sow clean seeds in the top 1" of a sandy growing medium.	3
Achillea millefolium (Baskin and Baskin 2002a, Baldwin et al. 2012)	Aug	Oct	Oblong fruit, usually 2 mm in length, contains brown disk achenes. Seeds mature in late summer-early fall.	Cut entire inflorescences, collect in paper bags. Clean seeds with a hammermill, screen, and fanning mill.	Lightly cover seeds with growing medium (milled sphagnum, peat, perlite, vermiculite w/ oscmocote). 90-100% germination rate.	3-5
Acmispon glaber (Montalvo and Beyers 2010c)	May	Jul	Narrow, bean-shaped, curved seed pods 1-2 mm long. Indehiscent pods ripen in 4-6 weeks. Mature pods are dry and brown or olive green.	Strip ripe seed pods from stems by hand. Avoid breaking seeds during thrashing. Rub pods with wooden block over #16 (medium) screen. Remove seeds from pods. Remove excess chaff with seed blower.	Heat or mechanical scarification needed to break dormancy. Soak seeds in boiling water or heat in 120°C oven for 5 minutes for highest yield.	Long-lived
Ambrosia psilostachya (Pavek 1992, Baldwin et al. 2012)	Oct	Dec	Brown bur 3-4.5 mm long contains tiny achenes.			3-5
Artemisia californica (Hauser 2006, Young-Mathews 2010, Baldwin et al. 2012)	Oct	Feb	Fruit 0.8-1.5 mm long. Very small achenes, generally mature in early fall or winter; wind dispersed.	Strip brown inflorescence by hand.	Seeds will germinate when fresh. Stored seeds need to be exposed to light and may require cold stratification. Other sources imply that pre-germination treatment is not necessary.	2-5

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Artemisia douglasiana Elkhorn Slough National Estuarine Research Reserve 2001, Shultz 2014)			<1 mm, glabrous fruit. Small, ellipsoid, hairless achenes without ribs or angles.	Seed is ready to harvest when it can be easily removed from the heads by shaking. Clip seed stalks and air dry in a paper bag. To thresh seeds rub the inflorescence through a screen. Remove chaff with a blower.	Germinates naturally at relatively cool temps.	2-5
Artemisia tridentate (Elkhorn Slough National Estuarine Research Reserve 2001, Baldwin et al. 2012, Tilley et al., n.d.)	Sep	early winter	Fruit glandular or hairy, 1-2 mm in length. Very small achenes, generally mature in early fall or winter.	Seed from genus is ready to harvest when it can be easily removed from the heads by shaking. Clip seed stalks and air dry in a paper bag. To thresh seeds rub the inflorescence through a screen. Remove chaff with a blower.	No pre-germination treatment necessary.	2-5
Arthrocnemum subterminale (Zedler 2001, Clarke et al. 2007, Baldwin et al. 2012)	Oct	Dec	Stems have tiny flowers that occur below the tip of the stem and contain brown, vertical seeds with hard seed coat, 1-1.4 mm in length.	Best to collect in November. Collect inflorescences and air dry. When dry, shake seeds from stalks.	Seeds are highly germinable. Germination promoted by low salinities.	3-5
Astragalus pycnostachyus* var. *lanosissimus (McCue 2010, Baldwin et al. 2012, U.S. Fish and Wildlife Service, n.d.)	Jul		Fruit ovate and inflated; 6-11 mm long and 3.5-6 mm wide. Seeds are smooth, compressed with a small notch at attachment site. 2 or more seeds/fruit.	Other plants in genus, specifically *A. sinuatus*, have seeds that mature in late July.	Hard seed coat may require scarification.	Long-lived
Astragalus tener* var. *titi (Showers 2010, Baldwin et al. 2012)	May		Fruit 6-50 mm long and 1.7-3.5 mm wide. Seeds are smooth, compressed with a small notch at attachment site. 2 or more seeds/fruit.	Endangered species. Extract seeds from fruits by hand. Thresh seeds over sieve large enough to let set seed pass through. Run seeds through seed blower to remove parasitized or aborted seed.	If stored for an extended period of time, hard seed coat may require scarification to initiate germination. 95% germination success rate on 0.5% agar plates with 11 hours light at 20°C and 13 hours dark at 12°C.	Long-lived

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Atriplex californica (Young 2001a)	Sep	Oct	Mature fruit is an utricle with 1 seed. Seeds are black, shiny, hard, round, and flat; 2 mm at maturity.	Gently seeds rub over #18 sieve. Remove as much chaff as possible with a seed blower.	Pre-planting: soak in water for 24 hours, rinse. 86% germination rate after sowing in peat moss, perlite, nutrients, gypsum, and dolomitic lime. Germination occurs after 10 days.	10
Atriplex canescens (Springfield 1970, Baldwin et al. 2012)	Oct	Apr	Cream-colored 4 winged utricle, 5-23 mm wide. Seeds 1.5-2.5 mm long with brown, papery inner seed coat. Species has high percentage of empty seed. Smaller fruits tend to have higher percentages of filled seed.	Strip seeds from branches by hand. If available, use a hammermill and a fanning mill to de-wing and clean seed. Collections made later (Dec-Apr) tend to have higher germination rates.	Germination is inhibited by lack of aeration, but improved with de-winging. Sow in medium with high substrate moisture at low temperatures, ideally at 18-24°C in California. Early collections may benefit from a 60 min. soak in sulfuric acid or a pre-chill at 5°C for 12 weeks.	5-7
Atriplex lentiformis (Young et al. 1980, Baldwin et al. 2012)	Sep	Jan	Produces large amounts of dark brown, 1.5 mm long seeds.	Dioecious.	Maximum germination between 10-25°C.	3-6
Atriplex prostratea (Khan and Ungar 1984, Zedler 2001, Baldwin et al. 2012)	Sep	Oct	Two types of seeds: brown, 1-2.5 mm long, and black, 1-1.5 mm long.	Fully mature fruit can be shaken or hand stripped from branches. Seeds will often remain on bushes until April, so late collections are possible.	Readily propagated from seed. In the field, germinates in late spring.	10
Atriplex watsonii (Zedler 2001, Bryant 2004)	Jun	Sep	Seeds light brown, about 1 mm long.		Readily propagated from seed, germinates and establishes easily in field.	10
Baccharis pilularis (Bonner and Karrfalt 2008, Montalvo et al. 2010b, Baldwin et al. 2012)	Aug	Dec	Single-sex white flowers. Glabrous, ribbed fruit 1-2 mm long, pappus 5.5-9 mm long. Mature seeds are tiny, dark brown achenes with ring of long, unbranched pappus bristles.	Dioecious. Collect seed heads by hand into open breathable bags. Alternatively shake branches over a tarp. Fruit should be spread out to dry in a well-ventilated room or in the sun. Rub dried heads between palms or over a screen to remove the pappus and phyllaries.	Seeds germinate without pre-treatment. Cool temperatures yield highest germination percentage.	1

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Baccharis salicifolia* subs. *Salicifolia (Bonner and Karrfalt 2008, Baldwin et al. 2012)	May	Jul	Glabrous, ribbed fruit 0.8-1.3 mm long, pappus 3-6 mm long. Tiny achenes with a bristly pappus.	Dioecious. Collect ripe fruits by hand or by shaking seeds onto canvases/tarps. Dry seeds at room temperature. Once dry, rub seeds over a screen to remove the pappus.	No pre-treatment necessary. Light necessary for germination.	1
Baccharis sarothroides (Bonner and Karrfalt 2008, Baldwin et al. 2012)			Glabrous, ribbed fruit 2-2.6 mm long, pappus 2-3 mm long. Tiny achenes.	Dioecious. Seeds can be collected by hand or branches can be shaken above tubs/tarps.	Germinates well in wet soils.	1
Batis maritime (Zedler 2001, Marcone 2003, Francis 2009, Lonard et al. 2011)	Oct	Nov	Hard-walled lenticular or oblong seeds. 1 mm in length.	Collect when fruits mature and turn from green to white. Extract seed from fruit. Dried fruits should fragment easily, exposing seed	Difficult to grow from seed. Marcone had success exposing seeds to natural light conditions and using a nutrient-enhanced potting medium. No known dormancy requirements.	2+
Cressa truxillensis (Elkhorn Slough National Estuarine Research Reserve 2001, Zedler 2001)	Jul	Aug	Fruits are small hairy capsules, 1/8" long. Seeds pinkish in color, broadly egg-shaped.	Produces mature seeds from late summer into early autumn.		2
Croton californicus (Young 2001b, Baldwin et al. 2012)	Jul	Nov	Flowers develop into compact, greenish seed pods. Mature seeds are smooth, round, and brown with tan spots. 3.5-5.5 mm in length.	Dioecious. Collect July 15th-November 17th. Remove chaff by hand. Remove seeds from pods.	Pre-planting: soak seeds for 24 hours in water, cold stratify for 30 days. Should germinate 30 days after sowing.	3
Distichlis littoralis (Zedler 2001, Clarke et al. 2007, Baldwin et al. 2012)	Jun	Sep	Spikelets, 8-13 mm in length, generally concealed by leaves. Seeds are quite small and remain in flowers until senescence.	Dioecious. Strip flowers with seeds from inflorescences.		4-5

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Distichlis spicata (Baskin and Baskin 2002b, Elsey-Quirk et al. 2009, Baldwin et al. 2012)	Sep	Nov	Spikelets 6-20 mm long. Seed likely dormant at time of dispersal.	Dioecious. Seed is 2 mm long and brownish-gray at maturity. Rub seeds over #18 sieve to clean.	Seed germination highest after wet stratification/ a fluctuating inundation regime and with low salinity (Elsey-Quirk, 2009). Soak in water for 24 hours before sowing. Establishes well at restoration sites.	4-5
Encelia californica (Bonner and Karrfalt 2008, Baldwin et al. 2012)			Fruit 5-7 mm long, slightly longer with pappus. Seeds dark brown at maturity.	Achenes are wedge-shaped and densely compressed. Edges are long-ciliate and faces are glabrous or short-hairy. Collection timing is critical as achenes are easily blown from plant after reaching maturity.	To break dormancy, pre-soak seeds in water.	2-5
Eriogonum fasciculatum (Zedler 2001, Montalvo and Beyers 2010a, Baldwin et al. 2012)	May	Aug	Glabrous fruit 1.8-2.5 mm in length.	Best to collect from Jun-Jul. Collect inflorescences as they begin to turn rusty brown. Push seeds through a screen to remove chaff.	Seeds germinate well in flats. Light improves germination rate. Sow in fall-early winter.	2-5
Frankenia salina (Young 2001k)	Sep	Oct	Ellipsoid seed capsules (8 mm) contain 1 mm long, brownish black seeds. Ovular in shape with pointed tips.	Collect: September 16th- October 21st. Collect mature flowers and rub over #25 sieve. Use gloves when handling, the plant can be spiky.	Seeds need no pretreatment. Germination naturally promoted by low salinity and high temperatures in spring.	0-2
Grindelia camporum (Zafar and Shah 1994, Bliss 2012)	Jun	Oct	Small, long, and flat achenes. Wind-borne, dandelion-like achenes with feathery tufts.	Harvest seed in June and again in October. Clip seed heads or shake/rub mature seeds from seed heads into a collection bag. To clean, rub seed heads over sieve. Remove chaff using additional sieves or an air separator. Air dry in oven at 203 °F.	Soak in water under continuous light OR use two-stage cold stratification at 32°F and 59°F in the dark (Zafar 1994) to pre-treat.	3-5

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Hazardia squarrosa (Keil et al. 2013)			Fruit: 5–8 mm, 5-angled, glabrous; pappus 7–12 mm, white to red-brown in color. Oblong to lanceolate seeds.			0-1
Heteromeles arbutifolia (Bonner and Karrfalt 2008, Baldwin et al. 2012, Gordon 2014, Recon Native Plants Inc. 2015)	Oct	Jan	Large, smooth brown seeds. 2–3 seeds per pome.	Clip or strip fruits from branches when bright red. Soak berries in water to ferment (over-soaking can be damaging). Pulp should float, making it easier to separate seeds from pulp. Alternatively, pulse berries in blender and then rub mixture over a screen to isolate fruit. Dry seeds before storing. RECON suggests keeping fruit intact.	Fresh seeds germinate readily. Chill stored seeds for 3 months at 3–5°C prior to sowing. Seeds germinate well 23°C.	2
Hordeum brachyantherum (Elkhorn Slough National Estuarine Research Reserve 2001, Young 2001d)	Jun	July	Mature inflorescences are light brown.	Seed easily removed when stalks are hand stripped. No additional cleaning required.	No pre-treatment required. Sow seeds in May. Seeds should germinate 21 days after sowing. Germination rate: 60%.	4-5
Isocoma menziesii (Zedler 2001, Wall and Macdonald 2009, Montalvo and Beyers 2010b)	Sep	Nov	Tan-colored achenes, longer than wide, wider on the plumose end, with lengthwise striations. The top of the achene has a ring of white bristles. Seeds mature when the pappus becomes fluffy and achenes detach easily from the receptacle.	Collect achenes golden in color, as seeds are usually eaten by time achenes turn brown. Shake ripe heads over open containers to collect achenes. Alternatively, remove ripe heads and keep in porous bags. For *I. acradenia,* Wall and Macdonald recommend rubbing flowers over a large screen, using a seed blower, and sieving over a #18 screen to separate seeds from bracts.	No pre-treatment required. Seeds germinate well in flats.	1+

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Iva axillaris (Montalvo et al. 2010b)			1-2 seeds/head. 2 mm long, turnip-shaped, light, and buoyant.	Strip seeds by hand or beat into a hopper/open container. Rub flower material over a screen and run through a blower to remove chaff.	Generally exhibits low germination rates. Scarification is not effective. Cold stratification may be (studies needed).	Short-lived
Jaumea carnosa (Young 2001e)	Jul	Oct	Seeds are linear achenes with longitudinal stripes.	Collect seed while fruits are swollen and green. Rub seeds over #12 sieve to clean.	Seeds germinate readily in moist soil.	1
Juncus acutus* subs. *leopoldii (Zedler 2001, Baldwin et al. 2012)	Aug	Nov	Shiny brown capsules contain multiple irregularly shaped seeds. Seeds can be narrowly winged.		Grows readily from seed in moderate salinities. Clones can be dug entire and transplanted.	2-5
Juncus bufonius (Zedler 2001, Baldwin et al. 2012)	Mar	May	Ovoid or elliptic seeds. Seeds generally 0.3-0.6 mm long.	Seed capsules dehisce; seeds should be collected quickly after plant death. Shake mature flowers to collect tiny seed.	Seeds germinate readily in low salinity soils.	2-5
Limonium californicum (Young 2001f)	Sep	Nov	3 mm long narrow ellipse, dark brown/red at maturity.	Collections made in October are best. Collect entire flower heads, which should detach easily when ripe. Rub flower heads over #20 sieve.	Sow in April. Propagates readily from seeds or plugs.	1
Lupinus chamissonis (Young 2001g)	Apr	Jun	Hairy legume pods 2.5-3.5 cm long. Mature seeds are dark brown and speckled and 3-4 mm in length.	Remove seeds from receptacles, no further cleaning required.	Scarify using sandpaper for 5 minutes. Then, soak in hot water over night (repeat for seeds that do not imbibe). Sow in growing medium mid-October. Should germinate after 3 days.	Long-lived
Lycium californicum(Zedler 2001, Baldwin et al. 2012)	Jan	Feb	3-6 mm red berries. 2 oblong seeds per berry.	Pick by hand. Berries best collected within 2 weeks of appearance, otherwise birds will eat majority. Extract seeds from berries within a week, before berries begin to mold.	Soak seeds in water for at least 12 hours, then transferred to moist soil. Reported germination rates are low, 5-10%.	1

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Melica imperfecta (Ashby and Hellmers 1959, Emery 1988, Young 2001h, Baskin and Baskin 2002c)	Apr	Jun	Mature inflorescences are brown; mature seeds are tan.	Strip inflorescences.	Plant has irregular germination patterns and a low documented germination rate, 30%. Literature inconsistent, certain sources suggest soaking seeds overnight in fresh water and cold stratifying for 2 weeks in peat. Conversely, Emery 1988 feels no pre-treatment necessary. Constant light (i.e. 24-hour photoperiod) exposure is documented to speed flowering.	4-5
Mimulus aurantiacus (Young 2001c, Baldwin et al. 2012)	Jun	Aug	Mature capsules are brown and contain tiny, black seeds less than 1 mm in length.	Rub seed capsules over a sieve.	Sow seeds in August. No pre-treatment needed, 50% germination rate.	2-5
Oenothera elata (Greiner and Köhl 2014, B & T World Seeds 2015, Dave's Garden 2015a, Kleinman, n.d.)			Seeds are irregularly shaped, stacked in small, brown, woody capsules with four chambers each with two rows of small seeds.	Collect seed from spring cultivars in October and from winter cultivars in September. Bag seed heads and allow them to dry on plant or collect early and allow to ripen in paper bags.	Surface sow (1 mm deep) to ensure sufficient light. Long-day conditions (16 hours of light/ 8 hours of darkness) should be simulated in the greenhouse. Should germinate after 15-30 days.	3-5
Peritoma arborea (Lippitt et al. 1994, Borders et al. 2008, Baldwin et al. 2012)			Capsules 3-6 cm long and 1-2.5 cm wide. Mature fruits will often split at the seam, revealing seeds. Dark-colored seeds tend to be more viable that light-colored seeds.	Flowers several times/year (except Dec-Jan). Ready for collection when capsules turn brown and are crisp. Strip mature fruits from plants by hand. Break apart pods by hand or with a hammermill or coater blender.	Species does not require high soil moisture to germinate.	2-5
Phacelia ramosissima (Baldwin et al. 2012)			Capsules contain 8-12, 1-2 mm long pitted seeds.	Collect seed when flowers are dry and brown. Strip seed from mature inflorescences directly into collection bag.		2
Plantago erecta (Gulmon 1992, Montalvo et al. 2010a, Baldwin et al. 2012)	Apr		2-2.5 mm long.	Dehiscent, ballistic seed dispersal. Collect inflorescences into a paper bag and let dry. Use sieve to clean.	Non-dormant, no pre-treatment needed. With ample water, will germinate from Sep-Dec with varying temperatures.	3
	Jun	Spring				2

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Platanus racemosa (Bonner and Karrfalt 2008)			Chestnut brown seed pods at maturity, many are empty. Achenes are 2-2.5 mm in length and have small tuft at base.	Collect seedpods after they have turned brown. The task is easiest after leaves have fallen. Seedpods remain on trees into spring. Cut seedpods directly from tree. Crush dried seedpods to open. Remove dust and fine hairs.	Cold moist stratification needed to break dormancy.	
Populus fremontii* subs. *fremontii (Gulmon 1992, Stettler, 1996, Clarke et al. 2007, Kleinman, n.d.)	Mar	Aug	Capsules contain seeds with long, silky hairs.	Dioecious. Collect seed as it is released from capsules during dehiscence or collect entire catkins prior to dehiscence. Separate cotton fibers from seed.	Germination is most successful at 20-30°C with adequate moisture. Seed should not be covered with soil.	1
Potentilla anserina* subs. *pacifica (Walker 2005, Stevens, n. d., Baldwin et al. 2012)			Fruits are oval, flat, and reddish-brown and about 2 mm in length.	Let seeds dry on plant prior to collection.	Non-dormant. Seeds should be planted in full sun in lightly packed soil. Keep soil moist.	Short-lived
Pseudognaphalium californicum (Keeley and Keeley 1987, Nesom 2013)			Oblong fruits with bristly, tuft-like projections (shed at maturity).		Germination stimulated by presence of charred wood or aqueous extracts of charred wood.	
Rosa californica (Young 2001i, Lady Bird Johnson Wildflower Center 2007)	Jul	Sep	Mature fruits (rose hips) are bright red. Each hip contains multiple seeds.	Collect hips as soon as they are ripe. Extract seeds by hand from dried hips. Alternatively, macerate hips in water; remove floating seeds.	Soak seeds in water overnight prior to sowing. Seeds germinate slowly, cold stratification helps speed process.	2-4
Salicornia bigelovii (Glenn et al. 1997, Zedler 2001, Baldwin et al. 2012)	Sep	Nov	1-1.5 mm curved, hairy seeds.	Entire inflorescences should be collected and air-dried. When dry, strip seeds from inflorescences.	Irrigate with seawater. Root zone salinity (top 15 cm of soil) should be kept at a salinity of 70-75 g for high yields.	1

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
Salicornia pacifica (Khan and Weber 1986, Young 2001j)	Oct	Nov	Mature seeds pinkish white, puberulent, and 0.5-1 mm long. Sequentially hermaphroditic.	Collect inflorescences when plant tips are purple. Dry seeds on a screen for up to 3 months.	Variety *S. utahensis* grows best at 5% NaCl treatment and under temperature regime of 15-5°C.	2+
Salix exigua* subs. *exigua (Young and Clements 2003, Anderson 2006, Clarke et al. 2007)	May	July	Glabrous ovular capsules. Small seeds with pappus. Normally dispersed via wind or water.	Dioecious. Harvest when catkins are yellow-brown and capsules begin to open. Shake catkins to remove dried seeds.	Seeds are non-dormant. Optimal germination temperatures: 2-15°C.	3-4
Salix lasiolepis (Bonner and Karrfalt 2008, Don 2014)	May		Glabrous ovular capsules.	Dioecious. Hand-harvest catkins when they begin to turn yellow/ brown. It is recommended to wait until capsules open. Separate seeds from cotton.	Sow near soil surface. Exposure to light increases germination rate.	3
Salvia apiana (Stevens 1994, Montalvo and Beyers 2010d, Baldwin et al. 2012, Native Plant Database 2015)	July	Aug	Shiny, light brown fruit. Fruits are 2.5-3 mm in length.	Collect seeds as capsules begin to dry, before seeds are dispersed. Shake seeds from seed heads. Use a sieve to isolate seeds.	Scarification and possibly stratification needed to break seed dormancy. Sow seed in early fall. Seeds may respond to light, so plant in surface soil (1/8-1/4" deep). After planting, soak flats in water.	2-4
Salvia mellifera (Montalvo and Beyers 2010e)	Jun	Aug	Dry calyces are gravity dispersed. Up to 4 seeds/calyx. Seeds are 1 mm by 2 mm.	Collect after inflorescences with calyces are dry and brown. Collect mature seeds by clipping, stripping, or shaking seed heads. Seed should be dried and passed through a sieve. Use of a blower is recommended.	Physiological dormancy. Exposure to light or components of fire (charred wood, smoke, KNO3) may stimulate germination.	1-2
Schoenoplectus acutus* var. *occidentalis (Lacroix and Mosher 1995, Johnson 2004, Baldwin et al. 2012, Baskin and Baskin 2014)	Aug	Sep	Wide, smooth fruits with 2 or 3 distinct sides. Fruit 2-3 mm long and 1.2-1.7 mm wide.	Because they are easily dispersed by wind, it is important to collect seeds close to the time of maturity. Seeds must be	Physiological dormancy. Cold stratification breaks dormancy. Germination rates are low for the species due to the thick pericarp of the achene. Germination rates increase with overwintering in a pond or water source.	2

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
				separated from the panicle and cleaned.	Pre-treat seed with 0.05% solution of sodium hypochlorite 5 days prior to sowing. Seeds germinate to a higher percentage when grown in light.	
Schoenoplectus californicus (Stevens 2003, Baldwin et al. 2012)			2-sided, smooth fruits. Fruits 1.8-2.2 mm long and 1.3 mm wide.	Harvest seed by hand from seed heads. Alternatively, use shears to clip entire seed heads from plant. Clean seeds.	Plant seeds 1/4" under the soil surface. Keep soil surface moist and at a temperature of 100°F.	
Spartina foliosa (Zedler 2001, Baldwin et al. 2012)	Sep	Nov	10-25 mm spikelets.	Multiple harvests may increase probability of collected good seeds prior to dispersal or herbivory loss.	Best success after cold storage in freshwater.	4 months
Stipa cernua (Laude et al. 1952, Amme 2003, Herrera et al. 2006)	Jul	Aug	Linear, smooth, glabrous seed.	Harvest by hand or with a flow-vac or combine at maturity. Collection possible for 2-3 weeks.	Overheating can kill seedlings.	
Stipa lepida (Ashby and Hellmers 1959, Elkhorn Slough National Estuarine Research Reserve 2001, Amme 2003, Dave's Garden 2015b)			Brown fruit. Dark seeds 4-7 mm in length.	Seeds mature in spring. Allow seed to mature on plant. At maturity, harvest seed. Clean prior to storage.	No pretreatment needed. Constant light (i.e. 24-hour photoperiod) exposure is documented to speed flowering.	
Suaeda esteroa (Zedler 2001, Baldwin et al. 2012)	Oct	Dec	Two types of seeds: seeds can be lenticular, black, and shiny (0.8-1.7 mm in length) or horizontal and matte (1-1.5 mm in length).	Best to collect in Nov or early Dec. Cut whole inflorescence or strip inflorescence. After cleaning, seeds should be dried.	Seedlings establish well at restoration sites.	2+
Suaeda nigra (Borders, n.d.)	Sep	Oct	Small, lenticular, shiny black seeds 0.5–2 mm long. Seed coat can be smooth, finely	Collect when seeds are hard, black, and shiny when calyces will be brown and crumbly. Strip seeds from stalk by hand.	Pre-chill recommended.	3

Appendix II. Continued.

Scientific name	Start	End	Fruit/seed characteristics	Seed collection details	Seed germination	Longevity (yrs.)
			dotted, warty, net-like, or prickly.	Pass seed through a hammer mill or a sieve prior. Seeds should be spread out to dry before being processed/stored.		
Suaeda taxifolia (Zedler 2001, Baldwin et al. 2012)	Jun	Jul	1-2 mm horizontal or vertical seeds. Seeds are shiny, lenticular and range from black to brown.	Strip inflorescence by hand.	Seeds germinate readily with freshwater irrigation.	3
Triglochin maritima (Young 2002, Baldwin et al. 2012, Recon Native Plants Inc. 2015)	Jul	Sep	Mature inflorescences are brown. 1 seed/fruit. Seeds of genus usually linear. Seeds can be flat or angled.	Collect seeds between July 17-Sept. 23rd. Rub dry fruits between fingers to extract the seeds.	No pre-treatment required.	3-5
Vulpia microstachys (Young and Young 1986, Howard 2006, Baldwin et al. 2012)			5.5-10 mm spikelets contain 4-6 mm long fruits.	Unknown exactly when seeds from S. California plants mature (intermountain varieties mature late July– late September).	Seeds germinate w/o pretreatment. Heating and litter do not increase germination.	4-5

*In instances where published information is insufficient to fill-in portions of the table, cells are intentionally left blank.
*Seed longevity data from Recon Native Plants Inc. used to supplement information found in the literature where necessary