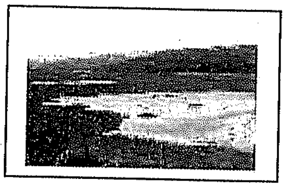

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TERRESTRIAL AND WETLAND VEGETATION MANAGEMENT PLAN

DRAFT FINAL

PIER 94, SAN FRANCISCO, CALIFORNIA

Prepared by

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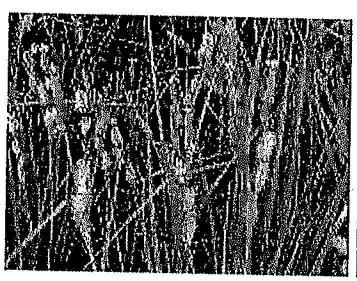
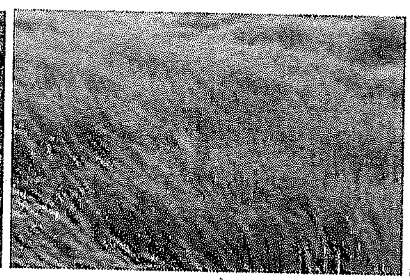
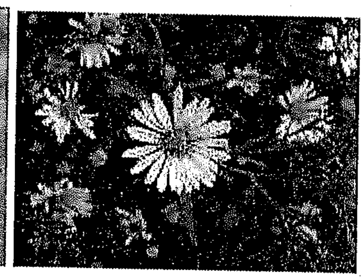




Prepared for

Golden Gate Audubon Society

2530 San Pablo Ave, Suite G

Berkeley, CA 94702-2047

November 2015

CONTENTS

Executive summary

Pier 94 shoreline open space areas support regenerated tidal wetland and upland habitats on formerly derelict urban port fill. The wetland and shoreline habitats were rehabilitated by Golden Gate Audubon and Port of San Francisco cooperative projects beginning in 2005-2006 (tidal wetland and shoreline enhancement: removal of rubble fill, gravel-sand beach nourishment, non-native invasive species removal, and reintroduction of extirpated native plants). Efforts to rehabilitate terrestrial vegetation were constrained by substrate conditions: compacted rubble and rocky fill restricted root establishment of many native plants, and favored invasive non-native weeds. In 2013, imported local excavated sandy sediments were placed on compacted rubble flats to provide suitable substrate for native terrestrial vegetation. Extreme drought conditions during and following fill placement constrained implementation of the original revegetation plans for the sandy fill platform. Weed invasion and dominance of the fill followed.

This vegetation management plan provides guidance for adapting and structuring revegetation efforts of terrestrial (fill platform) and wetland (tidal marsh and shoreline transition zone) habitats at Pier 94, to improve native plant species diversity and wildlife habitat. The plan proposes modification of planted assemblages of species native to naturally infertile sandy soils of southeastern San Francisco, adapted to local substrate and climate conditions that differ from cooler, moister maritime plant communities of western and northern San Francisco. Plant assemblages are modified as patches of compatible neighbor species, segregated by ecological "functional types" according to growth habit, mature size, life-form, and reproductive traits (e.g., woody species, clonal forbs and grass-like plants, annual and perennial erect forbs, bunchgrasses).

Biologically-based weed population management methods proposed in the plan emphasize concentration of seasonally timed activities on at critical life-history stages (seed germination and emergence, flowering prior to seed set) of the weed species present at Pier 94, avoiding the ineffective seasonal distribution of volunteer efforts on bulk weed removal during the late (seed-producing) developmental stages of spring and summer. Weed management methods are predicated on volunteer stewardship activities that preclude use of herbicides. Proper effective timing of weed treatments according to life-history stages (seedling and seed maturation) requires adaptation of volunteer stewardship schedules to be timed like farming activities, according to variable temperature-driven seasons, rather than fixed calendar dates.

Transplanting and seeding methods focus exclusively on restricted timing by season and weather. Successful planting depends on cool, moist weather of fall and early winter, when perennial and woody plants are either dormant or in relatively inactive growth stages. Native plant seed germination and emergence should be (naturally) synchronized with prolonged periods of intermittent rainfall that maintains soil moisture for growth and survivorship in the Mediterranean climate. Irrigation, fertilizer, mulching, and ongoing cultivation (manual weeding) are discouraged because in the long term they favor weed growth, reproduction, and spread over vegetation dominated by native species adapted to harsh, infertile sandy soils. Effective timing of transplanting and seeding activities according to (wet) fall-winter weather patterns, like dry-farming techniques, requires adaptation of volunteer stewardship schedules from fair (sunny, dry) weather to relatively foul (cool, moist) weather.

Native plant species diversification activities for the tidal salt marsh and shoreline, including expanding populations of endangered California sea-blite, are also prescribed.

1.0 Plan scope, approach and purpose

This report provides ecological background, practical principles, and guidelines for stewardship of the upland and wetland vegetation at Pier 94, San Francisco. Pier 94 is effectively an urban refuge for remnant native coastal vegetation near the historical mouth of Islais Creek. The **overall purpose** of habitat stewardship (long-term management of native and non-native vegetation) at Pier 94 is to **maintain and improve its dynamic native plant community diversity, wildlife habitat, and facilitate recovery of rehabilitated natural ecosystem processes, through community volunteer stewardship**. A key step in the enhancement of upland and wetland habitats at Pier 94 is the **transition** from weed-dominated urban industrial port vegetation and substrate, to dominance of reconstructed native plant communities that properly fit the modified substrates, topography, and local climate of the southeastern San Francisco shoreline, and conserve an oasis of local biological diversity. In addition, rehabilitation of vegetation and habitats here should contribute to resilience to climate change and associated coastal change (sea level rise and storm impacts).

This report is intended to be used by stewardship trainers (senior, experienced volunteers knowledgeable in native vegetation management) and volunteers with a wide range of experience. It is aimed at bridging the gap between urban native plant gardening (active horticultural management of static native species plantings in urban open spaces) and ecological restoration. Pier 94 wetland and terrestrial vegetation are not literally "restored" habitat, because they occur on artificial bay fill substrate. But ecologically coherent, geographically appropriate **analogs of native plant communities from the southeastern San Francisco shoreline** are being reconstructed by modifying the substrate and vegetation together. The substrate modifications are discrete events and features. But vegetation is dynamic, especially in early stages of establishment on new substrate, so its management must be ongoing.

The activities proposed in this plan are aimed at **steering dynamic vegetation changes**, and in some cases, re-setting their trajectories. It is **not a landscaping plan** with specifications for a fixed, static set of plant species intended to grow where they are planted. Although Pier 94 upland revegetation was designed as a 'blank slate' for a succession of seeded and planted populations on new weed-poor (nearly weed seed-free) substrate, weed populations (as well as excessively high densities of native coyote-brush seedlings) quickly dominated the new uplands before drought-impaired seeding and transplanting (see Section 2). Consequently, much of the management of upland vegetation in this plan focuses on **resetting upland native vegetation succession**, and reversing weed dominance until native vegetation can compete with it.

Vegetation management activities for uplands in this plan cover weed removal and native plant transplanting (horticultural methods), but without intensive artificial horticultural amendments (fertilizer, mulch, irrigation) that provide long-term competitive advantages for weeds. Enriching soil moisture and nutrients is competitively disadvantageous for native vegetation adapted to infertile sandy soils in a weedy urban port setting, where weed seeds rain down from outside the stewardship site. "Dry farming" and low-nutrient approaches to transplanting of native plants require careful seasonal and weather-dependent timing of transplants, during winter dormancy and moist weather, rather than fair-weather scheduled volunteer days.

Vegetation management in this plan also addresses reorganizing native planting species patterns and species composition within large and small-scale patches. Species composition is re-"screened" to segregate out elements of the San Francisco flora that are from western maritime ("fog belt") climates and soils or interior bedrock hills, and combine scrub and forb-grassland species native to the warmer, drier southeastern San Francisco shoreline and sandy soils. This is aimed at assembling coherent plant patches or assemblages composed of compatible neighbor species that are naturally associated in the same plant communities. These are expected to increase in resistance to weed invasion as they develop over time into functional analogs of natural, dynamic vegetation stands.

The scope of plan is primarily aimed at the newly constructed (2013) upland fill platform and surrounding upland areas, but it also covers the high tide shoreline (beach and tidal marsh transition zone) and native plant diversification of the high salt marsh.

2.0. Environmental setting and site history: Pier 94 and Islais Creek

2.1. Site Description and History.

Pier 94 is owned by the Port of San Francisco, and its undeveloped shoreline habitats are managed by Golden Gate Audubon Society. It is located south of the Islais Creek Inlet on the southeastern bay shore of San Francisco.

The eastern shore of Pier 94 supports approximately 6 acres of undeveloped open space on urban port bay fill (rubble, soil, and construction debris) that has partially subsided and formed tidal wetlands (salt marsh, flats, and pools) and upland flats with ruderal (weedy, disturbed) upland vegetation. Tidal salt marsh vegetation established in part directly on urban port fill, and partly on bay mud sediments (clayey silt) deposited naturally on top of the more subsided fill. (Port of San Francisco 2010; Baye 2006, Tetra Tech 2004).

The anthropogenic salt marsh (artificial fill with thin natural deposits of bay mud) at Pier 94 conserves a small but important legacy of the historical Islais Creek estuary, traces of which persisted on filled remnants into the 1950s with an impoverished local native salt marsh flora compared with today's:

> ...a pitiful stretch at the mouth of Islais Creek that is staging an heroic but losing battle for survival against the destructiveness of man. Here can still be found *Distichlis spicata*, ...*Salicornia virginica* [*Sarcocornia pacifica*], and *Grindelia humilis* [*G. stricta* var. *angustifolia*], but *Frankenia grandifolia* [*F. salina*] and *Jaumea carnosa*, for both of which San Francisco is the type locality, have succumbed to the adverse conditions.
>
> John Howell, Peter Raven, and Peter Rubtzoff, 1958, Flora of San Francisco

Some sand and gravel fill had been partially reworked by waves and tides to form small beach ridges at the south and north ends of the site, and at some locations along the landward edge of the high tide line. Upland flats, originally about 1 m in elevation above the high tide line, were composed of compacted fill on rubble, supporting very sparse, prostrate ruderal vegetation. The surrounding land uses are industrial: cement manufacturing, sand refining and stockpiling, container shipping, and other industries.

2.2. Tidal wetland habitat enhancement at Pier 94.

The Port of San Francisco implemented a habitat enhancement project for intertidal wetland habitats at Pier 94, San Francisco, which was completed in 2006. The Pier 94 site condition in 2003-2004 is described by Tetra Tech (2004). The goals of the wetland enhancement were to improve the physical, hydrologic, and aesthetic features of the wetlands. The construction was designed to achieve the following goals (condensed from Port of San Francisco 2010):

- Improve tidal flushing to provide varying levels of inundation to various sub-habitat types
- Expansion of the area of tidal marsh vegetation by reducing by removal of derelict construction debris where feasible
- Removal of large stands of invasive hybrid smooth cordgrass (*Spartina alterniflora* × *foliosa*), and control populations of hybrid *Spartina* and other invasive wetland plant species to the extent feasible.
- Limited and directed public access

A series of strong winter storms in 2006 caused some erosion of graded wetland surfaces and pre-existing salt marsh vegetation (mostly pickleweed). A coarse erosional rubble lag surface formed along the western upper intertidal shoreline. A segment of sandy beach (foreshore to high tide line) persisted at the south shore and a few other sheltered locations. A remnant concrete slab reef partially shelters the southern basin. A low, erosional rubble beachface and gravel barrier beach along the northeast shore partially sheltered the northern basin. It was partially stabilized with sparse high salt marsh vegetation. The low outer gravel barrier beach partially impounded shallow ponds (tidally choked pools; salt marsh pan habitat) in large depressions among marsh-covered fill remnants.

The salt marsh at Pier 94 has supported high plant species diversity, mostly native salt marsh flora. In addition to widespread salt marsh dominants (pickleweed, *Sarcocornia pacifica*; alkali-heath, *Frankenia salina*; saltgrass, *Distichlis spicata*; gumplant, *Grindelia stricta* var. *angustifolia*; and fleshy jaumea, *Jaumea carnosa*), the pre-project Pier 94 salt marsh supported small populations of less common native tidal marsh plant species, including sea arrow-grass (*Triglochin concinna*), California sea-lavender (*Limonium californicum*), Nutka goose-grass (*Puccinellia nutkaensis*), sea-spurrey (*Spergularia macrotheca, S. marina*). Submerged aquatic vegetation (wigeon-grass; *Ruppia maritima*) occupied portions of the tidally choked pools with resident fish in the northern wetland basin, but the pool outlet was breached to increase tidal circulation and reduce summer algal production. The former pools and *Ruppia* beds, which supported wading birds and avocets, were converted to high intertidal flats after 2008.

A California sea-blite (*Suaeda californica*; federally listed as endangered) founder population was first established in 2006 from seed stock derived from the small Pier 98 population (Heron's Head, Port of San Francisco (Baye 2008). Following successful pilot test transplants in fall 2004, sea-blite the founder population was transplanted as seedling/juvenile transition plants and rooted cuttings in March 2006. It was derived from a GGNRA Presidio Nursery population that was originally propagated for the Crissy Field marsh restoration. The Pier 94 sea-blite population spontaneously reproduced (seed production, seedling colonization, and recruitment of juveniles transitioning to mature plants) in some favorable early years, beginning in 2007, after some parent plants produced viable seed. The sea-blite population persists today, despite some mortality due to erosion and retreat of the outer barrier beach. Drought stress and dieback occurs in some sea-blite plants growing in shallow sand deposited over impermeable rubble fill.

Hybrid non-native smooth cordgrass (*Spartina alterniflora* × *foliosa*), the most invasive clonal perennial salt marsh plant in San Francisco Bay, colonized portions of the Pier 94 salt marsh in the 1990s. It was repeatedly removed by mechanical and chemical treatments, in coordination with the regional Invasive Spartina Project (California Coastal Conservancy). It has been effectively extirpated from the site. In 2007, another highly invasive perennial salt marsh plant,

Algerian sea-lavender (*Limonium ramosissimum*) was accidentally introduced to the site as nursery-grown transplants intended as salt marsh enhancement plantings of the native California sea-lavender (*L. californicum*). It reproduced by seed, and has persisted at variable density at Pier 94; its density has recently been low, but it has potential to increase rapidly. Other potentially abundant invasive salt marsh plants include the annual succulent Mediterranean saltwort, *Salsola soda*. Most other non-native salt marsh plants past and present at Pier 94 have much lower potential for invasion and significant ecological impacts.

2.3. Estuarine beach and sandy high salt marsh sediment nourishment at Pier 94.

In early 2006, Golden Gate Audubon Society, in cooperation with the Port of San Francisco, FarWest Engineering and Peter Baye, modified the shoreline (upland-wetland transition zone) of the tidal marsh enhancement area by establishing a set of estuarine beaches around the interior and outer Pier 94 shorelines. The primary purpose of the beach nourishment was to provide habitat to support the experimental (pilot project) reintroduction California sea-blite (*Suaeda californica*).

The design approach of the sand and gravel beach nourishment was to facilitate passive "self-construction" of suitable sandy high marsh and beach habitat. The existing outer gravel beach shoreline was used as a template for beach nourishment, and natural wave processes were used as the dynamic "construction" agents of the gravel-nourished beach. This was an alternative to engineered placement of sand in conventional beach nourishment (Nordstrom 2000). The outer gravel barrier beach, composed of about 0.6 m thick deposit of "screenings" (waste gravel and shell) from the adjacent industrial bay sand refining operation, was located along the rubble shoreline of the north basin. The landward (interior) edge of the salt marsh was dressed with about 0.6 m of coarse to medium sand, deposited over previously graded compacted fill.

Compatible native estuarine beach-salt marsh transition zone plant species were also established along the shoreline (beach-salt marsh transition zone) in association with sea-blite: beach wildrye *(Elymus mollis)*, beach-bur (*Ambrosia chamissonis*), and western ragweed (*Ambrosia psilostachya*), all from Central San Francisco Bay, Roberts Landing Long Beach, San Leandro. These populations have mostly persisted, but some beach wildrye colonies were mistakenly removed during contractor weeding of jubata grass (*Cortaderia jubata*).

2.4 Terrestrial Substrate and Vegetation Enhancement at Pier 94.

Golden Gate Audubon Society has planted upland artificial fill areas (above highest tide lines) with various plant species native a wide range of plant communities from the San Francisco Bay Area, since the mid-2000s. Most stock consisted of container-grown nursery plants of various sizes, transplanted directly into rubble and rocky artificial fill substrate. Transplants were introduced to a matrix of diverse weed-dominated fill, with local cultivation (weeding, mulching) around individual transplants (Baye 2008, in litt.). Dominant weedy vegetation at Pier 94 in 2012 consisted of a diverse assemblage of non-native invasive weeds, as well as some California species that are locally introduced and invasive beyond their native range. The most frequent, invasive weeds include non-native annual grasses (oats, *Avena sativa*; ripgut brome, *Bromus diandrus*; ryegrass, *Festuca perenne [Lolium perenne]*, outstanding in abundance), broadleaf perennial forbs (black mustard, *Brassica nigra*; nitrogen-fixing annuals (bur-clover, Medicago polymorpha; sweet-clovers, *Melilotus indica, M. alba*) (Perlmutter 2012)

Sandy and clayey sediments were placed on the compacted upland flats in 2013 to provide a shallow rooting zone about 2 feet thick above the root-restrictive compacted underlying rubble fill (Perlmutter 2013). A total of approximately 3900 tons of sediment from three local sources (Central Subway excavation, Transbay terminal excavation, and Hanson sand refinery wash fines) were placed on the flats. The majority of the fill was predominantly sand or silty sand (sandy loam/loamy sand; over 80% fine to medium sand), with silt dominating the fine sediment fraction. Most of the sandy sediment platform is therefore well-drained, low in nutrients, organic matter, and water-holding capacity, like naturally occurring Colma formation substrate in uplands. Clay-rich sediments (sandy clay, clayey silt) were limited to the estimated 1500 tons of Hanson wash fines, which were restricted to the extreme south end of the upland fill (Perlmutter 2013). These local Colma and bay-derived sediments are an approximation of the original types of terrestrial (paleodune and alluvial) substrates that existed above the original Islais Creek tidal marshes nearby.

The deep-excavated ancient sands (Pleistocene Colma formation) were essentially weed-free. The bay wash water of deep bay dredged sand (fine sediment) was presumably very low in upland weed seeds. Weed mowing to reduce weed seed rain from the vegetation at the periphery of the fill was performed after significant seed production and dispersal had occurred, and apparently did not significantly restrict weed colonization of the new sediment platform. The new fill was rapidly colonized by multiple weed species dispersing from the contiguous unfilled uplands on and off-site by 2014.

Severe drought (negligible fall rain, and almost no winter rain) and delay in cultivated seed production delayed sowing of native annual "cover crops" and native plantings on the bare fill platform in 2013-14. Native "cover crops" composed of fast-growing, prolifically seed-producing annual species adapted to colonizing disturbed, barren soils, were originally designed to be the primary dominant seed-producing populations on the fresh, nearly weed-free substrate. Pre-emption of weed dominance by sowing annual "weedy" native pioneer species at density prior to weed colonization was the goal for priming the fill for planting with long-term native perennial and woody target species. The two essential sequential steps in vegetation management to prime the fill platform (peripheral weed mowing prior to weed seed production and dispersal, and high density seeding of native annual cover crops), however, were circumstantially infeasible to implement on schedule.

The most abundant and invasive non-native weeds colonizing the sediment fill platform in late 2013, based on surveys by M. Perlmutter and R. Spadafore (2012) included nitrogen-fixing forbs (sweet-clovers, *Melilotus indica, M. alba*; bur-clover, *Medicago polymorpha;* vetch, *Vicia sativa*), as well as coarse short-lived perennial aster family forbs (Italian thistle, *Carduus pyncnocephala*; garland daisy, *Glebionis coronaria*; telegraph weed, *Heterotheca grandiflora;* bristly ox-tongue, *Helminthotheca echioides*), winter annual mustards (black mustard, *Brassica nigra*; radish, *Raphanus sativa*), facultative perennial/annual forbs (Mexican-tea, *Dysphania ambrosioides*), and many non-native annual grasses (ripgut brome, *Bromus diandrus*; oats, *Avena sativa*; foxtail, *Hordeum murinum*; many other Eurasian annual grasses), plantains (*Plantago lanceolata, P. coronopus*). Additional weed species with significant management burdens for volunteer stewardship include bull mallow (*Malva nicaeensis*; "*M. arvensis*" misappl. in Perlmutter 2012), star-thistle (*Centaurea solstitialis*), and fennel (*Foeniculum vulgare*) (N. Weeden, pers. comm. 2015). The relative abundance of various weed species, and their management burdens at Pier 94 should be expected to change among years with weather, climate, and succession. Extensive, dense seedling mats of yellow sweet-clover and bur-clover (thousands of seedlings per square meter) occurred in central portions of the sediment platform in November 2014, following germinating rains. These nitrogen-fixing forbs were present but not dominant on the compacted fill at the site prior to sediment placement. The new sandy fill sediment, low in nutrients, likely facilitated competition by these nitrogen-fixing weeds, which are well-adapted to coarse alluvium. The sediment platform became overwhelmingly dominated by a matrix of non-native invasive weeds by 2015.

Native woody and perennial forb species were planted within cultivated gaps in the weed vegetation matrix from 2014 to 2015.The original native plant "palette" and planting plans (selected species, relative abundance, and planting patterns) were modeled after regional remnants of natural plant communities representing inferred historical vegetation of the southeastern San Francisco shoreline. The planting design was substantially modified, partly because of nursery stock availability. Some native plant species from moister, maritime or riparian plant communities were added to the planting palette. The transplanted species in 2014-2015 were native to many different plant communities, geographic areas, and soil types from San Francisco Peninsula, but were not segregated by affinity to soil texture (predominantly sand and loamy sand). Combinations of neighboring plant species also were not sorted by compatible growth habits or natural plant associations. Competitive relationships among neighboring species were often very uneven and unstable: large fast-growing shrubs from rocky, arid, interior uplands, for example, were planted adjacent to low-growing, shade-intolerant forbs and bunchgrasses from (fog-influenced) coastal prairie vegetation, all embedded in gaps within the robust weed-dominated matrix. Transplanting during extreme winter drought conditions also triggered use of localized irrigation of transplants, which modifies natural root structure and competitive interactions among transplants as well as weeds. This initial vegetation is likely to be unstable and infeasible to maintain in the long term, even with intensive management.

3. Vegetation Conceptual Models, Ecological Goals and Objectives

3.1 Ecologically based goals for vegetation

Meaningful, non-arbitrary ecological goals for establishing new habitat ("creation" of habitat, or **primary ecological succession**) or improving ("rehabilitation" or "restoration" of habitat) requires some kind of reference system to on which to base them. Traditionally, "restoration" in vegetation has used evidence-based models of vegetation from a set of **reference systems.** For example, a set of relatively **intact remnant stands of vegetation and soils in analogous landscape settings** in a **common geographic** area may compose a reference system. Reference systems are useful to formulate a **working hypothesis** about the range of variability that should be sought in restoration designs, allowing for the constraints of the project site and its setting. Historical ecological data (like herbarium collections and other vegetation and plant records; the locality descriptions in the historical Flora of San Francisco; Howell *et al.* 1958) can be useful to inform what range of species may be compatible with a site-specific restoration project.

Unlike restoration goals for historical architecture, however, ecological restoration goals must also address **major changes in environmental context**, including climate changes and biological changes like new exotic floras (invasive species), herbivory, and human land use changes. Another important factor for establishing vegetation goals is the local climate. The local **interior Bay climate** at Pier 94/Islais Creek relatively sheltered from the strong marine summer fog flow that is most intense in the "fog belt" of the western half of the city and directly across from the Golden Gate.

For Pier 94 uplands, there is no literal "restoration" of original terrestrial substrate conditions because the site is entirely urban bay fill. The closest analog of natural uplands bordering the shoreline of Islais Creek would have been **ancient stabilized dunes (paleodunes) with sandy soils**, or stream valley **alluvium** (floodplain deposits). Franciscan bedrock outcrop types (chert, sandstone, and serpentine) also would be a potential upland vegetation type reflecting former steep headlands. The compacted pre-project urban rubble flats at Pier 94 resembles neither of these natural substrate and topographic conditions. Of the potential fill sources available to provide a root zone for terrestrial (upland) vegetation, fine sand and alluvium (ancient dune and water-deposited sands) were available for this project. Therefore, **terrestrial vegetation types** suitable for **lowland sandy soils adjacent to southeastern San Francisco shorelines** should bracket the range of ecological goals for upland vegetation at Pier 94. The lack of groundwater access by roots, due to the rubble fill, is presumed to make riparian vegetation infeasible as a potential vegetation type or goal.

3.2 Natural analogs for native vegetation and habitat goals

Two **terrestrial vegetation types** would be expected to occur on paleodunes and drier portions of floodplains bordering the fog-sheltered bayshore of **southeastern San Francisco: paleodunes scrub vegetation**, and **lowland valley grassland.** The "coastal bluff scrub" and "coastal prairie" vegetation of western San Francisco and the Golden Gate, strongly influenced by marine fog (high humidity, fog drip, cool temperatures in summer) are not appropriate for the warmer, drier local interior Bay climate of Pier 94. Similarly, the vegetation of younger (late Holocene) mobile or recently stabilized coastal dunes is not ecologically compatible with Pier 94 vegetation goals. The scrub and grassland vegetation of soils and bedrock outcrops on eastern San Francisco hills (San

Miguel Hills, Bayview Hills, Bernal Heights, Hunters Point, local bayshore headlands) would be suitable models for goals only if bedrock substrates were imported as fill.

There are no remaining well-preserved relict reference sites for the terrestrial and wetland vegetation types that originally occupied SE San Francisco shorelines. Approximating the structure and composition of suitable, natural vegetation of sandy or clayey flats adjacent to the Bay at this location is possible by interpretation of herbarium records and geological and topographic maps. In addition, native plant assemblages in vegetation remnants around the interior bay shores of San Mateo County and Marin County provides additional comparative basis for reconstructing suitable vegetation.

Reassembling native species and suitable soils, by itself, should not be expected to result in idealized "self-sustaining" or stable vegetation (even allowing for succession) at Pier 94. Scrub and grassland vegetation types are not necessarily stable when intermixed at a small spatial scale. Except for serpentine soils, coastal grasslands on the San Francisco Peninsula and Marin Headlands, tends to rapid succession to scrub vegetation in the absence of natural or anthropogenic disturbances that maintain them: frequent, recurrent aboriginal burning (to exclude brush and facilitate game hunting and harvesting of seeds and corms) or later historic era livestock grazing. Many coastal grasslands in the region have become dominated by early succession scrub, especially coyote brush. Coyote brush "invades" adjacent undisturbed grassland where heavy seed rain occurs. This is currently happening also at disturbed soils of Pier 94. Periodic modification of native vegetation (including removal, gap creation, or other disturbance) should be expected and planned for long-term management.

3.3 Species composition: synthetic analogs of natural plant communities

Functional groups of plants relevant to Pier 94 can be categorized practically for organizing plant assemblages (patches) of compatible species. A "functional group", or guild, is an artificial classification of plants based on their ecologically functional traits: growth habit, life-form, reproductive ecology, and physiological traits. Functional traits may help predict ecological outcomes more than taxonomic or geographic classifications of plant species. Mixed local populations of naturally associated, compatible species may mature together and form vegetation patches that function as analogs of native vegetation types that are suited to local substrate, topography, and drainage. Because functional traits of plants are not uniform within species, but vary among local populations, generic or pooled (commercial) stock of "native" species may not be expected to perform ecologically as populations from local soils, climates, and geographic areas (or close approximations) do. *Locally sampled and propagated populations of species from the San Francisco Peninsula* (primarily the SE San Francisco San Francisco Bay watersheds) are generally recommended for Pier 94.

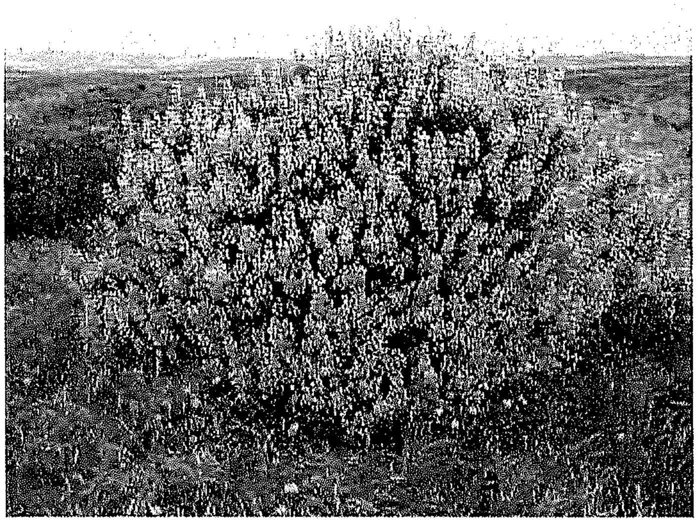
Ecological functions relevant to assessments of species traits supporting habitat at Pier 94 include:

- Flowering time (seasonal distribution), pollination syndrome (insect groups supported)
- Nutrient capture or transformation (uptake, fixation, or sequestration and release of nutrients in plant biomass; rapid turnover in annuals, immobilization in slow-decaying perennials)
- Soil moisture exploitation (water use at different root zones)
- Soil organic matter production
- Leaf litter production (duff, litter mats) and soil surface microenvironments

- Seasonal timing of growth (interference with weeds)
- Trophic support for wildlife (seed, shoot herbivory)
- Structure for wildlife habitat (plant structure, height, canopy)
- Growth rate, stress tolerance, and plant architecture (plant competition traits)
- Colonization ability (dispersal and establishment in gaps)

Functional groups of plants for Pier 94 are proposed below, along with key ecological traits. Functional groups can be *treated as "core species" assemblages for planting in ecologically coherent patches*, instead of a mélange of "native" species from different communities, with very unequal competitive abilities and growth forms.

- **Nitrogen-fixing rapid-growing shrubs.** Two fast-growing, strongly colonial lupine shrub species are native to sandy soils of the San Francisco Peninsula, and occurred historically along the southeastern San Francisco shore: bush lupine, *Lupinus arboreus*, and Chamisso's or silvery lupine, *L. chamissonis*. *L. arboreus* also grows in clay loams. Both species may be dominant where they occur, but they usually do not grow in the same patches. (A third species, *L. albifrons*, naturally occurs on rocky outcrops of interior hills, not sand or sandy soils). Both *L. arboreus* and *L. chamissonis* produce large numbers of seeds and form persistent, long-lived soil seed banks. They both can rapidly colonize gaps or sparse, open low grassland vegetation in sands. Seeds tend to disperse a few meters from parent plants (explosive seed pods) on flat ground, forming an expansive colonization "front". They both grow about 3 ft high, and tend to form dense single-species patches that out-compete shorter vegetation. The nitrogen-rich leaf litter they deposit increases nutrient content of sand or soil beneath them. *L. arboreus* is prone to cycles of dieback, and leaves enriched gaps that may be colonized by either native vegetation or weeds, depending in part on seed rain or seed banks present. A smaller, subshrub/perennial forb also in the pea family, deerweed (*Lotus scoparius*) may be treated as a member of this functional group.


Lupinus arboreus (typical yellow form)


Lupinus chamissonis

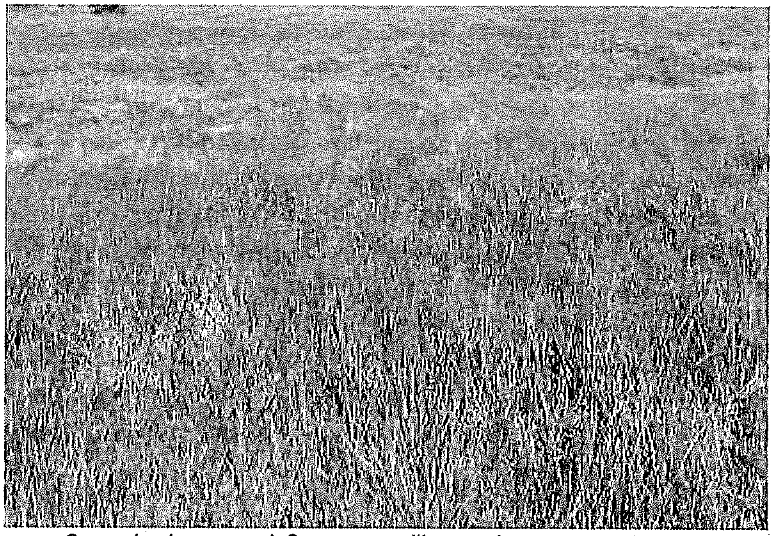
- **Clonal perennial forbs.** Herbaceous broadleaf plants (forbs) with perennial, creeping below-ground or ground-surface stems that creep and root as they spread, form physiologically connected clonal colonies, often in dense patches. They can persist for long periods and occupy areas where conditions are unfavorable (vegetation too dense or conditions too harsh) for seedling colonization. Many clonal perennials require multiple years to develop dense, spreading colonies that coalesce and often resist weed invasion when mature. They contribute to community diversity at the between-patch level, rather than within stands, because they often dominate or form single-species stands. Clonal perennial forbs that are native to sandy soils and shorelines of SE San Francisco include wind-pollinated aster family species such as *Ambrosia psilostachya* (western ragweed; previously reintroduced to Pier 94), *Artemisia douglasiana* (California mugwort), *Iva axillaris* (poverty-weed), and one insect-pollinated showy summer-flowering species such as *Symphyotrichum chilense* (common aster).

Symphyotrichum chilense

Ambrosia psilostachya

- **Clonal perennial graminoids.** Graminoids are grasses and grass-like plants. Unlike bunchgrasses and annual grasses, clonal perennial graminoids form extensive creeping perennial colonies, and dense root mats (sods), instead of discrete clumps. They are often associated with either mesic (somewhat moist) or sedimentary environments with soft substrate. Like clonal perennial forbs, they are strong soil binders and competitors once they are established. Many clonal perennial grasses take multiple years to form dense colonies, because they must allocate resources slowly in accumulating below-ground biomass. Grasslands dominated by clonal perennial graminoids are often relatively resistant to invasion by annual weeds because they form mulch-like persistent leaf litter mats and dense root and rhizome mats that capture soil moisture and nutrients. Species in this functional group range from slow-growing species of mesic lowlands, like *Carex praegracilis* (field sedge), or seasonally wet clay soils, like C. *barbarae* (basket sedge), to fast-growing species ranging from seasonal wetlands to dry flats, like *Elymus triticoides* (creeping wildrye). *Distichlis spicata* (saltgrass) also extends from tidal marshes to lowland terrestrial grasslands. *Melica imperfecta* is another creeping perennial native grass native to sandy flats and scrub; it tolerates dry soils and partial shade of trees and scrub (like creeping wildrye), providing a ground layer that may compete with weeds under shrubs.

Elymus triticoides



Carex barbarae and *C. praegracilis* meadow

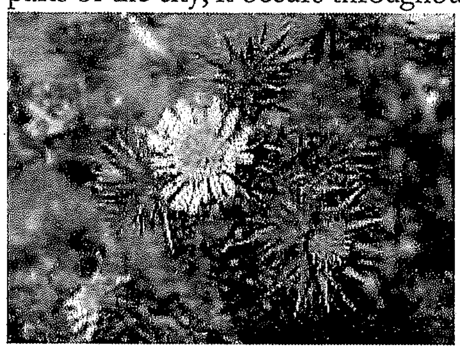
- **Summer-flowering caulescent (tall stem) forbs.** Flowering broadleaf plants (forbs) that form above-ground shoots (at least during flowering) and often grow from crowns and taproots, compose this broadly defined functional group. They are common in valley grasslands and coastal prairies. They are distinguished here from short, prostrate or acaulescent (rosette-form) forbs, which are usually unable to compete with coarse weeds. Most robust caulescent forbs selected for Pier 94 are annuals, but not all annual species are robust caulescent forbs that are competitive with weeds. Stands of robust annuals that are adapted to colonize "pioneer" disturbed soils are proposed for use as native "cover crops" at Pier 94 to seed over weed-cleared areas, and establish a rapid dense cover to compete with weeds.

Many annual Aster family forbs have "weedy" functional traits (slow initial wet-season growth above ground while producing deep taproots, adapted to disturbed but stressful soil conditions; producing large numbers of seeds that disperse efficiently) and typically form large, dense populations: coast tarweed (*Madia sativa*), hayfield tarweed (*Hemizonia congesta* var. *luzulifolia*), spikeweed (*Centromadia pungens*). The tarweeds and spikeweeds are summer annuals, growing and flowering through summer and fall, in contrast with winter and spring-flowering annuals that complete their life-cycles before soil dries. This enables them to compete with summer-active non-native weeds that can displace spring annual species.

Other tall summer-flowering annual forb (not aster family) native to SE San Francisco lowland terrestrial vegetation include ruby chalice clarkia (*Clarkia rubicunda*) and *Phacelia distans*. All of these species can grow and complete well in sandy flats. Another disturbance-dependent native annual "weed" of SE San Francisco bay shores was flowering tobacco, *Nicotiana quadrivalvis,* a species highly valued and cultivated by many California Indians tribelets throughout Central California. Native annual upland clovers (*Trifolium* spp.) are also well-adapted and native to sandy SE San Francisco soils. Most of these native annuals are rarely cultivated by native plant nurseries (focused on container production of perennial and woody species), and would need to be propagated on-site.

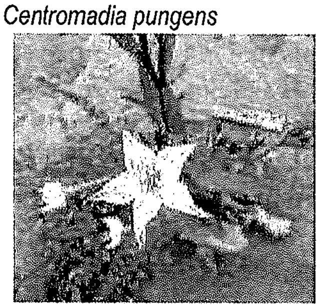
Perennial forbs well-adapted and native to arid sandy lowland soils of SE San Francisco, suitable for grassland-forb assemblages on the sandy flats, include the following species that still occur in remnant vegetation within San Francisco and the northern San Francisco Peninsula. These species are recommended for addition to planting at Pier 94 because of the greater extent of sand area and higher sand content than originally anticipated for the fill platform.

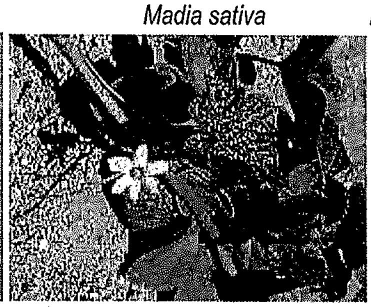
- Field chickweed (*Cerastium arvense*), a native low-growing creeping perennial forb;
- Sticky cinquefoil (*Drymocallis glandulosa*; syn. *Potentilla glandulosa*), a taprooted, low-growing perennial forb with taller flowering shoots;
- California Horkelia (*Horkelia californica*), a taprooted, low-growing perennial forb with taller flowering shoots;
- Wild cucumber (*Marah fabaceus*), a massive taprooted prostrate perennial forb;
- California phacelia (*Phacelia californica*): mounding, taprooted, spring-summer flowering perennial forb.
- Hedge-nettle (*Stachys ajugoides*), a highly adaptable creeping forb with erect flowering shoots, also occurring among scrub; collected by W.L. Jepson at Hunters Point, but not currently known from eastern San Francisco.
- Hooker's evening-primrose (*Oenothera elata* subsp. *hookeri*) is a robust rosette-forming taprooted short-lived perennial forb with tall summer-fall flowering shoots and strongly "weedy" habits (abundant seed production, colonizing and thriving in disturbed lowland terrestrial soils). Although historical San Francisco records are all from western maritime parts of the city, it occurs throughout San Francisco Bay.


Centromadia pungens


Madia sativa

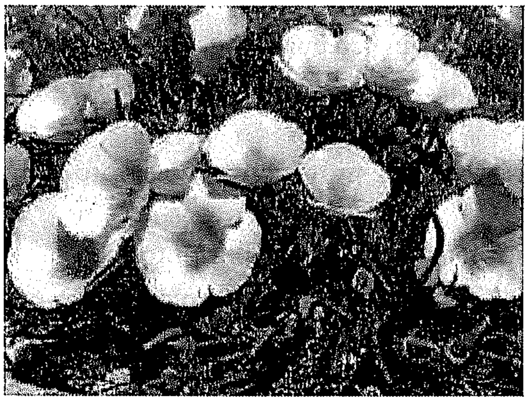

Hemizonia congesta var. luzulifolia


Nicotiana quadrivalvis

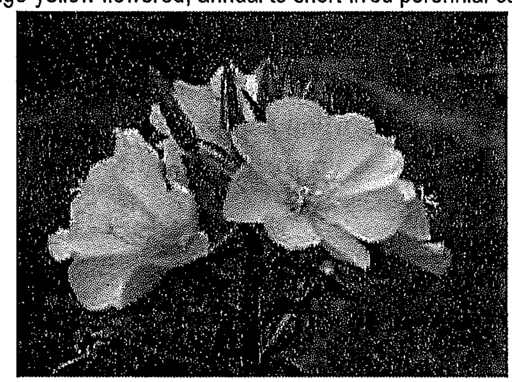

Marah fabaceus

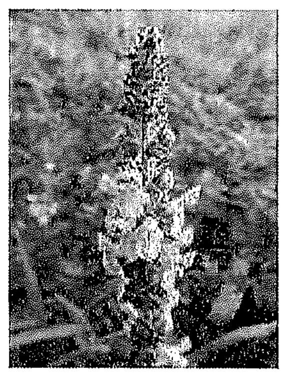

Phacelia distans

Another forb at Pier 94 is California poppy, *Eschscholzia californica.* Native San Francisco Peninsula populations are strongly perennial (large taproot), gray-green leaved, and yellow to orange-yellow flowered, in contrast with annual, tall, fast-growing and rich orange-flowered strains in commercial wildflower mixes (strains blended with populations from parts of southern California). The deep orange-flowered forms (some planted at Pier 94) that grow tall and rapidly are probably hybrids with bulk 'wildflower' seed mixes, and it would be advisable to remove them, and replace them with native SF peninsula populations. Perennial coastal ecotypes of California poppy colonize sandy flats by seed at rates similar to annuals.



Left, *Eschscholzia californica*, typical compact native Bay Area coastal perennial ecotype
Right, orange-yellow flowered, annual to short-lived perennial commercial seed mix type, Pier 94





Hooker's evening-primrose (*Oenothera elata* subsp. *hookeri*), summer-fall flowering short-lived perennial (left), and hedge-nettle (*Stachys ajugoides*), spring-summer flowering creeping perennial (right)

- **Winter and spring annual forbs.** Winter and spring annuals germinate and grow rapidly in fall when soil-soaking rains begin, and they flower and seed when soils dry in late spring or summer. Their early rapid growth, in combination with high seed density in the soil, can make them competitive with some weeds. Some winter annuals like miner's lettuce (*Claytonia perfoliata*) can tolerate open sun, but also thrive in moist partial shade under shrubs where growth of most annual forbs is inhibited. They can colonize and pre-empt space that would otherwise be available to weed seedlings. Winter-spring annuals adapted to open sun and sandy soils, and capable of forming dense colonies, include lupines (*Lupinus bicolor, L. nanus*).

- **Woody sclerophyll scrub and woodland** (hard evergreen leaf shrubs and trees). Woody plants with evergreen, hard leaves are usually slow-growing and tolerant of physiological stress like summer drought. San Francisco supported few trees, mostly low-growing groves of coast live oak (*Quercus agrifolia*) and scattered stands of bay laurel (*Umbellularia californica*; associated with seeps) and locally in SE San Francisco, Islay cherry *Prunus ilicifolia*. Sclerophyll shrubs were widespread, like toyon (*Heteromeles arbutifolia*), coyote brush (*Baccharis pilularis*), and coffeeberry (*Frangula californica*). Many sclerophyll woody species can regenerate vegetatively ("stump-sprout") from burned or cut trunks. Because their tough leaf litter can inhibit ground layer vegetation, sclerophyll vegetation stands tends to exclude species-rich grassland vegetation. Thus, only isolated sclerophyll species are proposed for Pier 94. Few deciduous trees are part of the local flora, but some small California buckeye (*Aesculus californica*) trees can tolerate stressful habitats along with sclerophyll species. Trees and large shrubs provide important foraging, nesting, and predator escape habitat for wildlife. All these native sclerophyll trees and shrubs are relatively slow-growing and relatively slow to spread by seed (non-invasive).

In contrast, coyote-brush (*Baccharis pilularis*) is a special case of a native "soft" evergreen sclerophyll shrub that readily becomes invasive and dominant in disturbed urban or post-agricultural grasslands (cessation of both livestock grazing and aboriginal burning). Many grasslands on the San Francisco peninsula and elsewhere in the region have become irreversibly dominated by coyote-brush. Coyote-brush regenerates from pruning or burning (stump-sprouts) once it establishes a substantial trunk, so after dense populations establish, neither grazing/browsing, mowing, nor burning are effective at reducing its population significantly. At Pier 94, coyote-brush has colonized the new upland fill platform at high density (nearest neighbors in the range of < 1 m – 2 m) over most of the fill areas. The high rate of colonization is likely due to the high density of local tall, mature female (seed) shrubs on the landward parts of the site, the receptive fill substrate, and little competition during the drought years following fill placement. Mature coyote-brush shrubs reach over 2 m high and across in sheltered locations like Pier 94. Coyote-brush can overtop and outcompete all forbs, grasses and almost all other shrub species at Pier 94. Coyote-brush would form a nearly monotypic stand and significantly reduce native plant species diversity at Pier 94 uplands if seed-bearing plants are allowed to establish on the relatively small fill platform. Ample stands of coyote-brush already exist at Pier 94, and additional population size is not justified if native species diversity objectives are to be met. Coyote-brush should therefore be actively removed or reduced to minimal density of male plants on the fill platform; it should not be planted. (See Sectoin 4.0)

- **Erratic (incongruous, out-of-place) "city-native" and regionally non-native species.** Some species introduced to Pier 94 are associated with either soils, climates, or vegetation types "native" to other parts of San Francisco that are not represented at Pier 94, or are not part of the natural flora of San Francisco or even the Peninsula. For example, California fuchsia (*Epilobium canum*), a perennial/subshrub of rock outcrops, is widespread in California but was historically absent in the natural San Francisco flora until native plant gardeners introduced it. Though a California native, it is neither ecologically nor floristically meaningful contribution to the "restoration" of native vegetation or habitat at Pier 94, and should be treated as a "native garden" specimen plant if it is retained. The educational value of Pier 94 upland vegetation would be compromised if an arbitrary mix of "native plants" from within and outside the San Francisco Peninsula were combined.

  Some San Francisco native plants like California sage (*Artemisia californica*) are ecologically "native" to warm, dry, rocky south-aspect cliffs, bluffs or hillslopes, but are not a natural element of lowland flats bordering the bay. Red fescue (*Festuca rubra*) is an element of coastal prairie in cool, moist fog-influenced western slopes near the ocean or Golden Gate, but is not native to interior San Francisco Bay lowlands. Willow (*Salix* spp.) requires root contact with high fresh groundwater. Dune sage (*Artemisia pycnocephala*) grows in recently stabilized western San Francisco dunes, but is not native to the interior San Francisco Bay shoreline. Blue-blossom (*Ceanothus thyrsiflorus*) grows primarily in the maritime fog belt climate of the western half of San Francisco.

If erratic "native" species popular in urban San Francisco native plant horticulture are retained at Pier 94, they should be segregated (relocated) as a border garden near the entry path, analogous with the entry native garden at Heron's Head park at Pier 98. This segregation would prevent confusion in natural area interpretation of the site and its vegetation in the future, and would enhance its educational value. Non-local native plant species should generally not be established in the fill platform vegetation otherwise. The activities applied to maintaining erratic plants may interfere with establishment of suitable plant assemblages on the sandy and clayey flats, and in some cases, the plants themselves may interfere with vegetation objectives. For example, erratic plantings of large California sage planted next to California sea-blite interfered with growth of the rare endangered species. Species that fail to spread, or die back, because they are not well-adapted to warm, dry sandy soils of SE San Francisco, may create unoccupied space available for weeds, where better adapted native species would advance development of vegetation.

4.0 Planting and Seeding

4.1. Layout and patch types.

A schematic planting layout for Pier 94 is presented in Figure 1. It is based on substrate, landscape position, and assemblages of functional groups of plants from approximated local (SE San Francisco bayshore) native plant communities. Site preparation for planting, specifically weed management that is integrated with planting or sowing native species, is treated in Section 5. The layout addresses the interaction of the constructed and pre-existing uplands with the adjacent industrial port land uses (weed dominated, weed seed sources), and the site's wetlands. Some plant species overlap between sandy flats, shoreline (transition zone), and tidal wetlands, so vegetation units are not entirely discrete.

The **western edge of the uplands** is recommended to include a **"buffer" strip of taller, dense sclerophyll woody scrub and low trees** bordering the sediment stockpiles of the sand processing facility and the lot west of the south end of the site. The purpose of increasing sclerophyll shrub height and density is to facilitate trapping of wind-dispersed seeds into the suppressive shrub canopy, reducing weed seed rain from the weed populations (perched on the sediment stockpiles) to the new sandy flats. Management of the stockpile weed population would also assist this function (see Section 5).

Twin **native landscaped garden strips**, bordering the entry path, are included primarily to accommodate translocation (rather than removal) of erratic regional native species already transplanted to Pier 94, but which are not compatible natural elements of the local native plant communities or soils (see discussion, Section 3) . The landscaped native garden borders may also be suitable for more conventional urban native plant gardening volunteer activities (more intensive weeding, mulching, watering, etc.), so they do not interfere with low-input management (no mulch, fertilizer, irrigation, intensive localized long-term manual weeding) of the sandy flats, wetlands, and shorelines, where facilitation of natural vegetation processes and patterns is emphasized.

An important secondary use of the native landscaped strips is the **on-site open bed nursery production** of native annual seed stock and clonal perennial population stock, for ongoing or sequential harvest, seeding, and transplanting. Along the back of the native landscaping borders, beds of actively cultivated stock populations can be efficiently managed close to parking and offloading of materials. These beds may be repeatedly harvested to supply the remainder of the site with seed and transplant stock, without ongoing costs and risks (pathogens, weeds, non-local genotype contamination) of imported off-site nursery stock. Nursery beds are proposed as non-structural features: local intensive cultivation (garden strips) without any raised or sunk beds, lining, or construction. The primary purpose of the border nursery is to supply steady, repeat-harvest source of secure on-site propagules for revegetation, but secondary purposes include: (a) consolidation of all erratic "California native" but ecologically and geographically out-of-place species like California fuchsia (Epilobium canum) and other non-local species; and (b) if desired, a park-like entry path (like Pier 98, Heron's Head) for visitors that will not compromise the rest of the upland native vegetation or spread horticultural plantings over restoration plantings.

The new (2013) fill platform is predominantly sand or silty sand, (sandy flats) with a local area of clay or clay loam near the south end (clayey flats). The greater extent of predominantly sandy sediments in the fill (Perlmutter 2013) requires some adjustment of the original planting specifications. The **sandy flats** would naturally tend to support both grassland (graminoid and forb) and scrub vegetation, but because of strong seed rain by coyote-brush, it would likely undergo rapid succession to relatively uniform dominance by scrub vegetation (especially coyote brush). This process is already in progress (2014-2015). In addition, natural spread of reintroduced lupine shrub species would tend to accelerate succession to "soft" scrub as well. Extensive solid stands of scrub on the sandy flats would provide high cover values for some wildlife species, but higher plant species diversity, higher wildlife habitat diversity, and better scenic/esthetic values would be conserved by a **matrix of grassland and forb communities with a scrub edge and local patches of scrub**. Active restriction of scrub invasion of potential grassland is therefore recommended as part of intermittent management of the sandy flats vegetation.

Two types of sandy flats grassland assemblages (patch types) are suitable for planting, one primarily valley grassland (herbaceous), one primarily scrub (woody). The valley grassland vegetation is a mosaic composed of two functional groups: **clonal perennial graminoids and forbs** and **caulescent annual and perennial forbs**. Sandy flats would support a patchy mix of semi-open vegetation, with lower density of clonal forbs and grasses than clayey flats. Sandy flats with grassland vegetation would likely be more vulnerable to weed invasion than scrub or clayey flats, because of the persistence of open sandy soil and thinner vegetation cover. The success of high diversity sandy flat grassland vegetation would depend on progressive reduction of weed seed rain from within the flats, and from its borders, as well as progressive reduction in soil seed banks of weeds.

The relatively **clayey flats** (south end of fill area) would support a higher density of clonal **perennial graminoids and forb vegetation** over a period of about 4-6 years, undergoing succession to form a more closed vegetation (dense cover, litter mat) with fewer gaps supporting caulescent perennial or annual forbs. This vegetation would incrementally increase in resistance to weed invasion because of closed cover, dense sod, and accumulated litter mats. Closed vegetation would also restrict the frequency of shrub seedling recruitment.

The **seaward edge of the sandy flats** is proposed for a continuous prevalence of **clonal perennial forbs and graminoid** vegetation patches, designed to spread out slightly into the relatively resistant unimproved rubble substrate, and provide some buffer resistance to weed incursions from the older rubble flats.

The sandy flats would also support a higher turnover of non-sclerophyll ("soft" scrub), fast-growing, colonial **nitrogen-fixing scrub**: bush lupine and Chamisso lupine, distributed in discrete (spatially segregated) patches. Bush lupines populations would likely undergo rapid spread and also rapid cycles of dieback and regeneration. Lupine shrub stands are likely to suppress weeds, but they also release weeds when they die and leave enriched vegetation gaps. Lupine patches are proposed for the edges and back of the flats, and also for "founder populations" within the matrix of upland coyote brush and weedy herbaceous vegetation.

The shoreline **transition zone** between "uplands" (terrestrial lowlands) and tidal wetlands is proposed for diversification with native shoreline species (see Appendix 1), many of which are also adapted to the similar sandy flats – especially clonal perennial forbs and graminoids, but also some caulescent forbs. See also Appendix 1.

A special treatment area for endangered California sea-blite is proposed for the naturally deposited low beach ridge on the north shore of the site (derived from erosion of 2005 beach nourishment updrift). Sea-blite transplanting is described in Section 5.

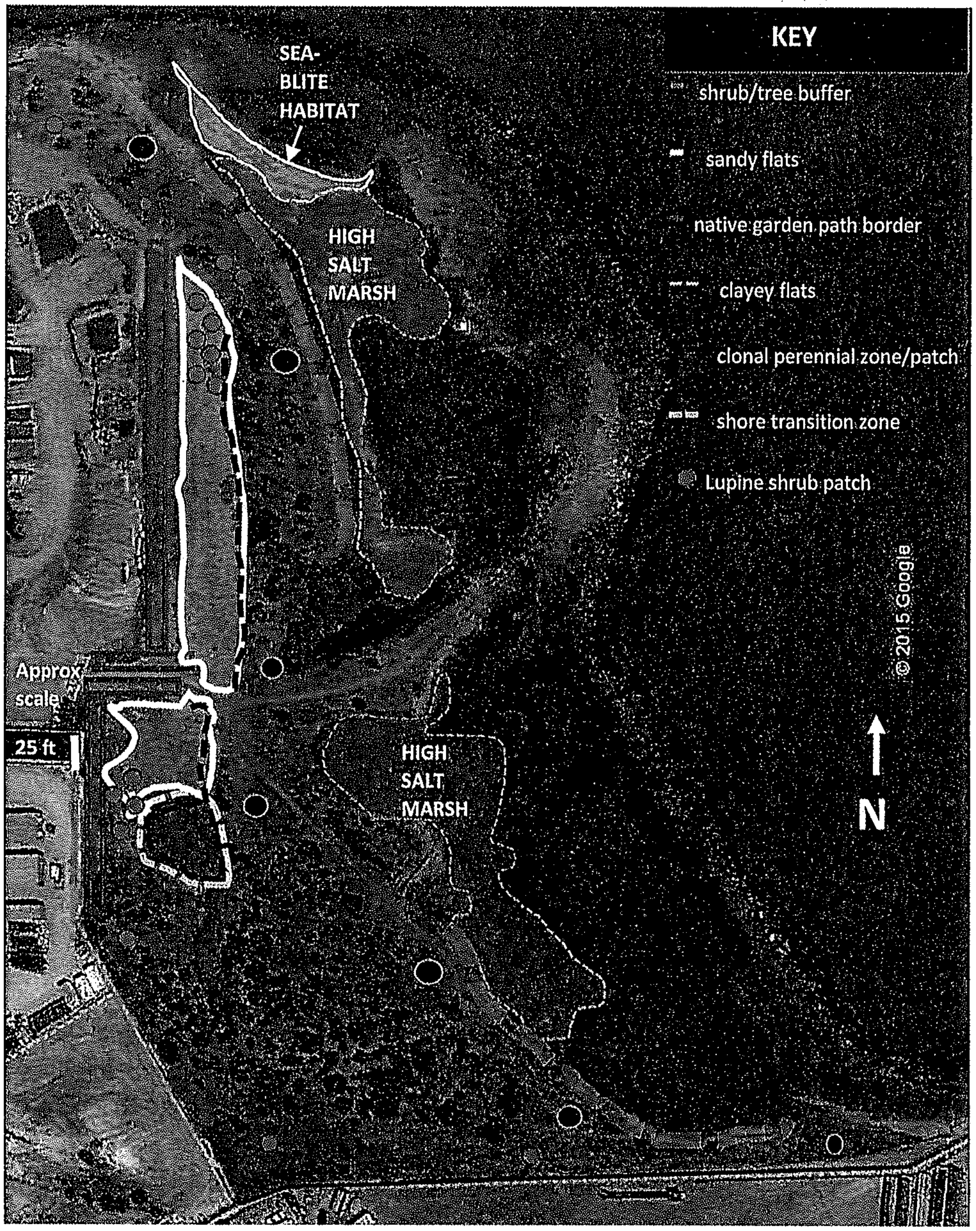


FIGURE 1. Schematic planting layout and vegetation management zones – Pier 94
Shrub/tree buffers along industrial land use boundary screen weed seed dispersal from waste areas off-site. Sandy flats are the foundation for valley grassland and lupine scrub patches, bordered by a clonal perennial grasses and forb zone. Isolated trees may be planted in sandy flats. Local clayey flats are vegetated with clonal perennials. Clonal perennial patches are also distrusted above the shoreline transition zone. Lupine shrub patches (*L. chamissonis*, *L. arboreus*) are clustered at corners or the back of sandy flats to restrict rapid spread by seed, but are distributed in older upland vegetation to facilitate spread by seed into existing weedy vegetation. Native wetland plant species diversification zones are shown in accessible high salt marsh, and also along the shoreline (terrestrial lowland/wetland transition zone). The low barrier beach/marsh transition zone formed at the north end of the marsh is suitable sea-blite habitat. Approximate scale is shown (concrete water basin edge). All boundaries and localities are approximate, schematic representations to be adjusted in the field.

4.2. Transplanting methods for perennial herbaceous and woody species.

Transplanting methods for perennial forb, graminoid, and woody species are summarized below.

- **Timing and weather**. Transplanting should occur only in cool (under 52°F) **cloudy, moist weather** from **late fall to early winter**, following rainfall sufficient to moisten at least the top foot of soil. The need to restrict transplanting to this critical time is based on the following factors:
    - *Minimization of transplant shock and post-transplant stress and mortality risk*. Stress and mortality risk are minimized by cool temperatures and moist weather during plant dormancy or low physiological/growth activity.
    - *Time for root development during moist soil season*. Planting later in the rainy season reduces the time available for development of root systems architecture to access sufficient volume or depth of soil to support survivorship or growth during the long dry spring-summer season. Fall-winter established transplants avoid need for aseasonal irrigation.
    - *Minimization of low turgor or wilt periods*. Moisture stress during post-transplant growth causes loss of turgor (cell sap pressure) needed for root growth and new root branch development. Repeated low turgor/wilt events due to transplanting in dry, windy, warm, or sunny weather (mid-winter to spring) risk inhibiting root development below thresholds needed for high survivorship.

  Like dry farming, native vegetation planting must be scheduled according to weather rather than fixed calendar dates. Dry or warm weather must postpone planting. Spot irrigation is not equivalent to rainfall for native plants. Localized soil wetting cones confine root system development to artificially narrow zones, leaving them vulnerable to failure when irrigation ceases or fails to keep pace with summer water loss. Irrigation also provides competitive advantage to annual weeds adapted to exploiting moisture during the spring-summer growing season (typically with higher growth rates and water use efficiency than plants adapted to Mediterranean climates).

- **Patch preparation: weed clearing and blocking.** Transplants should not be planted into a matrix of weeds. Weed seedlings should be "flushed" (stimulated to mass germination) by the time soils are sufficiently moistened for transplants. Weed seedlings and any persisting adults should be cleared completely from a radius of at least 1.5 ft from the transplant. Regeneration of weeds should be blocked by a water-permeable cover functioning like a mulch, but without adding soil organic matter, moisture-holding capacity at the surface, or nutrients (features typical of horticultural mulches) that enrich the soil around the transplant. Decomposing garden mulches facilitate weed invasion, growth and competition, which is counter-productive for transplanting. Suitable weed blocks include coarse wood fragments (not fine wood chips, which, easily decompose, hold moisture and facilitate weed seed deposition), such as coarse shredded bark or loose shallow layers of cut brushwood, piled around the base of the transplant. Weed-block fabrics may also be used, but they must be removed, and risk becoming loose trash if disturbed by high winds.

- **Bare-root dormant transplants and sod divisions.** Transplanting with container soil or growing medium surrounding roots is disadvantageous for transplants. Container growing media/soils generally have lower bulk density, higher moisture holding capacity, and higher fertility than surrounding soils, which promotes root branching within the transplant soil ball, and discourages root spread away from it. Container soil from nurseries is also a potentially significant vector for pathogens, harmful insects, or weeds. Containers are also heavy to transport. Their main advantage is that they enable transplant stock to be held or carried over time, in fair or cool, wet weather. This advantage is not significant if transplanting is properly timed for wet cool weather, and is completed on schedule. But bare-root transplants maximize root contact with matrix soils, and can be transported wet (wrapped in wet burlap or wet vermiculite/sawdust in plastic bags). Bare-root transplanting is recommended for all perennial and woody plants, with shoot trimming (see next).

  Clonal forbs and graminoids can generate transplant units as sod divisions – sections or plugs of soil with roots and rhizomes, a few inches across and deep (to depth of rhizome layer), dug from well-established colonies. Sod divisions of clonal perennials regenerate from transplanting with high vigor and more resilience than bare-root transplants, and is preferable as the transplanting unit, over nursery container-grown plants or bare root. Bare-root methods work very well (high survivorship) for dormant rhizomes handled properly, however. Priority species for open bed production of clonal sod divisions include western ragweed, common aster, creeping wildrye, poverty-weed, heliotrope, and sedges.

- **Transplant trimming: adjusting root:shoot ratio.** Transplanting leaves shoot leaf area largely intact, but causes loss of root length and surface area, particularly small branch roots that are most efficient at absorbing water and supporting mycorrhizae (beneficial root fungi). Transplanting thus reduces root:shoot ratio. Dormant or quiescent perennial and woody transplants have stored reserves in roots and shoots, and readily tolerate shoot pruning (like herbivory) to balance root loss during transplanting. Generally up to 2/3 of shoot mass can be pruned to reduce transpiration loss of transplants, and balance root:shoot ratio. Temporary reduction of shoot mass is rapidly compensated later in the growing season by superior root development and faster shoot development of pruned plants. Trimming further reduces post-transplant water demand and increases capacity to tolerate periods of dry winter weather. Trimming before handling transplants in the field enables bare-root transplanting to occur with no significant stress or injury to roots.

- **Nearest neighbors.** Spacing of transplants depends on growth form, species, mature size, and type of spread. Neighbors should be from the same functional groups or compatible functional groups for soil types (Section 3.3.). Clonal forbs and grasses should be expected to spread by rhizomes several feet in diameter or more around the transplant point within 5 years. They should therefore not be planted adjacent to other perennials or shrubs closer than this distance, unless a fine-grained clonal patchwork is intended. Tall shrubs should be planted only in borders or discrete patches, not interspersed with shorter herbaceous plants. Native annuals should be oversown into gaps between perennials and shrubs to occupy bare seedling space that would otherwise be available to weeds. Native annuals (native "weeds") are not expected to provide the same harmful intensity of competition with perennial species as non-native weeds.

- **Inoculate subsoil with sandy soil microbial diversity from mature native vegetation and drench transplants with organic leachate (dissolved or colloidal organic matter). [Optional].** Sandy and clayey sediments of the fill platform were obtained from deep subsoil excavation, and are likely very low in organic matter and soil microbial diversity. Some widespread, rapidly dispersed mycorrhizal species are likely to colonize the soils within the first two years, but to reduce risk of transplant establishment constraints by deficient soil microbial symbiotic interaction, two amendments are recommended. First, very small volumes of subsoil root zone sand from mature native vegetation stands may be obtained and "diluted" by mixing 50:1 (Pier 94 sand:mature vegetation sand) to provide a microbial diversity inoculum (bacteria and mycorrhizal spores). Potential SF borrow areas (with permission) include old oak stands in Golden Gate Park (Arguello), Grandview Park (Sunset Heights), and Presidio locations (Lobos Dunes, and Wherry Dunes). The 50:1 mixed sand can be "dusted" over the bare-root transplant root system (sand grains contact roots directly). Weed growth at Pier 94 has already contributed some initial soil organic matter and probably limited microbial diversity. To increase available dissolved carbon to microbes around the bare-root transplant, without enriching soil nutrients significantly, a dilute "compost tea" (water leached through compost, producing tea-colored water) may be used to drench the transplant root system after transplanting. If a "compost tea" is not applied, the transplant must be drenched with fresh water after transplanting, unless soil is wet from recent rain.

  Commercial mycorrhizal inoculants used in horticulture are not ecologically suitable substitutes for "wild" local soil microbial inoculum from native local donor soils. Commercial mycorrhizal inoculum used in horticulture and agriculture is composed of widespread generalist fungal species. Local soils from old (especially prehistoric) vegetation should be presumed to be significantly higher in native microbial species diversity.

- **Soil re-compaction or berm after transplanting.** Loose soil or sand with air pockets and large pore spaces between grains is a severe hazard for young transplants early in establishment. Brief periods of warm, dry weather can rapidly desiccate plants with insufficient root surface area in contact with moist sand or soil. Soil compaction is not a hazard for sandy soils, but loose soil is. After transplanting, moist sandy soil should be firmly compacted around roots, prior to soil drenching, with the heel. To ensure that rainfall runoff does not flow away from the transplant, the transplant compaction should either leave a very shallow depression in the soil, or a very small berm (1 inch high) should be made to encircle the transplant about half a foot to one foot in diameter. This also helps focus infiltration of the soil drench around the roots.

- **Brushwood shelters.** If prolonged periods of dry, windy, warm or sunny weather occur in weeks after transplanting, transplant transpiration (leaf water loss) can be minimized by constructing loose cut brushwood shelters (cones or "teepees") around transplants, to provide partial shade and reduced wind shear on leaf area. Shelters also provide temporary resilience to soil moisture deficits in spring. Brushwood shelter material may be obtained by either hard-pruning or removing coyote-brush on site, particularly seed-bearing female coyote-brush shrubs adjacent to the edge of the fill platform. Hard pruning coyote-brush does not injure the plant, which resprouts vigorously even from stumps. Suitable brushwood sources on-site include either coppicing (repeated harvest/hard-pruning) female coyote-brush (seed-bearing *Baccharis pilularis*) or removal of excessively frequent, invasive juvenile coyote-brush shrubs.

- **Prohibit all broadcast fertilizer applications or organic soil amendments.** Any application of added nutrients on the soil surface, aimed at transplants, will become relatively more available to weeds, and will be exploited more efficiently by weeds than native plants adapted to infertile sandy soils. Similarly, adding compost (organic soil amendments) to the planting hole will encourage concentration of roots in the enriched spot, instead of deeper or wider roots needed for stress tolerance. Enriched soil pockets also become oases for weed growth, since weeds usually have higher relative growth rates and nutrient use efficiency than stress-tolerant native plants. If any nutrient addition is provided for transplants, it should be available only to the transplant. One option is to dip transplant root in a slurry (silty mud, batter-like consistency) with very dilute dissolved balanced fertilizer (NPK ratio multiples of 1-2-1 or 1-1-1) at the time of transplanting. Placing a few pelleted fertilizer grains (1-2 g or less) directly beneath or within the transplant roots is another option.

- **Prohibit irrigation except as short-term winter drought emergency "bridge" between intermittent rains.** Irrigation of native transplants is generally misapplied in Mediterranean climates, often because transplant time is asynchronous with seasonal fall-winter rainfall, and delayed to dry spring weather, like temperate eastern U.S. climates. Irrigation favors weed growth over target species growth in infertile, summer-dry soils, and distorts root system development of native plants, confining or concentrating them to artificially narrow wetting zones of irrigation points. Irrigation should be applied only on an "emergency" (risk of mass mortality during winter droughts) basis only, to bridge dry periods between rainfall events. Irrigation should never extend into the dry season (March-April and later in the dry season).

4.3 Seeding annual forbs

Seeding native winter and summer annuals must be done in fall, synchronized to follow the first flush of weed seedling emergence. The first flush of weed seeds in the patch to be sown must be removed by shallow scraping with a hoe or spade, exposing bare soil. The cumulative density of all annual species sown should aim for 50-200 per square foot, allowing for significant mortality. Large seed (tarweeds, spikeweeds, lupines, fiddlenecks) should be pressed or very lightly raked into the soil surface, and firmly compacted with the spade, or a (weed seed-free) boot. Finer seed (Clarkias) should be sown last. Sown patches should not be irrigated at all; sown seed should depend on natural germination cues from rainfall and temperature. Seeded patches interspersed with perennial plantings should aim for a minimum size of approximately 10 ft diameter, to minimize edge effects of potential weed seed sources outside the patch.

4.4. Wetland plantings

Planting perennial tidal marsh and transition zone forbs and grasses employs essentially the same methods as terrestrial plantings, but initial irrigation/soil drench, brushwood shelters, and weed barriers are not applicable. Instead, for transplants in locations exposed to wave scour during storms (especially shoreline locations near the high tide line), punching sticks (cut brush) deeply into the substrate in a ring around the transplant, with above-ground segments about 0.5 ft above ground, may help shelter the transplant from erosion and uprooting. Wetland and shoreline plants must also be transplanted during late fall/winter, during cool, wet weather.

4.5. On-site open nursery beds

The back of the landscaped entry strips (native plant gardens) should be cultivated to produce native annual seed crops and perennial planting stock for sowing into sandy flat patches. Priority species for seed production are coast tarweed, hayfield tarweed, spikeweed, ruby chalice clarkia, miner's lettuce, and fiddleneck. Rows of annual plantings should be flanked with weed control fabric, facilitating both seed harvest and weed control. Patches of clonal perennials should also be grown at high density to annually supply sod divisions.

5.0 Weed management

Biologically-based weed management aims at population-level control of weed invasions. Population management of weeds has two aspects: direct negative aspects aimed at reducing weed reproduction and population size (removal methods), and indirect aspects aimed at facilitating native plant competition against weeds at the seedling or adult stage, or changing the environment to one in which weed competitive advantages are weakened (e.g., modification of seedling habitat, vegetation cover and density, frequency of disturbance or gaps, nutrient levels in soil).

Weed population reduction should not be aimed at bulk removal of fully grown, reproductive (flowering and seeding) weed stands. Mowing, cutting, pulling weeds in the seed stage is usually ineffective or counter-productive: it releases seeds back into disturbed open areas that favor weed recruitment. Weed removal should be aimed at manipulation of critical life-history stages to restrict reproductive success, dispersal, regeneration, and recruitment of weeds. The methods of removal themselves, and the total labor applied, are secondary in importance to the timing of removal in relation to weed development. The primary targets of weed control are:

- Pre-emption of seed production
- Management of seed rain from margins of Pier 94 (*peripheral* weed populations) and weed populations *internal* to the site
- Management of soil weed seed banks (short-lived and long-lived, persistent seeds)

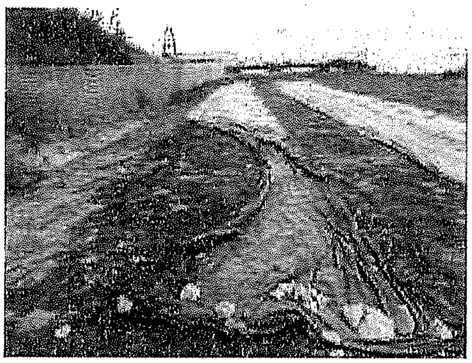
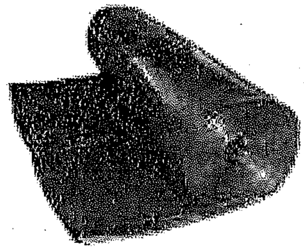
For annual weeds at Pier 94 (the majority of weed species), the **seed germination and emergence stage**, following **first germinating rains in fall**, and the **onset of flowering** (prior to formation of viable seeds) are the two most critical stages on which to focus weeding efforts. Flowering times for different weed species range from January (Bermuda-sorrel, *Oxalis pes-caprae*; French broom, *Genista monspessulana*, which may regenerate from dormant seeds for at least 15 years after eradication or cessation of reproduction) through February-March (many annual Mediterranean grasses) mid-spring to summer (bur-clover to summer and fall (Mexican-tea, sweet-clovers, telegraph weed, fennel, Italian thistle). The flowering times of different species vary seasonally (often according to temperature and timing of rains), and cannot be predicted for long-term scheduling: weeding activities need to be updated frequently based on regular and frequent monitoring (careful observation, not necessarily data collection) of weed populations. Allocation of weed removal efforts should switch among species, based on when they begin to flower. For annual plants, the optimum time to remove weeds is often after they have committed all their growing shoots and buds to flowering, but before they form viable seed. At this stage, they are least able to regenerate after mowing or partial removal by manual pulling.

Most problematic are weeds that form persistent, long-lived seed banks, like French broom. Long-lived seed banks can continue to enable seedling recruitment long after active seed reproduction has ceased, or long after mature plant populations have been effectively extirpated. Persistent weed seed bank management requires annual surveillance for seedlings, and the manual or mechanical removal of seedlings and juveniles before they reach flowering or seed stages. Persistent weed seed banks can also be managed by establishing competitive (suppressive) native vegetation cover, such as dense shrub canopies (lupine, coyote brush), or dense clonal perennial vegetation stands with persistent leaf litter mats that inhibit seedling emergence.

Spatial strategies for weed control should precede selection and application of weed removal techniques. The pattern and type of weed removal depends on the type of weed stand. Weed stands at Pier 94 can be classified as

(a) **monotypic** (pure, solid) weed stands, no significant frequency of native species;
(b) **low density/frequency** native plant populations in matrix of weed stands;
(c) **mixed or equitable interspersed** native and non-native invasive plant populations; and
(d) **native-dominated** stands with significant minority of weeds.
(e) **peripheral weed stands** that are important seed source populations located upwind and particularly adjacent or above the elevation of the fill platform (seed rain at high density and rates of deposition)

Pure or nearly monotypic weed stands should be efficiently treated with **bulk removal**: indiscriminate lethal treatments like **black plastic or geotextile,** anchored by heavy wood, concrete, or rubble weights added to prevent storm wind removal) applied after the first flush (cohort) of weed seedling emergence is complete (seedling-juvenile transition stage). Heavy-duty black plastic (6 mil thickness; 6 one-thousandths of an inch, 0.006" = 0.15 mm) should be used to minimize tearing and shredding due to wind shear and puncture. Black plastic is the best non-herbicide treatment for persistent *Oxalis pes-caprae* populations, but is effective only if placed over populations very soon after shoots emerge. Black plastic treatment of most broadleaf and graminoid seedling populations is effective throughout the winter-spring vegetative growth period, especially at earlier developmental stages (fewest leaves and stored reserves per individual juvenile plant). Black plastic is not effective as a control of weed populations once they have formed seed.

Thin (1-2 mil) black plastic (left) is prone to tearing, shredding, dislodging when exposed to high winds and friction during use as used as an opaque plastic mulch (Pier 94, October 2015). Heavy-duty 6 mil (0.15 mm) thick black plastic (right) is more durable through at least one year's use.

Mechanical manual removal (spades, hoes) are also feasible for mats of weed seedlings, but is less efficient than black plastic for large areas of treatment while juvenile weed height is low, and below-ground stored reserves in roots are very small. The time for bulk treatment is generally before late winter, and if it can be completed in fall (early rains, early complete mortality), the treated patch may cautiously be opened to allow light to trigger germination of residual weed seeds. If the second flush weed seedling density is low, it may be possible to make the treated patch available for native revegetation by sowing native annual cover crop species and transplanting perennial/woody species during wet winter months. Mechanical manual removal (spades or weed wrenches) is also most feasible for removal of juvenile or juvenile-adult transition coyote-brush shrubs (1-2 yr).

Weed stands with low density of native plants (survivors of previous plantings) in a matrix of dominant weeds indicates the need for **salvaging (translocating)** infrequent natives into holding beds (like the landscaped entry border garden; Figure 1) during fall-winter, so the patch can be treated as a monotypic weed stand (bulk removal of all weeds, versus weeding inefficiently around sparse native plantings).

Interspersed populations of weeds and frequent native plants may require manual removal methods over many months, with priorities shifting to weed species approaching or reaching flowering stage. Mechanical and manual removal is generally required for interspersed stands of native plants and weeds.

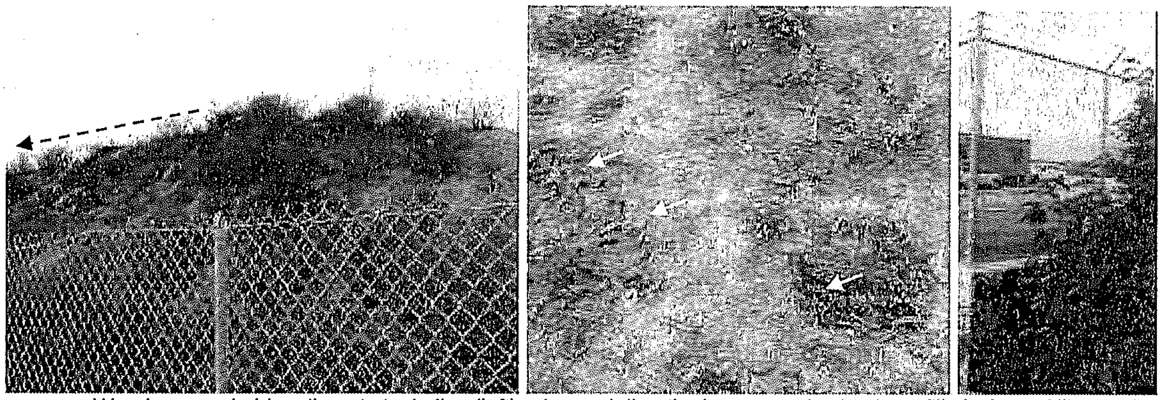
Manual and mechanical removal techniques suitable for seedlings and juvenile weeds interspersed with native plants requires some precision and selectivity. Selective weed removal with least impact to overlapping native plants is achieved when weeds are smaller to the same size (juvenile stage) as native species. Weeding at later stages of development has higher impact. Suitable tools for removal include tile spades (drain spades; long, narrow blades, short or long handles), D-spades (garden spades), hoes, and mattocks. Mattocks require more back and upper body strength than spades. Spades can be used as weeding tools using the toe or heel of a boot, to reduce labor burden on back and upper body. This may extend the duration of weed work if target weeds are juvenile, not requiring strong force to remove.

Weed removal should be performed in consolidated large blocks in which species-specific weed seed production is effectively eliminated or reduced to negligibly small levels. Weed-treated areas should be cleared of target species, and not merely thinned, before allocating weed removal labor to other plots. Boundaries of weed plots should be clearly delineated (symbolic flagging or temporary twine fence) to focus removal efforts. If adjacent plots cannot be fully treated before seed production begins, the edge of the treated plot may be buffered against re-invasion by mowing (close to ground as possible) the edge of the untreated weed stands several yards back. Mowing is likely to leave low-growing or prostrate weeds intact, but it may reduce seed rain of some highly invasive species.

Native species can also become excessively dominant, reducing diversity of other native species. This has already occurred where heavy seed rain of coyote-brush (*Baccharis pilularis*) has colonized sandy and clayey fill with high density of seedlings and juveniles, before active revegetation occurred. Native invasive populations can and should be managed as other invasive species, removed in bulk or selectively where they interfere with establishment of target native vegetation. Heavy colonization by coyote-brush was likely an artifact of the bare new substrate and lack of competition, but significant seed rain of this species from surrounding mature stands is likely to require active thinning/removal to maintain grassland vegetation diversity, and prevent succession to coyote brush-dominated scrub throughout the flats. Similarly, bush lupine (*Lupinus arboreus*) may become dominant in areas reserved for maintenance of higher grassland species diversity, and new "invasive", out-of-place colonies may justify removal.

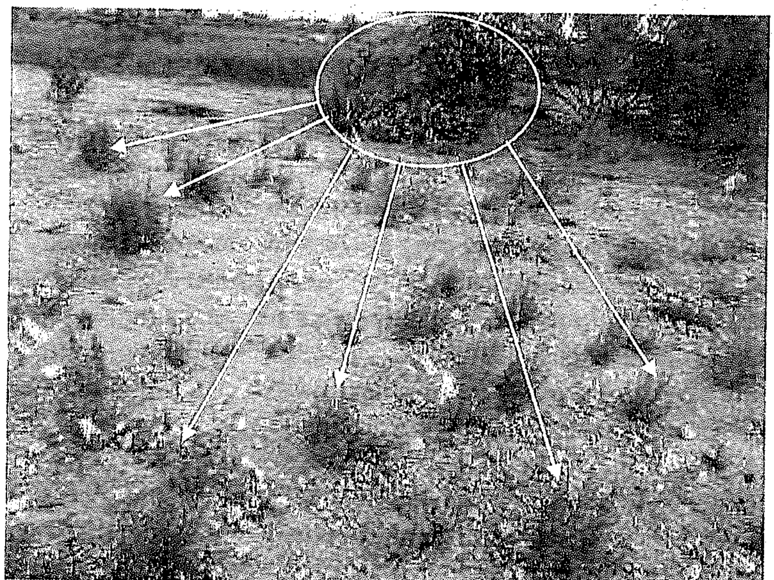
Pier 94 and the site vicinity should be surveyed for pioneer founder populations of new weed species or emerging weeds. For example Mediterranean tarweed or stinkweed (*Dittrichia graveolens*) has in recent years colonized the site, but has not become a dominant species yet. The new sandy flat fill has also been colonized by an invasive subspecies of a closely related native annual aster (*Symphyotrichum subulatum* subsp. *squamatum*, similar to native var *parviflorum*; see Appendix 1). Control of new terrestrial weed invasions should rely on early detection and identification, and prompt removal before seed production. This requires avoiding procrastination in identifying all unknown plant species detected on the site.

Management of peripheral weed populations, particularly those directly adjacent to the managed vegetation of the fill platforms, is as least as important as direct removal of weeds within the footprint of managed vegetation. Seed rain (transport and deposition) is an exponential decay function from seed sources, even for wind-dispersed seeds: most seeds fall close to the source population, significant decline with distance. The weed-covered sediment stockpiles along the west edge of Pier 94 fill platforms, and the coyote-brush, silk-tree (*Albizia julibrissin*), radish, and other weed stands bordering the south half of the site's west (upwind) edge, are important long-term seed source areas. The silk-tree should be killed by girdling (stripping a continuous ring of bark down to cambium/green underbark) if allowed by the Port of San Francisco. It would be prudent to obtain permission to enter the sand refinery stockpile areas to remove weeds or mow them to minimize weed seed dispersal to fill platform. Control of weed seed production and dispersal along the southwest edge bordering the fill platform is also recommended. Selective removal of female native coyote-brush (seed mother plants) is also recommended to reduce seed rain pressure of coyote-brush on the fill platforms.



Weed-covered old sediment stockpiles (left) rain seed directly down over the northern fill platform. Silk-tree (*Albizia julibrissin*) deposits dry fruits (yellow arrows) with highly persistent seeds litters the NW end of the southern fill platform. These are examples of peripheral weed populations whose management would reduce direct weed management of the Pier 94 upland vegetation.

High density of coyote-brush juveniles from seedlings on southern fill platform in October 2015 (left) likely originated from abundant seed produced on female (seed-bearing) shrubs on adjacent uplands (right; 2014). Selective removal of large seed-bearing female shrubs next to the fill platform (while retaining males for habitat) would reduce long-term seed pressure on the vegetation. Succession would produce dense thickets of tall, nearly single-species stands of coyote-brush, eliminating most other native species on the fill platform.



A large seed-bearing (white "fuzz") female coyote brush directly adjacent to the fill platform is a highly efficient source of intensive seed rain on the fill platform, and is potential parent of many nearby seedlings, especially while competition from native perennial vegetation is low.. Selective removal of female coyote-brush closest to the fill platform should allow time for perennials to form more continuous vegetation, closing vegetation gaps that are receptive to high density of coyote-brush seedlings. Thick perennial vegetation and litter mats inhibiti coyote brush seedling establishment.

Wetland areas are also subject to permanent re-invasion by tidally dispersed seed from nearby weed-infested marshes. Small re-invading founder colonies reaching reproductive maturity can quickly build high density seedling populations on site. Early detection and removal of juvenile or early-stage flowering individual founders is key to preventing rapid re-invasion by Algerian sea-lavender (*Limonium ramossisimum*), Mediterranean saltwort (*Salsola soda*), and hybrid San Francisco Bay cordgrass (*Spartina alterniflora* × *foliosa*)

6. Wetland and shoreline vegetation management

6.1. Appropriate plant species diversification of shoreline and salt marsh

The salt marshes of the northern San Francisco Peninsula bayshore supported a distinct subset of the region's salt marsh flora. Just as the San Francisco Bay salt marsh flora is similar but distinct from the Monterey Bay and West Marin salt marsh flora, the salt marshes within San Francisco Estuary differ among distinct regions within it, reflecting influences like substrate type, dispersal distance from species-rich marshes past and present, and diversity of local environments along the upper edges of marshes. Restoring the species richness of the local salt marsh flora with integrity requires that it not be overloaded with artificially high or erratic (out of place) species from other sub-regions. It also requires maintaining diversity among plant populations, where locally distinct or isolated populations occur.

Therefore, **source populations of most native salt marsh plants should be obtained as close to the eastern shoreline of the northern San Francisco Peninsula as possible.** Very widespread (far-dispersing abundant seed) species like pickleweed, saltgrass, and jaumea may illustrate exceptions to this principle, but there is generally no need to plant them because they are already abundant locally.

Many salt marsh species that were historically present in San Francisco Bay tidal marshes in southeastern San Francisco (south to Visitacion Valley), but were extirpated by urban development early in the City's history. Some have returned spontaneously to Pier 94 in recent years, but in small, unstable populations. A goal of this management plan is to re-enrich the local native salt marsh flora with founder populations of extirpated or scarce native species. This does not mean planting all over Pier 94 salt marshes. It means planting or seeding founder (starter) populations sufficient distribution and size to enable them to spread and establish larger, resilient populations (fluctuating but persisting) without "gardening" the populations into place by extensive planting or replanting of the salt marsh. It also means not planting species or populations of salt marsh species that may occur elsewhere in the region, but not in this part of the Estuary.

Founder population sizes should vary with the colonizing ability of the species, and its life-history traits – for example, whether it spreads by producing lots of seed, growing slowly and producing seed crops intermittently, or relying more on vegetative (clonal) growth. Founder population establishment also depends on variables like patch suitability (how well the local transplant or seeding site hydrology, soil, exposure, and neighbor vegetation matches the ecological "niche" for establishing a new colony of the species), time of year and weather following transplanting, competition from native and non-native species, herbivory, winter storm erosion, and summer salinity stress. Some of these factors can be controlled (like patch location selection), but other important ones like storm erosion or drought-related salinity stress cannot.

For a practical working management premise (hypothesis), salt marsh founder population sizes are recommended to be a minimum of 25-50 genetically distinct individuals (genets; seeds or cuttings/divisions from different individual parents) for annual forbs and non-clonal, outcrossing perennial plants (plants requiring cross-pollination, lacking rhizomes or stolons). For clonal (creeping) perennials, a minimum founder population of at least 10 genetically distinct genets is recommended. Distributing founder colonies in small groups of neighbors, in proximity for cross-pollination (3-5 individuals or replicated distinct clones), is useful for ensuring an effective population size of reproducing individuals. Founder population sizes over 50 are probably not necessary or even beneficial: over-planting a population means that a relatively higher proportion of individuals will reflect artificial planting rather than natural ecologically patterned populations. Having as much of the resultant population originate from natural colonization and spread from founders, rather than persistent planted founder colonies, is more valuable.

Assessing suitable patch locations for founder populations any given species can be done practically by carefully observing the variability of conditions in locations where it occurs in source populations. Plant neighbors (associated species), vegetation traits (height, density, cover), indicators of past disturbance (erosion or wrack deposition), tidal drainage (pooled, saturated, well-drained at high tide) and relative elevations below the high tide line are all useful indicators of potential local habitat suitability for transplants or seed sowing.

Generally, sowing of salt marsh plant seeds should be timed for fall, so seeds can undergo months of relatively low salinity (high rainfall months) and cool temperatures, which prepare seeds for germination. Germination and emergence usually occur in low salinity periods with gradual soil warming (increasing daylength in late winter), but some annual species may germinate and emerge soon after fall rains. Fall sowing does bring the unavoidable risk of seeds being transported by winter storm wave erosion.

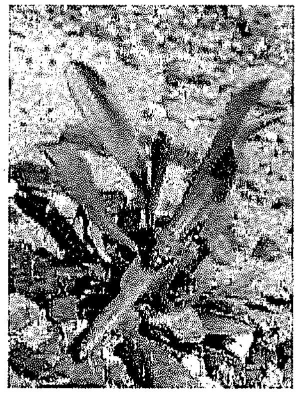
Transplants of perennial species should be done **only in cold, wet weather** in early winter when plants are **dormant or a state of inactive growth.** Tops of transplants should be **trimmed** (cut back; basal leaves removed, leaving only youngest leaves; or top-pruned for highly branched plants) before transplanting, to reduce transpiration and maintain turgor needed for root growth (cell sap pressure). **Bare-root dormant transplants** pressed into native local substrate is strongly recommended over transplanting root balls with container medium. Wilting effectively stops growth of new roots that are needed for survival after transplanting. A single immediate post-transplant irrigation with diluted bay water (half fresh, half bay water) is recommended to minimize wilt. **No ongoing irrigation** should be performed, however. Irrigation would risk indirectly harm transplants by providing a competitive advantage to larger established neighbor plants with extensive roots. Irrigation may also reduce the spread of transplant roots, concentrating them in unfavorably small areas of temporarily greater artificial moisture. **Transplant patches** should **generally avoid competition** with dense neighboring salt marsh or shoreline vegetation; small **vegetation gaps** (existing or created disturbed areas above and below ground) are most suitable for new transplants. Transplant roots (especially bare-root transplants) must be firmly pressed into the substrate to ensure full root surface contact with moist sediment, with no large pore spaces. Loose substrate around roots will risk post-transplant wilting, which is a high risk for mortality.

6.2 Augmentation of existing salt marsh plant populations

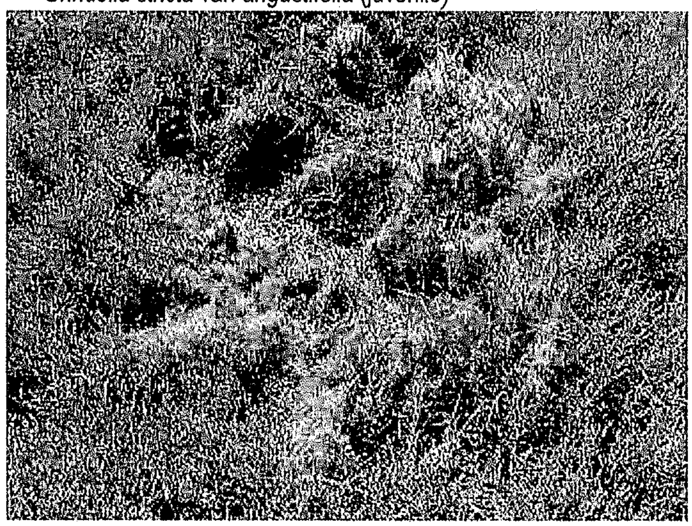
Some native salt marsh plants already present at Pier 94 may be circumstantially limited by small population size, seed production, seed dispersal, or seedling recruitment. Populations of such species would also benefit from "augmentation", through **facilitated (assisted) local seed dispersal** (hand-sowing seed into receptive sub-habitats that may not be close to seed parent plants) or **local on-site (in-marsh) propagation and transplanting in late fall/early winter.** Cultivating salt marsh plants in semi-wild conditions eliminates risks and costs of pathogen transfer, weed contamination, watering, and introduction of inappropriate genotypes from distinct populations. Small gaps in salt marsh vegetation near parent plants can be temporarily cultivated to provide semi-wild nurseries of seedlings or juvenile plants to transplant in cool, moist fall/winter conditions. These nursery gaps can be either directly sown or transplanted for propagation, or seedlings may be sown in sheltered (screen top) containers on site during wet weather to germinate and transplant into gaps at the first leaf stage. Suggested species for amplification include:

- San Francisco Bay gumplant (*Grindelia stricta* var. *angustifolia*) – seed propagation
- Alkali-heath (*Frankenia salina*) - clonal rhizome division in winter (pale pink to whitish rhizomes, fragmented with tips exposed above mud)
- California sea-lavender (*Limonium californicum*) – seed propagation
- Salt marsh dodder (*Cuscuta pacifica*) – direct seed translocation in late summer/fall; direct contact translocation of 1 ft long pickleweed branch fragments with attached

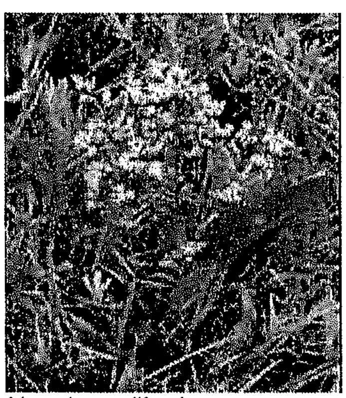
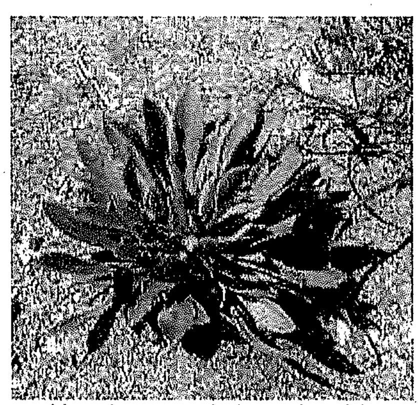
parasitic *Cuscuta* shoots before flowering, placed on uncolonized host pickleweed in early summer (foggy weather optimal)

Frankenia salina *Grindelia stricta* var. *angustifolia* (juvenile)

Cuscuta pacifica

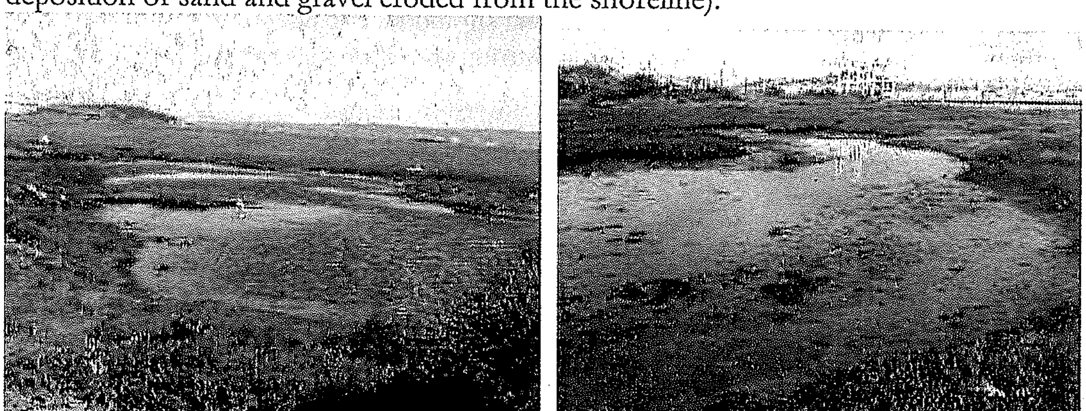

Limonium californicum *Limonium ramosissimum (exotic)*

Native salt marsh plant source population locations can be scoped out by salt marsh excursions with field botanists who are experienced with the taxonomy salt marsh plants, to avoid misidentifications or accidental collection of "lookalike" non-native invasive species.

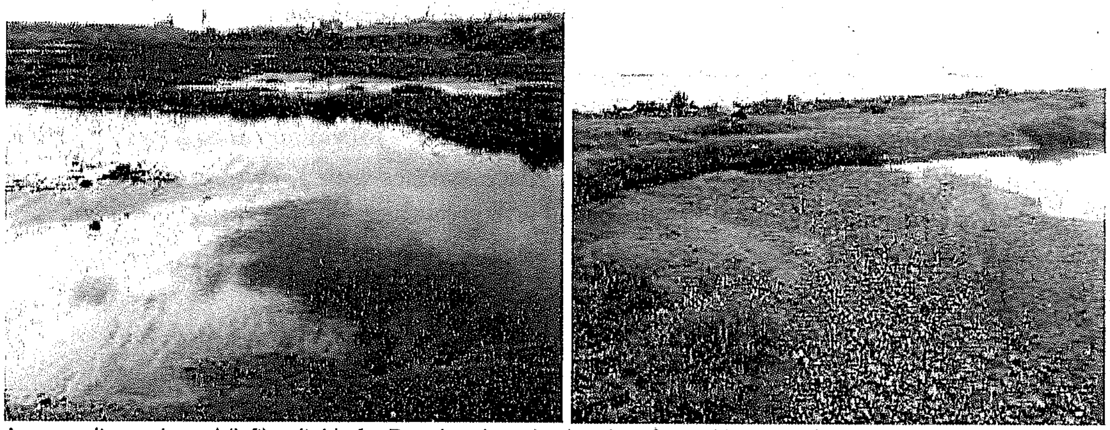
Examples of potential accidental non-native invasive species that could be erroneously keyed to native salt marsh plants:

- *Limonium ramosissimum* and *L. californicum* (2007 introduction to Pier 94)
- Hybrid *Spartina foliosa* x *alterniflora* (back-crosses with *S. foliosa* resemble the native parent but may have physiological and growth traits of invasive hybrids).
- *Spergularia marina* (present) and *S. media, S. bocconii*
- *Plantago maritima and P. coronopus*
- *Triglochin maritima* (native) may also be misidentified *Plantago maritima.*

Ruppia maritima (wigeongrass) is an ecologically important native submersed vascular salt marsh plant that formerly grew in a large salt pool with spring tide flows (choked or nontidal during neap tides) in the northern Pier 94 salt marsh. The wigeongrass was confused with algae that grew over it in warm August neap tides, and it was treated as a nuisance: the pool was drained by breaching an outlet through fill in 2005, eliminating the *Ruppia*, pool habitat and nesting avocets. This was a significant loss of habitat and species diversity. Simple tidal choking of the outlet, by rearranging existing rubble and boulders (no net fill) to constrict ebb outflows, would restore *Ruppia*, salt marsh pool fish, and wading birds and long-legged shorebird habitat – valuable native habitat and species diversity. *Ruppia* would likely re-establish spontaneously, but may be reintroduced actively by manual transfer of live plants in April from source populations nearby, such as Pier 98 (Heron's Head). A smaller new pool has formed at the north end of the north basin salt marsh through natural processes (wave deposition of sand and gravel eroded from the shoreline).

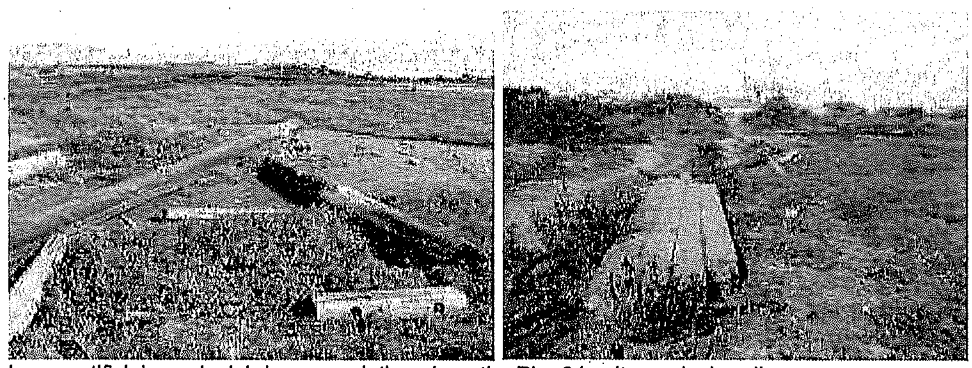


Former salt marsh pool with *Ruppia maritima* in late October 2005 was flooded at high and low tide, but is now (October 2015, right) mostly drained at low tide, eliminating avocet and *Ruppia* habitat.



A new salt marsh pool (left) suitable for Ruppia reintroduction, has formed by natural wave deposition of gravel and sand at its tidal inlet (right), at the north end of the north basin at Pier 94 (October 2015).

Large deposits of artificial woody debris (including creosote-treated pilings, fragments of docks, beams, etc.) occur and accumulate in the high tide line of Pier 94 beach and salt marsh transition zone. Removal of potentially toxic materials requiring heavy equipment is beyond the scope of this volunteer stewardship vegetation management plan, but selective removal of at least some artificial large woody debris is consistent with the aims of this plan. Removal of large woody artificial debris should be done selectively, because large wood provides some significant shoreline erosion buffering function, just as the artificial rubble provides the shoreline some important armoring and wave attenuation functions that limit shoreline erosion. Large debris also supplies moisture refuges for amphipods and other salt marsh invertebrates. Selective debris removal should be considered as a related shoreline enhancement or maintenance activity supporting shoreline vegetation management.



Large artificial woody debris accumulation along the Pier 94 salt marsh shoreline.

7.0 California sea-blite: special treatment area at north shore

The California sea-blite population established in 2006 at Pier 94 has persisted, but reproductive success has been intermittent, and limited primarily to the southern wetland basin. Seed production and seedling colonization have occurred mostly at the south end of the site, and only in a few favorable years. Factors that are leading potential causes of constraints in reproductive success include: (a) rooting depth of sand over buried restrictive layer of relatively impermeable compacted rubble; (b) pollen limitation among neighboring mature plants (compatibility of cross-pollinating individuals, genetic diversity); and (c) limited available uncolonized seedling or transpalnt habitat.

Sea-blite plants growing on deeper sand or bay mud at the Emeryville pilot population are more robust and productive of viable seed.

Longshore drift of sand and finer gravel from the outer nourished beach on the north shore has formed a beach ridge and high salt marsh berm dominated by pickleweed behind the crest of the beachface. The beach ridge faces the mouth of Islais Creek channel. This is a relatively more wave-sheltered shoreline orientation. The habitat appears to be highly suitable for California sea-blite, and because it overlies bay mud, it may be superior habitat relative to the 2006 planting sites.

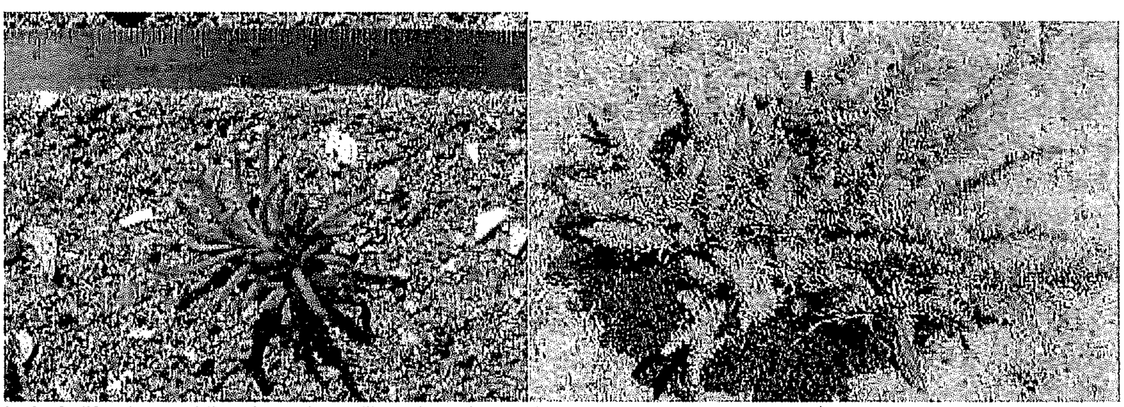
Seed from the Pier 94 population and the two other populations (related Emeryville and Pier 98/Heron's Head populations) should be collected (with coordination with U.S. Fish and Wildlife Service) to propagate a cohort of maximum genetic diversity available within San Francisco Bay, for transplating to the north shore beach. This work may be coordinated with San Francisco State University (Boyer wetland lab) to generate data about reproductive ecology of reintroduced sea-blite, and monitoring of results. Methods for population establishment should be adapted from Baye (2008), as summarized below.

Sea-blite seed should be soaked in seawater, followed by fresh water (24 hr each), refrigerated moist for 3 weeks, and set outdoors in containers of compost and sand, sub-irrigated (standing in tubs with shallow water at the base of the container). Seedlings should be fertilized with dilute high nitrogen fertilizer when they grow 3 or more leaves. Seedlings should be individually grown in containers outdoors when they reach the 5 leaf stage. When seedlings are approximately 0.5 ft in width and branching, they should be planted out near the crest of the beach (top of open sand) in planting holes enriched with decayed organic matter (compost) and drift-line deposits of local seaweed. Transplants may be made as late as March. Transplants should be irrigated with very dilute bay water (1:10 bay:fresh water or compost "tea"/manure leachate), sufficient to wet sand at depth below the transplanted roots. Irrigation should be maintained weekly through June, approximately 1 gallon/plant/week.

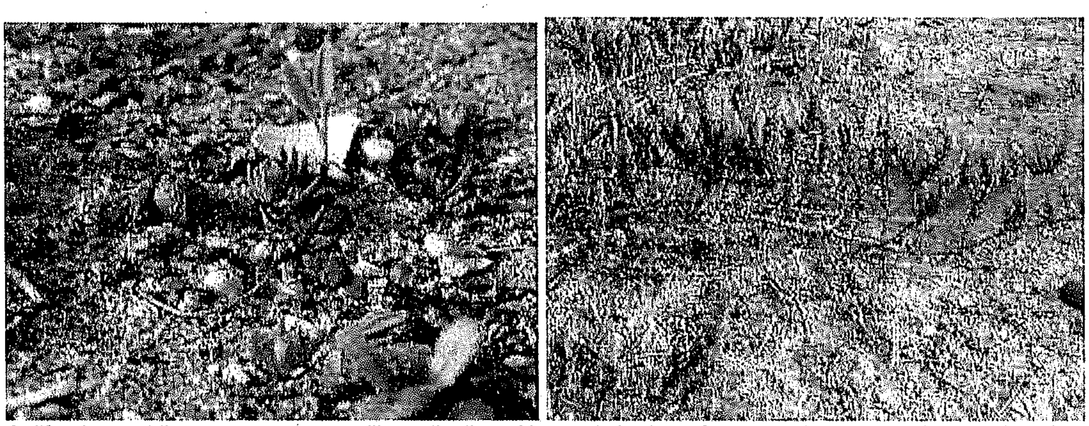
The long-term maintenance of the north shore sea-blite habitat would be supported by low-level, incremental nourishment of coarse sediment (waste "screenings" or non-spec shell and gravel) from the adjacent sand refining industrial site. Small-scale delivery (wheelbarrow) of 0.1 cy or smaller increments to the zone *above* Mean Higher High Water or High Tide Line (above USACE Section 404 jurisdiction), available for redistribution by winter storm waves, may not require additional federal permitting, particularly if it is below a *de minimus* threshold of a few cubic yards per year. Other means of authorizing small-scale, incremental estuarine beach nourishment (within jurisdiction) would be amendment of existing state (BCDC, RWQCB Section 401 certification) or federal permits (USACE Nationwide Permit 27; pre-authorized general permit designed for small, low-impact habitat enhancement projects like this). Low-level, chronic sediment nourishment of the shoreline in both the north and south basins is recommeded for maintenance of long-term sea-blite habitat stability at Pier 94.

As sea level rises, the remnants of the reef-like rubble wave barrier will become less efficient at reducing storm wave energy reaching the Pier 94 shoreline, resulting in increased erosion. This is a near-term (next decade and beyond) risk for Pier 94 salt marsh and shoreline resilience: increased erosion and reduced net sediment deposition (net erosion of marsh) due to increased wave energy due to a deepening nearshore profile, regardless of storm frequency or intensity. Because sea-blite is rooted in sandy high tide line habitat, it is likely to be most impacted by sea level rise/wave energy climate change. Sustained sea-blite habitats, as well as salt marsh, at Pier 94 may require placement of future wavebreak structures (reef-like features, potentially including native oyster (*Ostrea conchaphila,* syn. *O. lurida*) reef-bearing structures) as dual purpose wetland protection and rocky intertidal habitat enhancement.

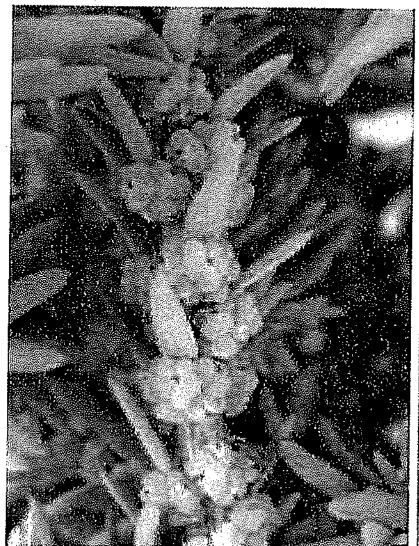
Northeast shore of Pier 94 facing mouth of Islais Creek channel: longshore drift of sand from the 2005 beach nourishment project has formed a naturally deposited berm (low wave-deposited beach ridge colonized by pickleweed in back of the crest of the beachface) in a relatively sheltered position, forming new suitable habitat for California sea-blite establishment.

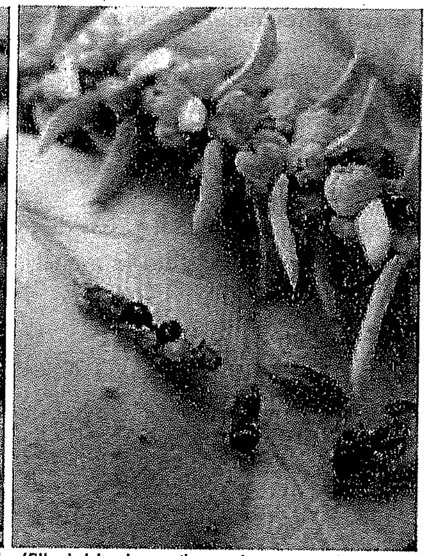


Left: California sea-blite planted seedling, June 2006
Right: California sea-blite second-year transplant at Pier 94, 2007. Note seaweed (*Fucus*) mulch.

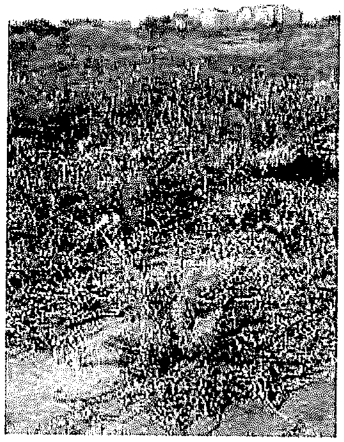


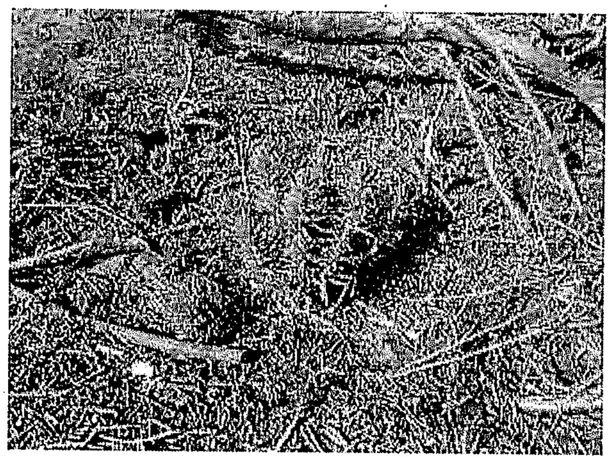
California sea-blite spontaneous seedlings distributed in seed shadow of parent 2nd year transplant at Pier 94 shoreline, April 2007





Suaeda californica mature fruits (left) and ripe viable (filled, black coat) seeds pressed out of fleshy fruits (right), Pier 94, 2007





Recent (fall 2015) transplants of Suaeda californica along south bank of eroded sandy fill peninsula between north and south wetland basins, Pier 94.

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