Revegetation of a San Francisco Coastal Salt Marsh

Figure 1 • Crissy Field during marsh excavation 1998.

ABSTRACT

In recent decades, 90% of San Francisco Bay's wetlands were destroyed for shoreline expansion and development. A unique opportunity arose to unearth and restore salt marsh wetland habitat buried for nearly a century in the heart of San Francisco with restoration of Crissy Field. The goal of restoration was to promote species diversity and advance establishment of a viable seed bank while maintaining an opportunity for natural vegetative recruitment. Over 14,000 salt marsh plants representing 18 species were propagated and planted as part of the restoration effort. Four months after outplanting, 68% of the plants were alive. Restoration practices associated with species palette selection, propagule collection, nursery propagation, and outplanting design and methods are in large part responsible for the revegetation project's degree of success.

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KEY WORDS: wetland, tidal zone, container nursery, restoration, seed germination

NOMENCLATURE: Hickman (1993)

In 1994, Presidio natural resources staff began planning the restoration of the 6.4-ha (16-ac) Crissy Field tidal salt marsh located on the northern bayshore of San Francisco in the Golden Gate National Recreation Area's Presidio. The marsh is 1 component of a larger effort to restore 40 ha (100 ac) of bayfront shoreline, including 6.8 ha (17 ac) of native foredune habitat (Figure 1). The project design was inspired by a 53-ha (130-ac) dune and tidal salt marsh system that flourished at this location until nearly a century ago when the US Army filled the site for land expansion. In 1994, with transfer of the Presidio from the US Army to the National Park Service, this land was designated for public use, making restoration of a fragment of the historic dune and tidal salt marsh system possible.

PLANT INTRODUCTION PALETTE

During spring 1998, research began to determine which salt marsh species would be appropriate for reintroduction. We made every effort to recreate the historic species palette by consulting early botanical records, journals, and herbarium records. Because these sources were incomplete, plant species occurring in contemporary adjacent and analogous wetland systems were also considered. From this list, dominant aggressively growing species like pickleweed (*Salicornia virginica* L. [Chenopodiaceae]) and some prolific native species like spearscale (*Atriplex triangularis* Willd [Chenopodiaceae]) were eliminated in anticipation of natural colonization. By limiting the presence of these species in the first phase of restoration, we hoped to provide greater opportunity for the establishment and expansion of the less common species selected for introduction. Locally uncommon, rare, or endangered species were given high priority for introduction. We selected 18 species (one-third of which are locally uncommon) for year 1 introduction (Table 1).

SELECTION OF PROPAGULE COLLECTION SITES

Because our site no longer supported salt marsh propagule resources, it was necessary to designate collection sites outside of the restoration footprint for each species selected. Ideally, plant materials we collected would share genetic links to historic plant populations or originate from sites with conditions similar to Crissy Field. To achieve our goals, we considered the following factors when determining propagule collection sites: 1) ecological habitat similarity (soils, wave exposure, disturbance patterns, nutrient inputs, and so on); 2) natural species dispersal vectors; and 3) proximity to reintroduction site. After evaluation, we selected 10 sites within 80 km (50 mi) of Crissy Field.

Most propagule collection was performed by a full-time collector with support from community volunteers during late summer and fall 1998. Usually, seeds were the propagule source, but divisions were collected for some clonally reproducing plants in order to curb introduction of artificial genetic diversity.

Photo by Erin Heimbinder

*Figure 2 • Pink sea-thrift (*Armeria maritima*) grows best between the high tide and the extreme high tide levels. Seeds germinated well when sown directly into growth medium. Nursery grown plants had 100% survival 3 mo after outplanting.*

TABLE 1

Salt marsh propagule collection and propagation information

Species	Propagule	Propagule collection time [a]	Seed processing	Most successful pregermination treatment	Germination (%)	Container [b]	Elevational habitat [c]	Survival (%)
Armeria maritima Willd (Plumbaginaceae)	Seed	Sep	Hand clean	Control	[d]	Deepot 16	EHT-HTL	100
Atriplex californica Moq. (Chenopodiaceae)	Seed	Sep	Sieve No. 18	24-h freshwater soak and 14 d stratification	[d]	Treeband	EHT-HTL	98
Castilleja ambigua ssp. *ambigua* Hook. & Arn. (Scrophulariaceae) [e, f]	Seed	Aug - mid-Sep	Hand clean	24-h freshwater soak and 24 d stratification	61	Square pot	HTL-MHHW	[e]
Cordylanthus maritimus ssp. *palustris* Chuang & Heckard (Scrophulariaceae) [e]	Seed	Mid-Aug - mid-Sep	Sieve No. 2	NaCl soak and 14 d stratification	59	Treeband,	HTL-MHHW	[e]
Distichlis spicata E. Greene (Poaceae)	Seed Division	Sep - Oct	Sieve No. 18	24-h freshwater soak	[d]	Square pot	EHT-MHW	80
Eryngium armatum J. Coulter & Rose (Apiaceae)	Seed	Oct - Dec	Sieve No. 12	24-h freshwater soak	58	Treeband	HTL-MHHW	54
Festuca rubra L. (Poaceae)	Division	Sep				RLC-7	EHT-HTL	73
Frankenia salina I.M. Johnston (Frankeniaceae)	Seed	Mid-Sep - Oct	Sieve No. 25	24-h freshwater soak	[d]	Deepot 16	HTL-MHHW	76
Grindelia stricta var. *angustifolia* M.A. Lane (Asteraceae)	Seed	Jul - mid-Nov	Hand clean	24-h freshwater soak	[d]	Deepot 16	EHT-HTL	68
Heliotropium curassavicum L. (Boraginaceae)	Seed	Oct	Hand clean	Control	52	Treeband	HTL-MHHW	65
Jaumea carnosa A. Gray (Asteraceae)	Seed	Sep - mid-Nov	Sieve No. 12	24-h freshwater soak and 15 d stratification	82	Square pot	MHHW-MHW	50
Juncus lesueurii Bolander (Juncaceae)	Seed Division	Mid-Sep - Oct	Sieve No. 25	24-h freshwater soak	[d]	Square pot	EHT-MHHW	54
Limonium californicum A.A. Heller (Plumbaginaceae)	Seed	Sep - mid-Nov	Sieve No. 20	24-h freshwater soak	[d]	Deepot 16	HTL-MHHW	67
Plantago maritima L. (Plantaginaceae)	Seed	Jul - mid-Nov	Sieve No. 16	NaCl soak and 14 d stratification	99	Treeband	MHHW-MHW	75
Potentilla anserina ssp. *pacific* L. (Roseaceae)	Seed Division	Sep	Sieve No. 14	24-h freshwater soak and 30 d stratification	[d]	Square pot	HTL-MHHW	54
Rumex occidentalis S. Watson (Polygonaceae)	Seed	Sep	Hand clean	Control	95	Square pot	HTL-MHHW	82
Scirpus maritimus L. (Cyperaceae)	Seed Division	Oct - mid-Nov Aug	Sieve No. 8	Control	50	Treeband	HTL-MHHW	23
Spergularia marina Griseb. (Caryophyllaceae) [e]	Seed	Mid-Sep - mid-Nov	Sieve No. 18	Direct seeded on site	[d]	—	HTL-MHHW	[e]
Spergularia macrotheca Heynh. (Caryophyllaceae)	Seed	Jun - mid-Nov	Sieve No. 18	Control	77	Treeband	HTL-MHHW	75
Suaeda californica S. Watson (Chenopodiaceae) [e]	Seed Cuttings	Sep Oct	Hand clean	24-h freshwater soak	28	Square pot	HTL-MHHW	[e]
Triglochin maritima L. (Juncaginaceae)	Seed	Mid-Jul - Oct	Hand clean	Control	88	Treeband	MHHW-MTL	Unavail-able
Triglochin concinna Burtt Davy (Juncaginaceae)	Seed	Jul - Oct	Hand clean	17 d stratification	75	Treeband	MHHW-MHW	Unavail-able

[a] Dates based on 2 seasons of collection.
[b] See Table 2 for descriptions.
[c] EHT = extreme high tide; HTL = high tide level; MHHW = mean higher high water; MHW = mean high water; MHT = mean high tide; MSL = mean sea level.
[d] Germination rate untested.
[e] Species introduced in winter 2000-2001.
[f] This hemiparisitic species was grown in containers with *Plantago maritima*, *Salicornia virginca*, or *Spergularia macrotheca* as the host plant.

Divisions were collected nearly a year later in July and August 1999.

Most collection field trips were scheduled during low tides to provide maximum accessibility to intertidal habitat. Seeds were collected by hand in paper envelopes or grocery bags. To protect propagule resources, no more than 5% of the seeds from any 1 population or individual plant was collected throughout the season. Seeds were collected from each species throughout its ripening season in order to include a diverse range of flowering times in the collection pool. Ripening times varied for each species and sometimes fluctuated significantly from 1 collection site to the next (Table 1). Divisions were extracted using flat-bladed shovels. Large clumps of soil, rhizomes, and top growth were removed and transported in 19 l (5-gal) plastic buckets to the nursery for transplanting.

SEED CLEANING, STORAGE, AND GERMINATION TRIALS

Once collected, seeds were brought to the Presidio Native Plant Nursery for cleaning and storage. Most species required a 2-wk drying period due to saltwater saturation and were aerated on window screens placed over large plastic containers to catch dried seeds and chaff. Once dried, seeds were cleaned with the aid of community volunteers using various tools, the most useful being U.S.A. Standard Testing Sieves (WS Tyler, Mentor, Ohio). Sieves of different sizes were prescribed for cleaning each species according to seed size and consistency and size of chaff (Table 1). Once seeds were cleaned, they were weighed and placed in brown paper envelopes inside of sealed plastic bags and stored at 4 °C (40 °F). Plant chaff was stored and later returned to its original site.

During fall 1998 and winter 1999, a private nursery performed germination tests on key species to determine the most successful propagation methods (Table 1). Before testing began, all seeds were examined under magnification and separated into seed "grades." Five hundred of the highest grade (best quality) seeds were selected for testing. Five pre-germination treatments were selected and tested in a prescribed order. If a minimum of 50% germination was achieved with any one treatment, no further treatments were administered. Treatments are described in order as follows:

1. Control: Clean seeds were planted in soil at a depth about 4X the seed's width, covered to the original soil surface (or 5 mm) with even-grained soil material, and firmed gently to ensure good soil-seed contact. Seeds were watered gently; even soil moisture was maintained until germination occurred.
2. Freshwater soak: Using 4X more water than seed volume, seeds were immersed in clean glass containers of fresh well water (not chemically treated or chlorinated) for 24 h. After soaking, seeds were filtered using unbleached coffee filters and planted as described for control.
3. NaCl soak and freshwater soak: Commercially obtained sea salt was dissolved in either 1 l (0.26 gal) of fresh well water (not chemically treated or chlorinated) or bottled, distilled water to obtain a salt (NaCl) water concentration of 44 parts per thousand (ppt). Seeds were soaked 24 h, separated from the salt water using unbleached coffee filters, and rinsed by immersion in fresh well water. Planted as described for the control.
4. Freshwater soak and stratification: After soaking seeds in freshwater as described above, seeds were gently mixed with clean, damp perlite, sealed in an airtight plastic bag, labeled, and stored at 4 °C (40 °F) for varying time intervals. Planted as described for control.
5. NaCl soak and stratification: NaCl soak and stratification as described above. Planted as described for control.

NURSERY PROPAGATION

We began propagation from seed in July 1999. If necessary, the prescribed pregermination treatments were administered. Seeds were sown in 39 cm X 44 cm X 5 cm (15.5 X 17.5 X 2 in) flats of Sunshine® Plug Mix #5 (SunGro Horticulture, Bellevue, Washington; 70% to 80% fine Canadian sphagnum, fine perlite, dolomitic limestone, gypsum, and wetting agent.) Seeds were covered 4X their width with a light covering of the medium. Sown flats were placed in a greenhouse with a bottom-heated bench system to maintain a target soil temperature of 18°C (65°F) and exposed to 6 s of mist every 20 min during daylight hours. Most seeds germinated within 15 d. When true leaves were apparent, seedlings were transplanted in Wheeler-Zamaroni Landscape Materials Soil Mix #4 (Santa Rosa, California; approximately 30% fir bark, 10% peat, 30% perlite, 30% sand, and 3 kg per m^3 (5 lb/yd^3) Nutricote® (90 d release at 21 °C (70 °F); 13N:13P_2O_5:13K_2O; Chisso-Asahi Fertilizer Co Ltd, Japan). Different pot sizes were selected to accommodate the appropriate root depth and development of each species (Tables 1 and 2). Transplants were grown on raised benches in the greenhouse until root tips were visible on the exterior of the potting medium when plants were removed from containers (up to 4 wk). While in the greenhouse, plants were irrigated 3X per week for 15 min with an overhead sprinkling system. Finally, plants were moved to outdoor shadehouses (30% shade) with raised benches until outplanting. Plants were irrigated 3X per week for 20 min with an overhead sprinkling system. Irrigation lengths

TABLE 2

Containers used to grow salt marsh plants

Container	Volume ml	Volume in^3	Depth cm	Depth in	Distributor or manufacturer
RLC-7	115	5.5	14	5.5	Stuewe & Sons Inc, Corvallis, Oregon
Deepot 16	260	16	18	7	Stuewe & Sons Inc, Corvallis, Oregon
Treeband	310	20	13	5	Anderson Die & Mfc Co, Portland, Oregon
Square pot	1000	64	10	4	Kord Products Ltd, Brampton, Ontario, Canada

and frequencies in both the greenhouse and shadehouse were adjusted according to weather so that containers were watered until soil reached water retension capacity and leaching was apparent at the base of the pot.

Salt grass (*Distichlis spicata*), rush (*Juncus lesueurii*), and silverweed (*Potentilla anserina*) divisions were transplanted during August 1999. Plant material was either potted immediately after field extraction or stored for up to 2 d at 4 °C (40 °F) in garbage bags filled with 240 ml (2 cups) of untreated tap water. Before dividing and potting, the plant material was placed in shallow tubs of water where soil was removed from the rhizomes and extraneous plants were separated. Rhizomes were subdivided with pruners allowing for at least 2 nodes per propagule, and top growth was reduced to 6 cm (2.5 in). Rhizomes were planted in 10 X 10 X 10 cm (4 X 4 X 4 in) square pots to accommodate the distance between nodes and in the same commercial potting mix used for seedling transplants. Potted divisions were stored in the greenhouse on heated benches to maintain a target soil tempaerature of 18 °C (65 °F) for up to 14 d and then moved to raised benches underneath outdoor shadehouse structures (30% shade) and irrigated at the same frequency as transplants until outplanting.

Plant Maintenance

While in nursery cultivation, some crops were impacted by pests and diseases. Control was maintained with cultural and organic methods. The rumex (*Rumex occidentalis*) crop was affected by both aphids and a rust type fungus. The rust affected leaves were removed by hand; fingers were dipped in alcohol frequently to prevent the spread of the disease to uninfected leaves. The aphids were treated with Bio-oil® (Bioscape Inc, Petaluma, California), a highly refined summer weight mineral oil. Two applications, 14 d apart, of diluted Bio-oil (8 ml Bio-oil per liter of tap water [1 oz/gal]) were applied with a Hudson-type sprayer. Aphids also infested the armored plant (*Eryngium armatum*) crop and were eradicated with a single spray application of soapy water (1 part liquid soap to 20 parts tap water) to the crown of the plant. The alkali-heath (*Frankenia salina*) crop developed powdery mildew. This was resolved by spacing plants in pot racks to promote greater air circulation. Top-growth of giant arrow grass (*Triglochin maritima*) and arrow grass (*Triglochin concinna*) were subject to predation from an unidentified pest. A litter of stems, leaves, and flowers were found in pots and on the ground; netting secured over the pots prevented further predation.

Very few of the salt marsh crops required fertilization. *Rumex occidentalis, T. concinna,* and *T. maritima* received a single top-dressing application of 5 to 8 pellets of Nutricote (same as described above) while recovering from pest and disease infestations. An identical application of Nutricote was applied to *Limonium californicum* to promote growth in a small crop transplanted late in the growing season.

Photo by P Kreiberg

*Figure 3 • Johnny-nip (*Castilleja ambigua *ssp.* ambigua*) seedling growing in the nursery. This hemiparisitic species was transplanted into 950 ml (64 in³) containers along with either* Plantago maritima, Salicornia virginca, *or* Spergularia macrotheca *during nursery production. Johnny-nip and its host plant grow best between the mean higher tide water and high tide levels.*

Salt Watering Plants

To prevent osmotic shock at outplanting, the salt marsh crop was placed on a graduated saltwatering schedule 3 mo prior to outplanting. Salinity levels started at 5 ppt and peaked at 25 ppt (the salinity level of San Francisco Bay in the winter), increasing 5 ppt every 2 wk. The specified concentrated solution of Solar Salt® (common salt used for home water softeners) was administered every 1 to 2 d using a Siphonex® hose attachment. The percentage of salt in the water was confirmed before application using a refractometer. Pots were watered until the potting medium was saturated. Because of the high concentrations of salt administered, medium moisture levels were closely maintained to prevent dry conditions that might lead to osmotic shock.

After salt watering levels reached 20 ppt, plant health declined. Wilting leaves and transparent roots indicated overexposure to water and osmotic stress. Apparently, this was caused by continuous medium saturation resulting from increasing winter rainfall and the intensifying salt watering schedule. Therefore, all medium was leached with freshwater and salt watering ceased for 6 wk. Salt watering then resumed at 10 ppt and continued on the regular graduation schedule reaching 25 ppt before outplanting.

OUTPLANTING DESIGN

We designed our outplanting plan to enhance survivorship by mimicking the natural distribution of tidal marsh vege-

tation. To simplify the outplanting process, planting specifications were determined for each species based on optimal tidal zone determinations and planting pattern designations.

Each salt marsh species naturally concentrates its growth within a specific tidal zone dictated by its tolerance of saline waters and tidal inundation and ability to compete with other species. Each species was planted within its optimal tidal zone as defined in local wetland flora references (Baye 1997; Faber 1996)(Table 1).

Propagules were planted according to 2 general planting patterns: independent and colonial. Colonial planting designations were assigned to species that grow in dense homogenous colonies (particularly clonal species) or require specific microhabitats. Independent planting designations were assigned to species that grow sporadically and indiscriminately throughout various microhabitats.

Colonial plantings were defined as groupings of 5 to 200 plants of a single species planted at a predetermined location on 30-cm (1-ft) centers. Species classified as colonial were designated to areas within the specified tidal zone that complied with their microhabitat (elevation, slope, wind exposure, soil contour, and saltwater exposure) specifications. For example, 1200 salty susan (*Jaumea carnosa*) plants (6 groups of 200 plants each) were assigned planting locations throughout the middle marsh, whereas 120 silverweed (*Potentilla anserina*) plants (4 groups of 30 plants each) were assigned planting locations in the middle marsh adjacent to freshwater outflows in order to match brackish microhabitat specifications.

Independent plantings were defined as groupings of 3 plants of a single species planted randomly within prescribed tidal zones on 30-cm (1-ft) centers. Independent species planting locations were not predetermined. For example, 872 groups (3 plants per group) of marsh plantain (*Plantago maritima* var. *juncoides* L. [Plantaginaceae]) were randomly planted throughout the middle marsh in unspecified locations.

SITE PREPARATION, OUTPLANTING, AND MONITORING

To identify planting locations, we staked tidal elevations between 0.5 and 2 m (2 and 6 ft) National Geodetic Vertical Datum at 15 cm (6 in) increments every 6.1 lateral m (20 lateral ft) using a self-leveling laserlevel. We spray painted the tips of the stakes unique colors to indicate specific elevations. Each colonial species was designated a flag color and the first 2 letters of the genus and first 2 letters of the specific epitaph were written on the flag with permanent marker. Perimeters of colonial planting locations were then marked with the designated colored and labeled flags.

Outplanting began during the last week of February 2000 and continued until the end of March. We scheduled planting during low tide windows to provide full accessibility to planting areas. Hand picks and small bulb planters were used to dig planting holes. Planting holes were tailored to pot size of the transplant and were approximately 2.5 cm (1 in) deeper and wider than the pot. When available, kelp salvaged from the site was planted at the base of planting holes to act as a natural fertilizer.

In mid-June (3 mo after outplanting was completed), we censused live salt marsh vegetation. Live vegetation fell into a broad range of very healthy plants to very unhealthy plants. All census data was entered in the monitoring section of the park database and indicated 68% survival.

CONCLUSION

Coastal wetlands are one of California's most endangered ecosystems, making restoration and conservation of these communities an environmental priority. While restoration of the Crissy Field tidal salt marsh does not replace the value of the system that was destroyed, the site serves an important role in restoring ecological processes and provides an opportunity to heighten environmental awareness. Public education through community based restoration is an important means by which the latter goal can be achieved. Support of community based volunteers made restoration of Crissy Field possible, garnered lifetime stewards for the site, and promoted personal environmental responsibility.

In a quest to learn more about this system and improve revegetation practices several adaptive management strategies will be implemented in the coming year. Outplanting will occur earlier in the season to take advantage of reduced soil and water salinities. One endangered and 2 locally uncommon species will be introduced to the site. New outplanting techniques and planting guidelines will be implemented to improve survivorship in high mortality zones. Select areas on the site will be modified to diversify and enhance habitat.

The achievable restoration practices described were in large part responsible for successful revegetation. Ecological processes suppressed for nearly a century are now engaged. The presence of shorebirds, waterfowl, invertebrates, fish, and of course, vegetative recruitment launch the most convincing argument for the projects continued success.

REFERENCES

Baye P. 1997. Limantour Spit Tidal Salt Marsh, Point Reyes: vascular plant species. Point Reyes (CA): Point Reyes National Seashore. Unpublished report.

Faber PM. 1996. Common wetland plants of coastal California. Mill Valley (CA): Pickleweed Press. 128 p.

Hickman JC, editor. 1993. The Jepson manual: higher plants of California. Berkeley (CA): University of California Press. 1424 p.

Holloran P. 1998. Reintroduction of salt marsh plant species to the Presidio of San Francisco, Golden Gate National Recreation Area. San Francisco (CA): Golden Gate National Recreation Area. Unpublished report.

Kreiberg P. 1999. A report on the germination of California coastal salt marsh species. San Francisco (CA): Golden Gate National Recreation Area. Unpublished report.

Rubenstein E. 1996. Crissy Field restoration action plan. San Francisco (CA): Golden Gate National Recreation Area. Unpublished report.

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