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VEGETATION MANAGEMENT IN

TERRESTRIAL EDGES OF TIDAL MARSHES,

WESTERN SAN FRANCISCO ESTUARY, CALIFORNIA

INTEGRATED VEGETATION MANAGEMENT STRATEGIES AND PRACTICAL GUIDELINES FOR LOCAL STEWARDSHIP PROGRAMS

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The following guidebook was prepared for Marin Audubon Society with funding from the San Francisco Bay Joint Venture. The original purpose of the document was to provide practical scientific guidance to local stewardship programs aimed at rehabilitating or enhancing degraded, weedy edges of tidal marshes (transition zones between terrestrial and tidal wetland vegetation) in the San Francisco Estuary. The San Francisco Bay Area Wetland Ecosystem Goals Project report (Goals Project 1999) and its companion volume on species and communities profiles (Goals Project 2000), recommended develop native vegetation structure and composition appropriate to the variable geographic settings of the Estuary (landforms, soils, climate, local flora) and the habitat requirements of its resident wildlife, including endangered wildlife.

This document aims to synthesize Goals Project guidance with integrated vegetation management strategies (combined weed control and native plant revegetation) for implementation by non-profit partners of public tidal land management agencies, and non-profit conservation organizations that own and manage tidal brackish and salt marshes in the San Francisco Bay Area. The document also incorporates conservation strategies adapted from draft versions of the U.S. Fish and Wildlife Service's Recovery Plant for Tidal Marsh Ecosystems of the Northern and Central California Coast, which includes the Bay Area's tidal marshes.

The recommendations in this guidebook are not proposed as substitutes for project-specific tidal marsh restoration designs. Recommendations and principles in this guidebook should generally be adapted to site-specific or project-specific ecological goals, objectives, geographic locations, and physical conditions.

The proposal for this document, and draft version of the final document were submitted for review by Giselle Block (biologist, San Pablo Bay National Wildlife Refuge) Beth Huning (Coordinator, San Francisco Joint Venture), Marilyn Latta (biologist, Save San Francisco Bay Association), and Barbara Salzman, Jude Stalker, and Lowell Sykes (Marin Audubon Society). The author gratefully acknowledges the review team's editorial contributions in preparation of the final document.

Plant nomenclature generally follows the most recent standard taxonomic treatments of species in the Flora of North America (www.efloras.org) or local floras (such as Howell *et al.* 2007). Synonyms with familiar nomenclature in wide use (Jepson Manual) are provided. Exceptions are noted in the text.

1.0 Introduction

1.1 Terrestrial edges (ecotones) of tidal marshes in the San Francisco Estuary

Many tidal marsh restoration projects have been initiated in San Francisco Bay since the 1970s, and are now in various stages of physical development and marsh succession. http://www.wetlandtracker.org/). Most emphasis on tidal marsh restoration design and monitoring in the San Francisco Estuary has focused on the intertidal marsh plain (Appendix 1, Figure 1), often dominated by pickleweed or cordgrass in early stages of succession. Less attention has been paid to the restoration or maintenance of "upland edges" or "upland transition zones" of tidal marsh restoration sites, the **terrestrial-tidal marsh ecotone**. The shoreline at the landward tidal marsh edge is the **ecological transition zone** or **gradient** (**ecotone**) between **terrestrial** and **tidal marsh** habitats (Goals Project 1999). It is usually marked by variable series of **drift-lines** (high tide debris lines, associated with extreme tides) and visible shifts or discontinuities in vegetation types.

The terrestrial ecotone is important for understanding and managing tidal marsh habitats and vegetation. Depending on local soils, slopes and hydrology (runoff, groundwater influence, soil permeability to rainfall or flooding), this ecological gradient may be sharp and abrupt, or gentle and gradual. Both steep and gentle shoreline gradients occur naturally in different parts of the Estuary, but prior to historic marsh diking and reclamation, gentle gradients were naturally more widespread, and they are associated with greater biological diversity (Appendix 1).

The typical contemporary terrestrial-tidal marsh ecotone of tidal restoration sites in the San Francisco Estuary, unfortunately, consists of **dikes** (artificial **levees**) that serve primarily as flood control, roads for maintenance access, or trails for public access, and secondarily as habitat for native plants or resident marsh wildlife. Most dikes in the Estuary are disturbed by maintenance activities, and consist of artificial soils made of dredged and drained estuarine mud. Most dikes are also used as roads or trails with permanently disturbed edges and bare tops. Dike soil and disturbance conditions generally constrain the natural ecological potential of the tidal marsh's terrestrial ecotone.

Only rarely are dikes managed to emulate or replicate the habitat conditions of natural tidal marsh edges along native terrestrial vegetation. Most have become dominated by non-native weeds that generally have less wildlife habitat value than equivalent native vegetation. Despite the ecological importance of the upper tidal marsh transition zone, the terrestrial edge of tidal marshes are usually neglected in long-term maintenance, and are often given marginal attention (or budget) in restoration design. Neglect and inertia maintain them as weedy (ruderal) habitats.

Despite degradation, the terrestrial edges of restored tidal marshes (including dikes) have inherent importance as **high tide flood refuge habitat** for resident marsh wildlife, providing escape habitat and cover when marshes are flooded, including cover to avoid exposure to predators. Deficient vegetation cover in the high tidal marsh-terrestrial habitat gradient is widely regarded as a critical limiting factor for many resident marsh wildlife species. These include the state/federal-listed endangered California clapper rail and salt marsh harvest mouse, and the state-listed threatened California black rail. Other wildlife species of concern depend on the high marsh-terrestrial habitat edges of restored tidal marshes, including songbirds (Suisun song sparrow, San Pablo song sparrow, Alameda song sparrow, salt marsh common yellowthroat; foraging and nesting habitat), small mammals (Suisun shrew, salt marsh wandering shrew; high tide/flood escape habitat; see Table 1), The terrestrial edges of restored tidal marshes in the San Francisco Estuary also have potential to support the zone of the tidal marsh that usually has the highest diversity of native plant species (Baye *et al.* 2000). Some special-status plant species that occur in the Estuary's high tidal marsh-terrestrial ecotones are listed in Table 2.

Table 1. Principal native wildlife species of concern for management of terrestrial-tidal marsh ecotones.

Species	habitat and range	potential high tide refuge	Typical nest subhabitat
California clapper rail (*Rallus longirostris obsoletus*)	Tidal salt marsh, tidal brackish marsh: San Francisco Bay, San Pablo Bay, western Suisun Marsh and Martinez marshes.	Gumplant (tidal creek bank), tall, shrubby pickleweed, gumplant/coyote-brush (terrestrial marsh edge), woody debris	Gumplant, pickleweed (high marsh zone); alkali-bulrush (brackish marsh)
California black rail (*Laterallus jamaicensis coturniculus*)	Tidal brackish marsh (occasionally salt marsh): Suisun Marsh, Martinez Marshes, San Pablo Bay; local in San Francisco Bay.	Gumplant (tidal creek bank), tall, shrubby pickleweed, gumplant/coyote-brush (terrestrial marsh edge), woody debris, tules, alkali-bulrush, tall grasses	Tall grasses or tidal marsh vegetation, including dense pickleweed and alkali bulrush, and other bulrushes (high marsh zone) (Trulio and Evens 2000)
Virginia rail (*Rallus limicola*)	Tidal brackish marsh, nontidal brackish or freshwater marsh; throughout Estuary.	Gumplant (tidal creek bank), gumplant/coyote-brush, woody debris, tules, alkali-bulrush, tall grasses, cattail, riparian woodland	Reed-like vegetation of sedges, tules, bulrush, marsh grasses
Salt marsh harvest mouse (*Reithrodontomys raviventris*)	Tidal or nontidal salt or brackish marsh, middle and high marsh zone; abundant pickleweed; throughout Estuary.	Gumplant (tidal creek bank), tall, shrubby pickleweed, gumplant/coyote-brush (terrestrial marsh edge), woody debris	dense low vegetation with pickleweed duff, woody debris (Shellhammer 2000a)
Salt marsh wandering shrew (*Sorex vagrans halicoetes*)	Tidal salt marsh, middle marsh zone, abundant invertebrate prey, driftwood; San Francisco Bay south of Golden Gate	Gumplant (tidal creek bank), gumplant/coyote-brush (terrestrial marsh edge), woody debris	dense low vegetation with pickleweed duff, woody debris (Shellhammer 2000b)
San Francisco Estuary song sparrow subspecies **(***Melospiza melodia* sspp.*; M.m. samuelis, M.m. pusillula, M. m. maxillaris)*	Tall high tidal marsh vegetation near tidal creeks and adjacent terrestrial scrub.	(Mobile; general terrestrial cover)	Tall high tidal marsh vegetation near tidal creeks and adjacent terrestrial scrub
San Pablo vole (*Microtus californicus sanpabloensis*)	Tidal marshes around the mouth of San Pablo Creek (Contra Costa County; Lidicker 2000)	Unspecified terrestrial flood refuge, extending from terrestrial grasslands (Lidicker 2000)	n.d.
Suisun shrew (*Sorex ornatus sinuosus*)	Tidal salt or brackish marsh, northern San Pablo Bay, Suisun Marsh, dense low vegetation with woody debris	Unspecified terrestrial flood refuge (McCay 2000)	dense low vegetation with woody debris(McCay 2000)

Table 2. Principal native tidal marsh plant species of concern affected by wetland weed invasion of the terrestrial edge of tidal marshes.

Species	habitat and range in Estuary
Soft bird's beak (*Cordylanthus mollis* ssp. *mollis*)	Tidal brackish or salt marsh, high marsh zone with sparse, low cover; northern San Pablo Bay to Suisun Marsh, Martinez Marshes
Northern salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *palustris*)	Tidal salt marsh, high marsh zone with sparse, low cover; Sausalito to Petaluma River (Marin County)
Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*)	Tidal brackish marsh, middle to high marsh zone, Suisun Marsh
Salt marsh owl's-clover (*Castilleja ambigua* ssp. *ambigua*)	Tidal salt or brackish marsh, high marsh zone, San Pablo Bay and Suisun Marsh (historic range also in San Francisco Bay)
California sea-blite (*Suaeda californica* – reintroduced in San Francisco Bay)	Tidal salt marsh bordering sandy beaches, Central and South San Francisco Bay (historic range)

Natural tidal marshes border a wide range of terrestrial habitats (Appendix 1), including well-drained "uplands" (hillslopes) and valley "lowlands" (alluvial fans near sea level). These may also border some tidal marsh restoration sites that afford rare opportunities to reconnect natural terrestrial landforms, vegetation, and restored tidal marshes. The terrestrial habitats that naturally border tidal marshes in the San Francisco Estuary include riparian woodland or scrub, coastal scrub, oak woodland, valley grasslands, and even freshwater marsh. These terrestrial habitats may include wetlands formed by seeps (emergent groundwater), seasonal depressional wetlands, and freshwater stream mouths.

1.2 Management and restoration of terrestrial-tidal marsh edges

Management of the terrestrial edges of restored tidal marshes is often an exercise in a zone of compromise or conflict among different land use priorities: flood control, public access, native wildlife habitat (and buffer zones), non-native predator management, native plant diversity, and weed management.

Public agencies sometimes provide funding and professional technical support to maintain levees, trails and manage predators along terrestrial-tidal marsh ecotones. Land management agencies, however, rarely have resources to support vegetation management or habitat enhancement there. Volunteer stewardship is usually the only resource available for weed control or vegetation management. There is relatively little published or unpublished literature to provide scientifically sound guidance for organizations and volunteers who perform extensive weed management and native plant transplanting actions along the terrestrial edges of restored tidal wetlands. Most of the technical literature on tidal marsh vegetation management is focused on the intertidal zone, rather than the upper limits of tidal influence. Consequently, the management challenges of this important local habitat are left with little practical guidance that incorporates scientific understanding of vegetation and wildlife needs.

Improvised, short-term weed removal, or opportunistic transplanting activities (driven by availability of volunteers and wild or propagated planting stock), may provide limited benefits, especially if they are guided only by generalized long-term objectives. Weed removal can also result in short-term reduction of wildlife cover, and can have unintended adverse short-term impacts. Vegetation management need to address basic technical weed control matters, but they also must carefully consider potential native vegetation patterns and methods to cultivate them in artificially modified, sensitive wildlife habitats.

1.3 Purpose and need

- There is little published, widely available, ecologically informed guidance for volunteer stewardship crews engaged in weed management along the edges of restored tidal marshes. Information on vegetation and habitat management of tidal marshes, and tidal marsh ecology, is fragmented among academic research publications, resource agency "gray literature", and highly informal local information. This document aims at integrating scientifically sound ecology with practical information and recommendations for management of vegetation and wildlife habitats at tidal marsh shorelines where terrestrial ecotones occur.

The basic purpose of these guidelines is to provide site managers, planners, and stewardship volunteers with practical, general vegetation management strategies for weed control and native revegetation in degraded tidal marsh edges. These guidelines emphasize the use of native vegetation as a long-term means of controlling weed invasion (by pre-emption and competition with suitable native species) and providing suitable cover for wildlife and predator management, compatible with other land use requirements of tidal marsh edges.

These guidelines include some selected working examples of site-specific vegetation management strategies for some representative weed and habitat problems (Appendix 5). The overall purpose of the guidelines, however, is to provide a general basis for site-specific stewardship planning efforts.

1.4 Scope. The geographic scope of these guidelines covers the tidal marshes of the western San Francisco Estuary, the lower reaches that are subject to significant fluctuations of salinity: San Francisco Bay, San Pablo Bay, and the western Suisun Marsh and Martinez marsh subregions. The ecological focus of this report is the tidal marsh zone above Mean Higher High Water (high marsh) and the terrestrial vegetation that directly interacts with it.

2.0 Wildlife habitat and vegetation in terrestrial edges of salt and brackish tidal marshes of the San Francisco Estuary

2.1 Flood refuge habitat: essential high tide escape cover for resident tidal marsh wildlife

One of the principal wildlife objectives for tidal marsh restoration projects in the 1970s to the present has been the recovery of endangered or rare wildlife species that are endemic to tidal marshes of the Estuary (Table 1). The loss of adequate high tide escape habitat for marsh wildlife (cover, shelter during extreme high tides, including storm surges) has been identified as one of the critical limiting factors for habitat suitability of the endangered California clapper rail and salt marsh harvest mouse (U.S. Fish and Wildlife Service 1984, Shellhammer 1989, Albertson and Evans 2000). Lack of protective cover during high tides can result in exposure of wildlife to predators, or drowning during storm events.

The suitability of vegetation as high tide escape habitat (**flood refuge habitat** or "high tide refugia") is related to two factors:

> (1) the <u>distribution of cover by tall, dense, vegetation canopies</u> (especially evergreen or semi-evergreen species) that remain above the water surface during high tides, including extreme high tides or storm surges; and
>
> (2) the location of <u>flood refuges in proximity to the home ranges of resident marsh wildlife</u> (including clapper rails and salt marsh harvest mice), which live mostly within the intertidal marsh vegetation of the marsh plain.

Most resident marsh wildlife movements normally occur within their home ranges or territories. Long-distance wildlife movements may expose them to risks of predation (particularly by avian predators such as northern harriers) or competition with other territories. Therefore, well-distributed flood refuges within a wildlife species' home range are important to tidal marsh habitat quality.

2.2 Dikes and flood refuge habitat. Dikes (artificial levees) adjacent to tidal marshes have replaced much of the natural flood refuge habitats formerly provided by natural marsh levees or terrestrial vegetation. Many dikes along tidal marsh edges are routinely maintained by capping with fresh bay mud, followed by disking and grading. This results in a disturbance cycle that can minimize development of native perennial or woody vegetation cover, and facilitate weed invasions along tidal marsh edges (Baye 2000). Many weeds are annuals or perennials that die back and mat down in winter, and provide limited or poor cover during winter high tides. Low-growing nonnative annual grasses in particular may dominate levees and provide very poor flood refuge habitat.

Because many tidal marshes have only dikes to serve as their terrestrial edges by default, and because maintained levees often are deficient in high tide cover, habitat management recommendations for "peripheral halophyte" (high salt marsh) or "upland transition" zones in the 1970s to the early 1990s often stressed maximum revegetation of narrow transition zones on dikes with dense, tall vegetation, such as gumplant (*Grindelia stricta* var. *angustifolia;* Appendix 4) and coyote-brush (*Baccharis pilularis;* Appendix 4).

Dense, tall, shrubby cover on diked margins of tidal marshes was often recommended for wildlife priorities, without regard to native plant community composition, soils, hydrology, or other restoration objectives.

2.3 Non-native predators and flood refuge habitat: moderate and excess terrestrial vegetation cover.

This general recommendation to maximize shrubby "peripheral halophyte" vegetation as flood refuge habitat had to be modified in some situations where non-native red fox predation was causing abrupt and severe declines in local clapper rail populations (Harding 2000). The U.S. Fish and Wildlife Service began a predator control program for red fox in South Bay salt marshes within the San Francisco Bay National Wildlife Refuge in 1991 (Foerster and Takekawa 1991).

Dikes can serve as artificial travel corridors for red fox and other terrestrial predators such as rats, raccoons, feral cats, and skunks. Wide prehistoric marshes with large sloughs resisted efficient foraging by terrestrial predators, but modern slender marsh fringes and extensive dike networks facilitate predator dispersal. In addition, excessive, continuous, dense brush along tidal marsh edges can interfere with predatory control activities in some situations (J. Browning, U.S. Fish and Wildlife Service, pers. comm.) or provide shelter and cover for predators as well as high tide refuge for resident marsh wildlife.

Dense brushy cover exceeding the needs of resident wildlife for high tide refuge may have indirect adverse effects by creating refuges or "attack habitat" for their non-native terrestrial predators (including burgeoning urban populations of raccoons, skunks, feral cats, Norway rats), especially where levees provide artificially enhanced travel corridors through small tidal marshes.

Excessive interspersion of terrestrial vegetation in restored tidal marshes may have other adverse, indirect effects on wildlife. Ecological barriers that separate widespread, terrestrial wildlife species from rare, endemic (locally restricted) species may be broken down by artificially increased upland edges. For example, there is evidence of interbreeding between the rare Suisun shrew (*Sorex ornatus sinuosus*), which does not utilize terrestrial grasslands, and the more common California ornate shrew, *S. o. californicus*, which does. Conservation recommendations for Suisun shrew include providing high tide escape habitat that floods only occasionally, so habitat barriers to contact with *S. o. californicus* are maintained (McCay 2000)

2.4 Natural patterns of tidal marsh flood refuge habitat: creekbank gumplant vegetation.

High tide cover (flood refuge) for clapper rails and salt marsh harvest mice (and other resident tidal marsh wildlife, such as shrews, black rails, Virginia rails, etc.) occurs along upper marsh edges and also in high marsh and debris within the marsh.

During most spring high tides (the highest tides of the month), the extensive, dense, tall, shrubby cover of gumplant (*Grindelia hirsutula;* syn. *G. stricta* var. *angustifolia*) bordering tidal creek banks of mature salt and brackish tidal marshes provides ample emergent cover above the submerged pickleweed-dominated or saltgrass-dominated marsh plain during most high tides. Shrubby lines of gumplant often delineate the banks of tidal creeks in mature tidal marshes (Appendix 1). The well-drained, high banks of mature tidal creeks also support taller, denser growth forms of pickleweed. This creekbank vegetation pattern, however, is often deficient or absent in young tidal marshes.

High tide cover provided by gumplant and tall-form pickleweed in natural mature tidal marshes, therefore, is <u>mostly distributed along creek banks within the marsh plain itself, where resident marsh wildlife (rails, small mammals) seek immediate flood refuges within their home ranges during high tides</u>. Gumplant canopies associated with the banks of tidal creeks were closely associated with the home ranges (territories), nest sites, and travel corridors of clapper rails in historic mature salt marshes (Zucca 1954, DeGroot 1927, Grinnell *et al.* 1918). The height and density of mature gumplant canopies is variable, but often exceeds 60 cm (over 2 feet), and often reaches 1.0 m (over 3 feet). It normally provides flood refuge during all but the most extreme high tides or storm surges.

The **tidal debris** trapped by gumplant also provides important flood escape habitat for small mammals (Johnston 1957). Thus, the first line of flood escape habitat is potentially within the intertidal marsh plain, and within the home range of sensitive wildlife species.
In many tidal brackish marshes, alkali-bulrush (*Bolboschoenus maritimus*, syn. *Scirpus maritimus*) also provides extensive, dense, tall cover (persisting after shoots die) within marsh plains, with plant height matching or exceeding gumplant. Mature, tall alkali-bulrush stands may also serve as flood refuge for all but the most extreme tides in some tidal marshes (Appendix 1).

In contrast, the primary zone of gumplant establishment in most youthful restored tidal marshes is a <u>narrow fringe along the high tide line of relatively steep artificial levee slopes</u> (Appendix 1, Figure 6). Tidal marshes with natural terrestrial soil edges, in contrast, seldom develop dense stands of gumplant at the high tide line. Gumplant in natural tidal marshes occurs primarily along tidal creek banks (Appendix 1).

Young restored tidal marshes plains are often relatively homogeneous stands of pickleweed, cordgrass, or alkali-bulrush. In youthful, restored tidal marshes, tidal creek banks are seldom high or steep enough to support gumplant. In young, restored tidal marshes, however, the development of tall gumplant vegetation along internal creek banks often lags significantly (decades) behind establishment of pickleweed, cordgrass, and other pioneer tidal marsh vegetation. Gumplant does, however, establish relatively rapidly along the high tide line of dikes. Young tidal marshes backed by dikes, therefore, often exhibit "inverted" patterns of gumplant distribution relative to old, natural tidal marshes lacking dikes: the high tide cover they provide is concentrated along the high tide line of dikes, but is scarce or absent along internal creek banks of restored marshes for many years or decades. This pattern has important influence on wildlife habitat structure of young restored tidal marshes for resident small mammal and rail species.

The scarcity (or absence) of gumplant or tall pickleweed along tidal creek banks in youthful restored tidal marshes may force resident marsh wildlife to leave deeply flooded tidal marshes altogether, and cross open marsh (or water) to reach the nearest higher gumplant cover at the outer marsh shoreline. The deficiency of local, "internal" flood refuge of tall evergreen vegetation canopy within the marsh plain's creek network may expose them to avian predators (especially harriers) or terrestrial predators when marsh plains are submerged during spring high tides.

Similarly, during extreme high tides associated with storm-elevated flood levels (storm surges), the entire tidal marsh plain vegetation is submerged, and the only marsh cover occurs as either floating or attached debris within the flooded marsh, or terrestrial vegetation and debris along the marsh edge. The terrestrial-tidal marsh ecotone vegetation structure is therefore highly important as flood refuge for immature, restored tidal marshes lacking "internal" creek-bank gumplant, and for all tidal marshes during storm surges or extreme high tides.

2.5 Natural patterns of flood refuge habitat: terrestrial scrub and grassland vegetation.

Above the intertidal marsh plain, and above the potential outer marsh shoreline edge of gumplant, other types of vegetation provide alternative flood refuge for resident marsh wildlife. These higher elevation vegetation canopies mostly function as flood refuges only during infrequent, extreme high tides and storm surges when the entire marsh is deeply flooded. These extreme events usually occur in winter storms of December-February, but they may also occur on the solstice tides of summer.

Not all native vegetation of tidal marsh edges provides optimum high tide cover for wildlife. Often, native grasslands bordering tidal marshes lack dense, extensive stands of tall gumplant or shrubs, and instead have perennial grassland cover (Appendix 1). On levees, effective terrestrial vegetation canopy serving as flood refuge is usually provided by the weedy native shrub, coyote-brush (*Baccharis pilularis*; Appendix 4), which develops only if levees are left undisturbed for long periods of time.

In some types of natural terrestrial vegetation, alternative flood refuge cover may be provided by a wide range of plant species and types of debris, including evergreen shrubs and trees with ground-level canopy (toyon, *Heteromeles arbutifolia*; coast live oak, *Quercus agrifolia*; California bay, *Umbellularia californica*); live or dead masses of relatively short-lived coyote-brush), driftwood, and dense stands of tall grass-like plants with shoots that remain erect in winter (creeping wildrye, *Leymus triticoides*; basket sedge, *Carex barbarae;* wire rush, *Juncus arcticus* (syn. *J. balticus*).

3.0 Landforms and vegetation in terrestrial edges of salt and brackish tidal marshes of the San Francisco Estuary

3.1 Shore gradient landforms. The shorelines of restored tidal marshes in the San Francisco Estuary can be classified into a few general types of gradients with respect to vegetation management. These represent the types of conditions in which stewardship activities (weed control, planting) may occur.

3.1.1 Dikes (artificial levees).

Because most tidal marsh restoration occurs within diked baylands of the Estuary, dikes (artificial levees) border most tidal marsh restoration sites. They are generally steep-sided (2:1 or 3:1 slopes, seldom gentler except in locally widened areas) artificial deposits of dredged bay mud, sometimes capped with terrestrial fill for roadbeds. Top widths are generally less than 12 feet, and heights are usually less than 4 feet above the adjacent marsh plain. Bay mud levees are prone to wave erosion where they are exposed to the open bay mudflats, and they tend to subside (sink) over time. Interior slopes may become gullied from water overtopping the levee crest and spilling down the steep interior slope during extreme high tides. Erosion and subsidence are countered by periodic capping with additional bay mud dredged from adjacent ditches. Dried mud is disked and graded in subsequent years where the levee is used as a road. Slope erosion is corrected by placing either mud or rock slope armor. Rock slope protection (including concrete debris) in older levees restricts vegetation and may provide nuisance habitat for Norway rats.

All forms of levee maintenance disturb soil and create vegetation gaps suitable for weed invasion. Levee soils themselves, formed from bay mud, are rich in clay and nutrients, and support rank growth of weeds unless they retain toxic levels of acidic sulfates (formed from organic oxygen-starved muds in ditch sources). Levee soils are not necessarily highly saline because they leach salts rapidly in winter rains. Once weed seed banks accumulate rapidly on disturbed levees, overwhelming abundance of weed seeds or buds (on roots or below-ground stems) makes colonization by native species slow.

3.1.2 Hillslopes. Hillslopes are true "uplands" with terrestrial soil derived from weathering of bedrock and gravity-driven slope processes. They are well-drained, except at local seeps (zones of emergent groundwater). Hillslopes around the Bay Area generally support either shrublands (coastal scrub, chaparral), woodlands (coast live oak/bay), savannah (mixed grassland and oak woodland), or grasslands dominated by forbs, non-native annual grasses, and bunchgrasses (Holstein 2000).

Hillslopes adjacent to the bay support soils developed from different types of bedrock in different geologic formations. Most of the modern bayside hillslopes are fractured shale, greywacke, and sandstone-derived soils. Sedimentary rocks and weakly consolidated sediments also contact the bay edge, and a few historic bay shorelines contacted local metamorphic rocks and serpentine soils (e.g. Tiburon and Newark).

Most of the hillslopes adjacent to tidal marshes have been stripped of native vegetation and urbanized, except in the North Bay and Suisun Marsh. Along the diked baylands of Marin and Sonoma County, and portions of Solano County, native hillslope vegetation may contact the historic margins of the bay. Local remnants of hillslope vegetation adjacent to the South Bay also occur at Coyote Hills and the Don Edwards San Francisco Bay National Wildlife Refuge Headquarters.

Types of terrestrial vegetation adapted to hillslopes generally differ from those of lowlands. Some examples of relatively intact hillslope vegetation contacting the historic or modern high tide line occur at China Camp, Bahia and Rush Creek/Cemetery Marsh (Novato, Marin County). Hillslope woodland and scrub vegetation has high potential to function as high tide refuge habitat, and also has high potential to compete successfully with typical weeds of tidal marsh edges.

3.1.3 Lowlands. Most of the Estuary's tidal marshes historically contacted gently sloping lowlands only slightly higher than sea level. Lowlands are terrestrial landforms, usually with gentle slopes and low elevations only slightly above sea level. They are associated with complex deltas of large (historic) streams, alluvial fans of canyon creeks, partially submerged old valley floors, and also modern beaches. (Estuarine beaches support a distinct vegetation type and tidal marsh ecotone, and are outside the scope of this report). Artificial fills also create lowlands adjacent to the bay's modern tidal marshes. Artificial fill lowlands often occur on top of historic alluvial fans and deltas bordering the bay, and in diked baylands (historic tidal marshes).

The soils of alluvial fans and deltas tend to be composed of fine sediment, including clay and silt loams. Some have sand or gravel layers with greater permeability. They generally lie close to the water table, unless the water table is artificially depressed by drainage or pumping. Coarse sediment (sand, gravel, or shell deposits) are characteristic of the Bay's modern beach shorelines. Beach lowlands are more narrowly distributed in the Central Bay and South Bay, compared with widespread alluvial fans and deltas. Estuarine beaches support very distinctive, atypical soil conditions and native vegetation types.

Few partial remnants of native lowlands exist in San Francisco Bay, and none are on intact soils. All remnant lowlands around the bay edge have some agricultural history of either grazing or tillage (cropping).

The remaining natural vegetation of lowlands bordering the Bay included a wide spectrum of so-called "upland" (infrequently flooded) and true wetland (seasonally or frequently flooded) types, not just well-drained "upland" vegetation. Historic herbarium collections, soil series descriptions, and botanical descriptions indicate that lowland vegetation bordering the Bay varied among its subregions, and included:

- riparian woodland (primarily willow woodland or thickets associated with shallow groundwater);
- valley oak woodland or savannah;
- valley grasslands and alkali grassland (primarily sod-forming grasses and forbs interspersed with vernal marshes and vernal pools);

- sedge-rush meadows (seasonal marsh);
- perennial freshwater marshes and associated shallow open water (pond, lake).

In large areas of South San Francisco Bay, valley oaks (*Quercus lobata*) grew in lowlands near the tidal marsh edge (Cooper 1926).

Very few lowlands with natural vegetation still contact tidal marsh edges because most flat lands were converted to agriculture or urban areas. Valleys and swales contacting the bay edge or even diked marshes today include some modified but revealing remnants of native vegetation, including many species that occur repeatedly at one or more sites (e.g. China Camp, San Rafael, Marin Co.; Coyote Hills and upper Newark Slough, Alameda Co.; Bahia-Rush Creek, Novato, Marin Co.; Sears Point and Tolay Creek mouth, Sonoma Co.; Southhampton Marsh, Benicia, Solano Co; Point Pinole, Richmond, Contra Costa Co.). These modified, dynamic relict stands of bay-edge vegetation suggest models for revegetation of tidal marsh edges with gentle slopes, near-surface groundwater, and fine sediment. Some remaining natural alluvial fans edges are associated with high marsh pans and uncommon annual salt marsh plants (Baye *et al.* 2000).

Most of the Estuary's relict semi-natural tidal marsh edges are characterized by a high proportion of native perennial forbs and grasses or grass-like plants with rhizomatous growth-forms (creeping below-ground stem growth; clonal plants). This vegetation type is also common in natural vegetation of tidal marsh edges along Gulf of Mexico and Atlantic U.S. coastlines. The root and rhizome structure of many lowland grasses and grasslike plants provides them high potential to stabilize soils and compete successfully with typical weeds of tidal marsh edges.

3.2 Weed vegetation and flora of San Francisco Estuary edges.

A complete list of terrestrial non-native weeds that grow near edges of tidal marshes would include nearly all naturalized non-native species in the flora of the San Francisco Bay region. A comprehensive weed flora of the region is beyond the scope of this report. Some weeds, however, are particularly abundant or dominant around the edges of mature, modern, or recently restored tidal marshes. An account of some of the most widespread weed species, their patterns of invasion, abundance, and regional distribution, is provided in Appendices 2 and 3. This account is illustrated with photographs of most widespread weeds, emphasizing vegetative and flowering growth phases (when weed removal is most effective). The nonnative species listed here include those that occur close to high tide drift-lines, or within the influence of extreme high tides around the Estuary.

The local weed floras of tidal marsh edges tend to reflect the relative abundance of weeds in the source areas of adjacent terrestrial landscapes, the primary source areas for weed invasions. Local weed floras are also strongly influenced by local disturbance regimes (e.g. brush-cutting, mowing, or frequency of levee maintenance) and human vectors of weed dispersal (trucks, pedestrian access, railroad tracks, or smooth road or trail surfaces with disturbed edges that facilitate weed seed dispersal and colonization). Weed vegetation composition is also influenced by local or regional salinity regimes. Brackish tidal marshes edges affected by pulses of relatively low salinity in winter high tides may become invaded by more shrub or tree species, such as figs or Himalayan blackberry. Local weed floras of dikes are highly dynamic: they change in response to rainfall variations, disturbance (particularly levee maintenance), and time since disturbance (age).

Many other weeds (Appendix 2) can be as or more invasive or dominant in tidal marsh vegetation in local conditions. Some weeds may be particularly dominant in specific areas because of site history, invasion history, adjacent terrestrial vegetation, and local environmental conditions. Ranks or priorities of weed invasiveness cannot be generalized throughout the Bay Area's highly variable tidal marsh edges.

Recent weedy non-native species have demonstrated their ability to spread and locally dominate tidal marsh edges, but not all are currently widespread (possibly because of time factors and stages of invasion history). Examples are listed in Appendix 2. These may be part of the "next generation" of major regional weeds of tidal marsh edges.

3.3 Identifying weeds in tidal marsh edges.

Accurate weed identification is critically important for vegetation management because of the potential for two common types of errors:

> (1) damage to native plant species caused by weed removal actions misdirected at misidentified uncommon native species that resemble them;
>
> (2) planting non-native species that are easily misidentified as native species (e.g., hybrid Atlantic cordgrass, Chilean cordgrass, Mediterranean sea-lavender, fat-hen).

The photo-illustrated tidal marsh edge weed guide (Appendix 2) is aimed at assisting initial recognition of weeds, and is a first step towards identification. Identification of weeds consists of verifying the species by checking it against a diagnostic key and diagnostic species description in a flora, such as the Jepson Manual (Hickman 1993). Many weeds, especially grasses, can be difficult to distinguish from native plants of tidal marsh edges. Even familiar weeds may be difficult to recognize during early stages of growth in winter or spring, such as seedling stages. Most weeding activities must occur during early vegetative and or early flowering stages, when many weeds are difficult to recognize.

Weeds should not be hastily identified by matching with photographs. Casual misidentifications based on recognition characters only, rather than diagnostic ones, may readily spread socially among volunteers. Volunteers focused on weed removal tend to perceive unfamiliar plants that resemble known weeds as mere variations of familiar weeds. Once volunteers are trained on an accurate "search image" of a weed, attuned to stages of a species growth present, they usually develop excellent and accurate plant recognition skills.

If in doubt, stewardship volunteers should not remove unidentified putative "weed" species, because some uncommon or rare native species can resemble weeds. Conversely, weeds that are familiar and readily recognized as mature plants, such as *Salsola soda*, may be unrecognized during early vegetative growth stages, even by experienced and knowledgeable amateur botanists.

Weeds should always be identified in the growing season when diagnostic parts can be observed, and before weed removal activities are initiated. Once identified and observed throughout the year, weeds can be recognized the following year, and distinguished from native plants. Site stewardship project managers should ensure that weeds are properly identified by responsible lead individuals who coordinate with volunteers in advance of weed removal activities.

3.4 Historic and modern native vegetation of San Francisco Estuary tidal marsh edges: models and objectives for management

For simplicity, the basic types of native vegetation that correspond with the major natural landforms of terrestrial edges of tidal marshes (hillslopes, alluvial fans and deltas) can be classified into relatively few types with characteristic or dominant species (Table 3). These simplified native vegetation types are conceptual models based on reconstruction of historic vegetation at the estuary's edges (Cooper 1926; Appendix 7), interpretation and synthesis of historic geographic data sources such as the EcoAtlas (SFEI), and reference to modern relict vegetation stands in the region (Baye *et al.* 2000 and unpublished data). These types of native vegetation are subject to many local ecological variations with high levels of species diversity (Baye *et al.* 2000), and do not represent standardized "plant palettes" like those of landscape architectural designs. Examples of potential reference conditions for tidal marsh edges are found in repeated plant assemblages that occur in remnant, undiked prehistoric tidal marshes. Examples are shown in Appendix 1. Some widespread and repeated patterns of native ecotone vegetation include:

(1) dominant perennial clonal grasses, sedges, and rushes intergrading with high salt marsh species such as saltgrass and alkali-heath, including creeping wildrye (*Leymus triticoides*) and wire rush (*Juncus arcticus;* intergrading locally with *J. lescurii* in eastern Marin County shorelines; Howell *et al.* 2007), sometimes with meadow sedge (*Carex praegracilis*) or basket sedge (*Carex barbarae*) in moist clay soils. These grass-sedge-rush dominated vegetation types reflect reduced salinity (local brackish edge conditions of salt marshes, or fresh-brackish edges of brackish marshes) near the high tide line.

(2) perennial clonal forbs or subshrubs, often in the aster family, extending into brackish marshes or brackish edges of salt marshes, including marsh baccharis *(Baccharis douglasii*), western goldenrod (*Euthamia occidentalis*), common and Suisun asters (*Symphyotrichum chilense, S. lentum*) and occasionally western ragweed (*Ambrosia psilostachya*). Non-clonal (clumped, single-crown) small-clone perennial forbs also occur in the northern Estuary marsh edges, such as salt-tolerant marsh ecotypes of yarrow (*Achillea millefolium*; northern estuary) and bee-plant (*Scrophularia californica*).

(3) low-growing annual or perennial forbs in high marsh pans (dry, hard clay or sandy clay soils with sparse cover and poor drainage in winter), including smooth goldfields (*Lasthenia glabrata*), salt marsh owl's-clover (*Castilleja ambigua*), toad rush (*Juncus bufonius*), and species found in alkali vernal pools or alkali grassland.

(4) shrubs in well-drained and porous stony soils on steep hillslopes with fractured bedrock (mainly eastern Marin County, western Contra Costa County), especially coyote brush (*Baccharis pilularis*), monkeyflower (*Mimulus aurantiacus*), blue elder

(*Sambucus mexicanus*), toyon (*Heteromeles arbutifolia*) poison-oak (*Toxicondendron diversilobum)* and California rose (*Rosa californica*). Trees such as California bay (*Umbellularia californica*) and coast live oak (*Quercus agrifolia*) or valley oak (*Q. lobata*) may also occur along bay edges.

Table 3. General terrestrial vegetation types forming ecotones (transition zones) with tidal marshes, San Francisco Estuary. Representative species are based on author observations from relict pre-reclamation tidal marsh floras. For botanical names, see Appendix 7.

General terrestrial vegetation type	landforms	major species above high tide line	major species below high tide line	variations
Dry alkali grassland (low groundwater level in summer)	Alluvial fan (equivalent: levee slope)	Maritime spikeweed Saltgrass Creeping wildrye* Alkali-heath Meadow barley tarplants fiddleneck	Saltgrass Creeping wildrye Alkali-heath Pickleweed Gumplant	Upper salt pan ecotone: many uncommon native annuals Valley grassland ecotone: many native bulbs, native grassland annuals
Moist alkali grassland (high groundwater level in spring and summer, seeps present)	Alluvial fan, swales or valleys of hillslopes(equivalent: levee slope)	Saltgrass Creeping wildrye Alkali-heath Marsh baccharis Western goldenrod Wire rush Iris-leaf rush Meadow sedge Meadow barley	Saltgrass Wire rush Iris-leaf rush Meadow sedge Meadow barley Creeping wildrye Alkali-heath Pickleweed Gumplant	Seeps: local dominant patches of marsh baccharis, common aster, Suisun aster, slender aster, California loosestrife, other fresh-brackish wetland plants
Riparian woodland (near-surface fresh groundwater)	Alluvial fan and natural stream levee	Red willow Arroyo willow black willow (Suisun) Blue elderberry California rose Bee-plant (N Bay) Yarrow (N Bay)	marsh baccharis common aster Suisun aster mugwort (other fresh-brackish wetland plants)	Local dominant willow species; Valley oak; Sedge marsh patches;
Valley grassland	Hillslope	Purple needlegrass Foothill needlegrass Common rush Whiteroot sedge Brodiaea spp. Creeping wildrye	Saltgrass Creeping wildrye Alkali-heath Pickleweed Gumplant	Red fescue *(note: salt marsh ecotypes of red fescue are rare in SF Estuary, but common in West Marin)*
Mixed coastal scrub	Hillslope (equivalent: well-drained bay fill)	Toyon Poison-oak Sticky monkeyflower Coyote brush	(Canopy extends over and below high tide line) creeping wildrye wire rush meadow sedge gumplant	California sage Nude buckwheat; Interspersion with valley grassland
Oak woodland	Hillslope (equivalent: well-drained bay fill)	Coast live oak California bay Poison-oak Toyon Sticky monkeyflower	(Canopy extends over and below high tide line) creeping wildrye wire rush meadow sedge gumplant	Local seeps (sedge, rush, creeping wildrye, marsh baccharis, riparian woodland)

This simplified classification of widespread native vegetation types of terrestrial-tidal marsh ecotones can be adapted to local geographic variations that consider local groundwater and seep conditions, variation in soil texture, exposure to winds, freshwater drainage gradients, topography, and historic or relict floras. The basic dominant or frequent species for each type can be considered as a preliminary plant species planting selection, depending on local wetland management objectives and environmental settings. (Table 3).

Soil texture, wind exposure, patterns of marine airflow (bay breezes, fog), surface drainage, slope, and groundwater are important environmental influences to consider in selecting appropriate vegetation types for guiding vegetation management at tidal marsh ecotones. Examination of pre-existing vegetation, even weeds, can indicate prevailing local climate, soil, and moisture regimes.

Most dikes are composed of dredged bay mud with variable amounts of peaty organic matter or organic muck. The high clay content of bay mud levees, and the bottom sediment origins, tends to promote relatively productive, nutrient-rich conditions that favor many fast-growing weeds. The same high clay content can also support enough moisture in low rainfall areas to support native terrestrial plants such as creeping wildrye, coast live oak, and most high tidal marsh plants. The growth of occasional trees on levees (Appendix 1, Figure 2) surrounded by salt marshes indicates localized, internal "reservoirs" of nonsaline soil moisture from winter rainfall (freshwater lenses).

Soil salinity in aged, rainfall-leached dike soils is generally within the range of tolerance of most native terrestrial plants, as indicated by the prevalence of salt-intolerant weeds. Levee soils may be alkaline (due to residual salts) or quite acidic, due to reaction of metal sulfides (produced in waterlogged bay bottom sediments) with air. Many dikes and fills adjacent to tidal marshes, however, also contain old remnants of roadbed materials, concrete or asphalt rubble, or rock slope armor. These materials may restrict transplanting and rooting depth, and may cause stunting of perennial plants, and favor annual plants. It is important to examine soil profiles by digging test trenches or boreholes in terrestrial soils when assessing them for habitat or vegetation management. It is generally impractical to amend existing soils of tidal marsh edges (except during construction of engineered restoration projects).

High exposure to drying winds can restrict the growth and vigor of woody trees and shrubs, and favor grasses and low-growing, drought-tolerant grasses and forbs. Recognizing microclimates by growth responses of old, pre-existing vegetation is a useful first step in assessing potential for revegetation. Surface seeps of groundwater near sea level, or seasonal (winter-spring) surface drainages, provide important, special opportunities to diversify terrestrial ecotones with a wide variety of native plants (Table 3). Careful observation of tidal marsh edges for seeps in early spring, and detection of distinct patches of fresh or brackish marsh plants may reveal the presence of small seeps or surface drainages.

4.0 Vegetation management in terrestrial edges of San Francisco Estuary tidal marshes

4.1 Species of concern for conservation and vegetation cover at tidal marsh edges

Numerous wildlife species of concern to biological conservation, including some federal or state-listed endangered or threatened species, depend on the availability of adequate flood refuge habitat within and adjacent to tidal marshes (Goals Project 1999). Their needs for particular sub-habitat structure along tidal marsh edges are important considerations for stewardship of restored tidal marshes. Representative species and their nesting and high tide refuge habits are shown in Table 1.

In addition, there are many native plant species of concern, including federal and state-listed endangered species, which inhabit the high tidal marsh zone, and may be strongly affected by weed invasions encroaching from the terrestrial marsh edge. Some representative examples are cited in Table 2. Most rare tidal marsh plants are threatened by wetland weeds that develop dense, extensive stands along the high tide line, such as perennial pepperweed (*Lepidium latifolium*), and Mediterranean saltwort (*Salsola soda*).

Designs for patterns of shrub cover adjacent to tidal marshes need to strike a balance between providing adequate high tide refuge for resident marsh wildlife and avoiding excessive cover that helps terrestrial predators travel deep into tidal marshes, or establish dens near or in them.

Many resident tidal marsh wildlife species are distributed according to the patterns of tidal creeks and their banks of tall emergent vegetation, such as California clapper rails, black rails, song sparrows, and yellowthroats. Locations where small tidal creeks are closest to the landward edge of the tidal marsh are appropriate potential locations for establishing multiple patches of shrubs or similar tall, dense vegetation cover to be used as local flood refuges (Appendix 1)

In contrast, planting continuous, dense stands of shrubs like coyote-brush in otherwise open, low vegetation may provide cover for predator movements, attack habitat, or shelter for den entrances. Dense woody cover may also provide too many large snags or dead branches in some settings that may be used as perches by ravens or raptors that may prey on endangered tidal marsh wildlife. Dense shrub cover may also interfere with necessary predator control activities for non-native red fox. Native large mammalian predators, such as coyote (likely to be beneficial, because they prey on or compete with non-native red fox) do not require or prefer dense shrub cover.

Dense shrub or tree cover is suitable for steep, well-drained hillslopes with deep, gravelly loams that naturally support oak woodlands, coastal scrub, or mixed evergreen forest.

4.2 Native revegetation and weed management

Weed management efforts sometimes focus more on short-term weed removal tactics than on the long-term goal of developing geographically suitable, resilient, weed-resistant native vegetation with high habitat values. This is probably because weed removal activities can be done in the short term with planning limited to organization of volunteer "weed bashes". In contrast, integrated native vegetation planting and ongoing inspection requires long-term goals, planning and commitment of resources. These guidelines aim to integrate both essential aspects of vegetation management in terrestrial-tidal marsh ecotones.

4.3 Native revegetation to suppress weeds. Weed removal and weed suppression are short-term tactics to reduce the abundance and distribution of weeds in tidal marsh edges. Repeating weed removal activities without managing for a desired dominant vegetation to replace weed stands can be equivalent to cultivating weeds unintentionally: soil disturbance, maintenance of unoccupied soil, disturbance of plant competition, and redistribution of weeds seeds by weed removal activities can perpetuate weed dominance. Escaping the disturbance cycle of weed removal and weed regeneration requires a transition to a suitable native perennial vegetation type that resists the weed regeneration and dominance.

Mature stands of many native vegetation types can be highly competitive against weeds along edges of tidal marshes, even on artificial soils of dikes. The same potentially competitive native species may have very limited competitive ability when they occur as small clumps of young transplants in a matrix of weeds or disturbed soil. Gaps of disturbed soils with weed seeds, or surrounded by weeds, tend to be re-invaded by weeds. Weeds often have the advantage of superior numbers, regardless of the competitive ability of some native species, even natives that may be competitively superior in undisturbed conditions.

Some native plants are unlikely to be able to compete successfully with terrestrial weeds in tidal marsh ecotones. Native bunchgrasses (*Nassella* spp.) are sometimes proposed for revegetation of disturbed terrestrial edge soils, but native bunchgrasses can be difficult to establish with weed competition, even in locations where they may have been historically native. Creeping, sod-forming native grasses and sedges are more feasible for revegetation (see 4.4.)

The success of revegetation with native species as a tool to manage weeds is strongly influenced by the selection of native species to match local conditions and weed competitors. The selection of appropriate transplanting schedules and methods are also important (Appendix 4).

4.4 Emphasis on revegetation with clonal perennial (creeping) native plants. Some native plant species, particularly some creeping, sod-forming native grasses and sedges are particularly effective at establishing extensive, competitive perennial vegetation that resists weed invasion, or actually crowds out weeds over time. Clonal (creeping, rhizomatous) perennials capture and retain most available potential seedling space (small-scale vegetation gaps) above-ground and below-ground. Small-scale gaps in vegetation or leaf litter mats are often required for successful seedling establishment by annual weeds. Dense stands of native perennial vegetation, especially grasses, rushes, and sedges, also deposit natural "mulch" layers of persistent leaf litter that can inhibit establishment of weed seedlings.

Most native clonal perennials of tidal marsh-terrestrial ecotones are poorly represented in young tidal marshes and disturbed levees, because they require a long time without disturbance to build up extensive, mature populations. Clonal perennials establish by slow lateral vegetative spread of colonies that merge and coalesce in either single-species or multi-species stands. Most establish from seed infrequently, and few are strong pioneer colonizers. In old, undisturbed tidal marsh edges connected to natural terrestrial vegetation (e.g. China Camp, Point Pinole, upper Newark Slough, clonal perennial plants are abundant in most terrestrial-tidal marsh ecotones, and often dominate them. They are relatively more abundant than the familiar linear, hedge-like assemblages of broadleaf weeds, and gumplant vegetation that is typically found along edges of disturbed levees.

Creeping wildrye is the most adaptable, tolerant, competitive, and wide-ranging of the native clonal perennial plants of tidal marsh ecotones in the Estuary. Other native creeping perennials with high potential for use in management of terrestrial-tidal marsh edges include western ragweed (*Ambrosia psilostachya*), mugwort (*Artemisia douglasiana*), meadow sedge (*Carex praegracilis*), marsh baccharis (*Baccharis douglasii*), western goldenrod (*Euthamia occidentalis*), wire rush (*Juncus arcticus*, = *J. balticus*), iris-leaf rush (*J. xiphioides*). Native perennial asters (*A. chilensis, A. lentus*), though relatively uncommon in modern tidal marsh edges, are also strong colonial plants in brackish marsh edges (which also occur along seeps at the edges of salt marshes), similar to western goldenrod.

All of these native creeping perennials thrive best where high soil moisture or near-surface groundwater occurs in winter and spring. Relatively high moisture zones are likely to occur where either hillslopes or alluvial fans contact the tidal marsh, and at the toes of levees. Dikes in brackish or intermittently brackish reaches of the estuary are generally likely to be able to support all these species. Fresh wastewater discharges from urban areas, and seeps driven by irrigation of urban landscapes, are now common in San Francisco Bay. These artificial hydrologic modifications of tidal marsh edges may also facilitate revegetation with native clonal perennials of tidal marsh edges. Creeping wildrye and western ragweed are distinguished from their associated species by their relatively high tolerance of prolonged dry soil conditions in summer.

The distribution of the some weeds can be useful indicators of potential soil suitability for native clonal perennial vegetation. Invasive nonnative clonal perennial pepperweed (*Lepidium latifolium*) along tidal marsh edges is one indicator of suitable soil conditions for clonal perennial sedges, grasses, rushes, and forbs.

Past convention in revegetation of levees has emphasized non-clonal (unitary, single-trunk or single-crown) plants that are fast and easy to raise in cultivation (e.g. coyote-brush, gumplant). When these are planted among dominant weeds, their growth is likely to be limited to the narrow point of planting, and weeds tend to fill the large gaps between them. In contrast, competitive clonal perennials tend to fill gaps as they spread, leaving less room for weeds to persist.

4.5 Temporary cover crops to manage weed competition. After weed removal and replanting of tidal marsh edges, most of the treated area consists of bare soil or mulch. These interim conditions are highly vulnerable to rapid reinvasion and dominance by fast-germinating, fast-growing annual and perennial weeds. This challenge is inevitable because transplanted perennial and woody native species, no matter how densely planted, take longer to grow and spread than most weeds. A transition period between weed vegetation and establishment of native vegetation require an interim maintenance period. Perpetually weeding around native transplants may be infeasible for the entire long period of establishment required by some native perennial plants.

Mulching with landscaping materials can make some weed invasions worse, as do many conventional horticultural landscaping solutions to weed management. Organic mulches (shredded bark, wood chips, straw) applied for temporary, short-term suppression of weeds rapidly decompose and leave residual surface organic matter than usually favors weed seedling survivorship in subsequent years. Straw mulches are usually contaminated with weed seeds, and can increase weed species richness or weed seed density. Weed-free straw mulches can be useful for protecting the base of transplants, but broadcast application of even weed-free straw mulch tends to facilitate survival of weed seedlings recruited from pre-existing seed banks. Sawdust mulches are sometimes recommended as a weed control measure to elevate carbon:nitrogen ratios of the soil surface (temporarily immobilizing available nitrogen, "reverse-fertilizing" weeds), but this temporary effect is followed by decomposition and release nitrogen of nitrogen in an ameliorated, organic matter-enriched soil surface environment; this risks facilitating long-term weed seedling regeneration. Organic landscape mulch materials are not recommended as a primary method of weed control in tidal marsh edges. In contrast, long-term production of persistent leaf litter by creeping grass-like vegetation (truly natural mulch; see 4.6), and short-term use of competitive fast-growing cover crops are recommended as alternatives to artificial temporary mulches for weed control in tidal marsh edges.

A more feasible approach to interim weed management during establishment of native perennial species may be to apply high sowing rates of selected native or non-native annual species as competitive "cover crops". Cover crops are fast-germinating, fast-growing seeded plant populations grown from broadcast sowing of seed. They are aimed at early and strong competition with weed seedlings, taking up unoccupied soil space otherwise available to weeds. Cover crops may be designed to develop leaf canopies or leaf litter deposits that smother (shade and compete with) weed seedlings of more noxious weed species. Cover crops can also be used to prevent the facilitation of one weed species following the removal of another (possibly worse) weed species -- a common occurrence in weed removal programs. Cover crops must be carefully selected so that they do threaten long-term native vegetation dominants with excessive competition.

For example, Italian and perennial ryegrass (*Lolium multiflorum, L. perenne*) are non-native annual to short-lived perennial grass weeds that are widespread and often dominant in seasonal wetlands of diked baylands. Ryegrass tends to suppress seedling germination and emergence of other species, but it tends not to out-compete taller native perennial or woody plants in tidal marsh edges. Heavy accumulation of ryegrass leaf litter may interfere substantially with seedling regeneration of noxious, tall weeds such as yellow starthistle, wild radish, and fennel. Ryegrasses are undesirable weeds in wetland vegetation supporting native annual species (such as vernal pools), but they are often readily displaced by gradual clonal spread of taller native creeping perennial grasses and sedges, such as creeping wildrye, meadow sedge, or basket sedge. Shrubs and trees are also likely to out-compete Italian ryegrass over time.

Most tidal marshes, dikes, and diked baylands in the Bay area already support extensive populations of non-native ryegrasses. Where they are already abundant, ryegrass use as a temporary cover crop following weed removal may be considered as a management option. Ryegrasses should not be introduced to sites where they are not already relatively abundant, and they should only be used when there is a firm commitment to displace them in succession with planted native clonal perennial vegetation.

Few native annuals and perennials can be cost-effectively seeded over weed-cleared tidal marsh edges with pre-existing weed seed banks. Meadow barley is significantly more expensive than Italian or perennial wildrye, and is seldom as competitive against broadleaf weeds in disturbed, dry levees or fill soils. No other native grasses are good prospects for seed sowing as cover crop competitors against weeds of tidal marsh edges. Some coarse native annual broadleaf plants that form dense stands in disturbed alkaline or slightly saline clay soils, however, may be good candidates as cover crops in tidal marsh edges. Examples include spikeweed (*Centromadia pungens*; reportedly not native to Marin County, but native to the rest of the western Estuary), tarplants (*Hemizonia congesta* subspecies), and fiddleneck (*Amsinckia menziesii*). Heavy seeding rates required for effective cover crops may make annual native forb seed an expensive alternative to commercially available ryegrass or even meadow barley.

4.6 Creeping wildrye and associated clonal grasses and grass-like plants as native matrix vegetation. Creeping wildrye is a clonal perennial sod-forming native grass that is widespread around intact tidal marsh edges of the Bay Area (Appendix 1). It is highly tolerant of a very wide range of soil conditions, including prolonged soil saturation and dryness. On bay mud levees, it slowly spreads (about 10-30 cm/yr) vegetatively to form dense, closed cover with thick leaf litter mats and dense below-ground root/rhizome mats (sods) that resist weed invasion. Thick stands of creeping wildrye can slowly exclude many annual weeds such as wild radish and many annual grasses. Dense creeping wildrye stands appear to be able to exclude, inhibit or displace even perennial pepperweed (*Lepidium latifolium*) in some seasonal wetlands. Plantings of creeping wildrye may be useful as a defensive matrix of native vegetation where weed populations are overwhelming, if long-term, slow results are acceptable. In addition, creeping wildrye produces perennial sods that strongly bind soils and help stabilize levees against wave erosion and gullying from overtopping.

Creeping wildrye is widespread along natural tidal marsh edges in the Bay Area, and it is an outstanding candidate species for planting as the matrix of designed vegetation on levees and other tidal marsh edges. It can, however, be excessively successful: the same competitive traits that enable it to suppress weeds can inhibit native species diversity as well: monotypic stands of creeping wildrye readily establish themselves, and thick stands may need to be broken (interplanted with shrubs or other clonal perennials) to prevent homogeneous stands. The most robust, competitive forms (natural hybrids with giant wildrye; *L.* x*multiflorus*) should be avoided or used sparingly for planting because their dominance may reduce long-term native plant community diversity.

Creeping wildrye thrives in drained bay mud, even moderately acidic or fresh-brackish bay mud of dredge spoils and levees. Creeping wildrye spreads slowly by rhizomes at variable rates, depending on soil moisture and fertility. In clay loams that are seasonally wet, creeping wildrye can spread about 10 to 30 cm per year, and occasionally more. Transplant density can be calibrated to local growth rates to provide closed cover by approximate target dates. Dense, closed stands of creeping wildrye may take a decade to develop at planting densities based on 3 to 6 foot centers (nearest neighbor distances; see Appendix 4).

Creeping wildrye rarely establishes from seedlings, and viable seed are relatively scarce. It is most efficiently propagated by transplanting vegetative divisions of pruned leafy shoots, or rhizome fragments with buds. Larger vegetative divisions or sod fragments have greatest viability in harsh sites. Significant genetic variation exists in creeping wildrye around San Francisco Bay. Imported, cultivated clones from other regions in California may not have the same desirable growth characteristics and adaptations as local, native populations, such as relatively high salt tolerance. Local populations adjacent to the bay (or as close as possible) should be sought and propagated for tidal marsh ecotone revegetation.

Other creeping grass-like plants with similar sod-forming and weed-suppressing abilities are associated with creeping wildrye along tidal marsh edges in different subregions of the Estuary. They include **saltgrass** (Distichlis spicata), **meadow sedge** (*Carex praegracilis*; northern San Francisco Bay, San Pablo Bay, Suisun Marsh and Contra Costa shoreline), **basket sedge** (*Carex barbarae*, also northern estuary), and two subspecies of **wire rush** that occur all around the Estuary, Baltic or wire rush (*J. arcticus* ssp. *balticus*) and Mexican rush (*J. a.* ssp. *mexicanus*). All are tolerant of winter soil saturation and flooding, but basket sedge is somewhat less tolerant of aridity and soil salinity in summer, and usually depends on seeps, depressions, or swales for late-season moisture. See Appendix 4 for details of planting and propagation.

Large clones of meadow sedge and wire rush can grow down into the high tide line of salt marshes. Saltgrass is equally capable of growing in salt marshes and well above the high tide line in alkaline clay soils or sandy soils, depending on competition. All these associated species can occur in discrete patches (sedges) or mixed stands (wire rush) with creeping wildrye, and they can be co-planted with it. Creeping wildrye tends to become dominant in clay soils with low to moderate salinity and summer aridity.

Some of the salt tolerance of creeping wildrye, sedges and rushes depends on the size of clonal patches, and rooting above the high tide line to access non-saline soil. Clonal plants can translocate water to salt-stressed portions of the clone. Therefore, individual plantings may lack the drought tolerance or salt tolerance of older, larger clones. Long-term competition and differential growth in local soil and climate conditions will sort out which clonal grass-like species prevail where in the tidal marsh ecotone, and in what proportions.

4.7 Weed removal and suppression methods potentially applicable to tidal marsh edges

4.7.1 Weed-on-weed competition. Weed removal and weed control are not the same. Weeds compete with one another, just as they compete with native plants. Removing one weed and its seeds may provide a competitive advantage to another weed species, or produce a gap that may be invaded by a new weed arrival. Weedy vegetation often exhibits a hierarchy of invasion: when one weed species declines, others encroach on its formerly occupied space, often faster than stress-tolerant, slower-growing natives. For this reason, weed removal must be integrated with follow-up control and revegetation with stable, competitive native vegetation adapted to local environments.

Saline irrigation of levee kills terrestrial weeds on contact, and conditions soil to inhibit salt-intolerant generalist weeds. SF Bay National Wildlife Refuge, Alviso

4.7.2 Soil salinization. Salinization refers to irrigation with saline water to raise soil surface salinities to levels unfavorable for weed seed germination or seedling growth, but tolerable for native vegetation. Saline irrigation can directly injure salt-intolerant weeds, but most weed inhibition from this method is achieved by soil conditioning. Most terrestrial weeds have limited salt tolerance compared with natives of the high tidal marsh zone. Weed seedlings may be highly salt-sensitive during dry weather, before taproots develop access to permanent underlying nonsaline soil layers below the surface. Surface irrigation with saline water on sloping clay soils (like levees) usually has only superficial penetration. The effectiveness of soil salinization depends on seasonal timing in relation to active plant growth. Soil salinization occurs naturally during extreme high tides. Winter high tide flooding tends to occur when perennial plants are dormant and relatively insensitive to salt exposure, and when bay salinity is lowest. Summer high tide flooding usually occurs after spring annual weeds have set seed and died. Applying salinity pulses "out of season", targeting the most sensitive developmental stages of local weeds, can cause injury, reduced growth and competitiveness, dieback, or mortality. Soil salinization requires portable pumps (subject to corrosion by salts) and truck access and overhead spray irrigation used in professional landscaping. It may be considered as an alternative to broadcast applications of herbicides.

4.7.3 Black plastic mulch and "solarization" techniques. Solarization refers to the amplified "greenhouse effect" of heating vegetation under geotextile or plastic covers. Clear, heavy layers of polyethylene plastic are placed over low vegetation, and are sealed along their edges to retain hot, steamy air. The shallow solar tent generates lethal high temperatures after prolonged exposure to full sun in spring or summer. Leaves in contact with the top of the plastic are rapidly burned, and extremely hot, humid air usually kills shaded leaves below. Opaque black plastic or geotextile is also used for solarization. It has the advantage of causing stress due to prolonged lack of light, but the disadvantage of maintaining lethal high temperatures mostly in a narrower upper zone near contact with plastic (no sunlight penetrates to the ground itself to directly heat it), while ground surface temperatures may be buffered. Black plastic mulches are effective in cool winter weed germination periods when solarization may be ineffective.

Black and clear plastic "mulch" methods do not generally affect below-ground perennial buds, but they are highly effective on annual weeds (especially sensitive seedlings) before they set ripe seed. Solarization techniques may be challenging at windy sites, where heavy planks or rocks may be needed to stabilize the plastic cover. Tears or perforations can prevent lethal temperatures from being achieved. Solarization is not practical for vegetation with tall or woody stems. Solarization is a potentially useful "knock down" or defoliation method to use prior to planting.

4.7.4 Vinegar desiccant defoliation. Vinegar (5% acetic acid) is an organic defoliant: it acts as a desiccant that burns most non-waxy leaves on contact, especially if applied with a wetting agent like coconut oil soap. Defoliation may be used to kill sensitive weed seedlings, or to set their growth back by injury to give transplants a temporary competitive advantage. Vinegar is an organic acid that is metabolized by soil bacteria, and is unlikely to penetrate soils or inhibit subsequent growth of transplants. It is non-selective, and may injure native vegetation as well, so its application must be judicious. Vinegar (with a trace of soap added) full strength solution may be applied by home gardener pump sprayers. The efficacy of vinegar sprays in field conditions is variable.

4.7.5 Herbicide spot-treatment. Herbicide applications in and around wetlands are restricted to only two herbicides applied by licensed professionals, and so they are unlikely to be used in volunteer stewardship programs. Broadcast application of herbicides, even herbicide tank mixes with presumed low toxicity to wildlife, is problematic in the high tidal marsh zone and terrestrial ecotone for several reasons. Native plant species diversity is sometimes relatively high in these zones, and weed control using broadcast applications (sprays) of non-selective herbicides there can do more harm than good in most situations where native vegetation is common.

Most herbicide formulations used in terrestrial habitats rely on surfactants (detergent-like substances) that can be toxic to wetland and aquatic invertebrates and vertebrates, and are illegal to apply in or near aquatic habitats. Herbicide applications in sensitive vegetation or habitats of tidal marsh edges would normally be restricted to cut-stump applications (to prevent root regeneration or stump resprouts, rhizome resprouts), or wick applications (wiping leaves with herbicide-soaked fabric "wicks").

4.7.6 Manual weed removal. Manual removal of weeds consists simply of pulling them out or grubbing (digging) them out by hand, mattocks, weed wrenches, or cutting them with pruning saws. Manual removal is labor-intensive, slow, and tedious, but often effective in limited, concentrated areas of effort. It can also be hazardous: skin contact with toxic plants like poison-hemlock can cause skin irritation or nausea, and many bristly, spiny, or pollen-producing plants can cause skin irritations or allergic reactions. Manual removal also causes some soil disturbance, and can effectively cultivate soils for subsequent weed reinvasion. Manual removal must therefore always be coordinated with either revegetation or a cover crop. Manual removal by pulling may be ineffective or counter-productive for some clonal perennial plants with rhizomes or roots with buds, such as perennial pepperweed. Mechanical removal must be performed before target weed vegetation sets ripe seed, or else the disturbance from pulling weeds will not only effectively till the soil, it will sow weed seeds into it. Some perennial weeds are entirely infeasible to remove by hand without strain or injury, such as Harding grass, iceplant, or jubata grass.

A curved folding pruning saw is a highly useful tool for removing woody rootstocks at or slightly below ground surface level. Sharp pruning saws can sometimes work more efficiently than mattocks, which are pickaxe-like tools with axe-like blades. Mattocks are useful for cutting off taproots or rootstocks below ground level (below the crown of buds on taproots – points of shoot regeneration) so bud sprouting is less likely to occur. Tile spades (spades with long, narrow blade for ditch digging) can also be used as below-ground cutting tools.

Grass whip, swing blade, tile spade, and lightweight mattock

4.7.8 Mechanical mowing and manual blade cutting. Mowing is a somewhat selective method for reducing seed production of weeds, particularly for annual species that do not survive or growth well in the rainless summer period. Annual grasses in particular are well-suited to control of seed production by mowing or manual cutting. Where management areas are small, and native plants are interspersed closely with stands of annual grasses, either motorized weed-whackers or manual blade cutting may be preferable over mowing equipment. Manual swing-blades or grass whips (non-motorized predecessors of weed-whackers) are very precise in cutting, and have the benefit of silence, which may be an important advantage for wildlife disturbance in sensitive tidal marsh habitats. Cutting heights should be adjusted for the stage of growth, to minimize the likelihood of branching and resprouting while plants are actively growing. Repeat mowing annuals until plants are either growing minimally, or are dead. Cutting with swing blades or machetes, or motorized brush-cutters may be used to prevent the bulk of seed production during flowering of large weed stands, even where removal is infeasible.

4.8 Adapting weed removal strategies to sites

4.8.1 Spatial patterns and rates of weed removal. Spatial patterns of weed removal should be viewed from both perspectives of wildlife cover and weed population management (see examples, Appendix 5). Project managers should either coordinate with wildlife experts to assess existing wildlife use patterns, or carefully observe sites for weeks before stewardship crews begin work. Wildlife signs and behaviors (droppings, tunnels, tracks, grazing/browsing, calls, movement) should be understood before weed management begins. The distribution of high tide cover around the site should be evaluated, particularly in relation to the positions of tidal channels that act as wildlife movement corridors, foraging areas, and nest sites. If most tall vegetation or high tide cover is supplied by weeds along the tidal marsh edges, and sensitive wildlife is present, weed removal should be phased over more than one year (with native revegetation between) to avoid abrupt removal of wildlife cover. If sufficient native vegetation supplies cover within the adjacent tidal marsh and along its landward edge, more aggressive, rapid weed removal may be appropriate.

4.8.2. Principles for site-specific weed control strategies. From a weed population management perspective, patterns and levels of effort at removing weeds should consider the following factors.

- **Early elimination of small outlier weed colonies**. Some weed species are widely distributed, but others, especially in early or incomplete stages of invasion, occur as multiple, large and small colonies. Outlier colonies act as outposts for seed dispersal or creeping rhizome spread. For weeds with persistent seed banks, the dispersion of outlier colonies can dictate patterns of future spread. Outlier colonies of minor weeds do not need to become urgent priorities merely because they occur in small colonies, but highly invasive plants in marginal small colonies should almost always be high priorities for eradication efforts.

- **Pre-empting invasion: controlling corridors of local weed seed dispersal**. Often, weeds travel along smooth, open surfaces by wind or attachment to fur or fabric, so foot trails and roads (such as levees) are often major pathways for invasions. Look for seed sources of weeds that are not widespread at tidal marsh edges, but occur in nearby patches at parking lots, trail entrances, fence lines, etc. Either remove them as soon as feasible, or at least prevent their seed production by cutting, mowing, defoliation methods.

- **"Weed hygiene" (sanitation)**: Boots, truck tires, weeding tools, socks, bags, and "native" transplants taken from one weed work site to another may transport weed seeds. This is significant for introduction of founder populations of weed species not already present at a stewardship site. Equipment and footwear exposed to potential new weed sources should be cleaned (washed) before entering a weeding work site. "Native" transplants should be carefully inspected to ensure both accurate identification (discriminating look-alike non-native species) and absence of entrained weeds or weed seeds. Bare root dormant transplants that can be washed are always preferable for this reason.

- **Reversing spread of discrete clonal weed populations.** For clonal weeds (creeping by rhizomes or bud-sprouting roots) established in discrete colonies, focus removal efforts on the leading edges of below-ground spread. For clonal colonies with vegetative edges and flowering/seeding shoots a short distance back from the edge (a common pattern), cut or mow seed-producing edges to increase the distance of seed dispersal from the colony's edge. Even with seeds adapted to long-distance dispersal, most seeds fall close to the parent shoot, usually in a "seed shadow" only a meter or two wide.

- **Concentrating repeated removal of widespread annual weeds in large, consolidated patches**. For widespread annual weeds, such as most annual non-native grasses, it is generally unhelpful to make diffuse or patchy weed removal efforts that merely reduce the density of seed-bearing annual weeds. Weeding redistributes weed seeds, exposes seeds from the soil seed bank, and disturbs the ground, creating a favorable weed seed bed for the subsequent winter-spring growing season. To significantly reduce the extent and viability of local annual weed populations, focus efforts on preventing seed production, maturation, and dispersal in a well-defined, consolidated area for at least two, and preferably three consecutive growing seasons. Most annual grasses, and some annual broadleaf plants, have short-lived soil seed banks. Any method that prevents or significantly inhibits production of viable seed is likely to be more effective than visually impressive physical removal of the standing crop of weeds, particularly after seed have ripened.

- **Timing weed removal efforts to vulnerable life-history stages.** Many weed removal parties ('weed bashes") are scheduled in pleasant spring weather when volunteer turnout is most likely to be high, usually in spring. Often, annual grasses have already set seed by spring, and most annual and perennial broadleaf weeds have their relatively sensitive seedling emergence and establishment periods in winter or very early spring. It is usually most efficient (but not always most practical) to schedule weed removal efforts in the seasonal stages of weed development when they are most vulnerable, and most responsive to treatments. This is usually in early stages of seasonal growth and development. Weed control of annuals must be performed prior to seed maturation, and usually prior to flowering, depending on species-specific development patterns. Spring and early summer are periods suited for follow-up or clean-up weed work on most weed species, rather than the primary season of removal. Exceptions include some "bolting" broadleaf weeds (rapid stem elongation at flowering) that are most detectible and least likely to regenerate in earliest flowering stages, such as thistles, poison-hemlock, and starthistles.

- **Frequent re-inspection and repeated treatment**. Conventional monitoring of tidal marsh vegetation is highly expensive and labor-intensive, and therefore tends to be done infrequently or for very short multi-year annual monitoring periods. This is the opposite of what is needed for effective weed control, which demands frequent re-inspection of sites within a single growing season to detect weed growth responses, life-history stages, and short-term outbreaks or regeneration after treatment. It is critically important to repeat weed removal treatments so that weed regeneration and seed production are prevented within the growing season. For this reason, <u>contemporary</u> (within-season) <u>frequent</u> (monthly or biweekly) <u>"site inspections</u>" (rapid field assessments focused on weed survivorship, growth and developmental stage) with recorded observations (photographs, interpretable field notes) that provide rapid feedback for management actions are recommended. Frequent site inspections should be higher priority than annual (after-the-fact) monitoring reports that focus on administrative, long-term recording, often out of synch with current-year weed management needs and feasible adaptive reaction time. The frequent, rapid inspection/feedback approach is a well-tested convention for range managers and marsh managers. Project managers should develop close rapport with individual tidal marsh edge sites and habitually re-visit them at least twice a month. Meandering, semi-random "transects", and repeated opportunistic or scheduled visits to permanent viewing locations or permanent plots, are efficient inspection habits for projects with very little budget and project time available.

- **Pre-emptive control of weed invasions: pre-construction weed control and post-grading cover crops.** If stewardship of tidal marsh edges can begin with project construction, there are great potential long-term advantages for vegetation management. Most weed legacies at tidal marsh restoration sites originated from neglect of weed invasions during the first two to three years after levees or project boundaries were graded. Most weeds are superior colonizers of disturbed ground, and occur in superior numbers during site grading. But many weeds (arguably most) are less able to aggressively invade pre-established vegetation if their "seed rain" abundance is low, particularly if the established vegetation is dense. If weed management actions like weed seed source reduction and active vegetation recruitment are initiated before weeds colonize restoration sites, subsequent effort is likely to be limited to minor maintenance rather than major, long-term removal efforts. Two actions are essential to pre-emptive weed control.

First, the primary weed seed 'inoculum" sources for the site should be identified before construction begins, and seed production should be prevented. Stockpiled weed-covered soils, weedy truck/equipment access roads, and site boundaries (especially roadsides and tidal marsh edges adjacent to the project site) are the typical immediate sources of weed invasion for new restoration sites. These immediate pre-construction weed sources should be suppressed to minimize weed "seed pressure" on the site. Mowing and cutting may be more practical to achieve this than complete weed removal.

Cover crops (temporary vegetation cover produced by high seed sowing rates) of non-native plants such as Italian wildrye that are unlikely to interfere with long-term establishment of native tall perennials and shrubs, may also be seeded to inhibit spread of noxious weeds. Third, pioneer colonies of highly invasive weeds should be detected before they set seed, and should be the focus of concentrated weed removal efforts. No amount of weed control efforts initiated after construction and pioneer weed invasion can be as effective as pre-emptive control.

Constructed terrestrial-tidal ecotones should be planted early with at least native clonal perennial species to initiate rapid revegetation, and intercept available open ground as soon as possible, before weeds dominate.

- **Weed species prioritization**. Not all weed species are equal in the degree of threat they pose to long-term establishment of native vegetation in terrestrial-tidal marsh ecotones. Many weeds can be tolerated where native plants are actively transplanted because they mainly interfere with seedling regeneration stages of natives, a life-history stage that is bypassed by artificial planting. Highly invasive weed species that are also very strong competitors – able to interfere with growth and survival of established or establishing native plants – should be the highest priority for removal. See Appendices 2 and 3 for regional assessment of potential weed invasiveness and abundance/dominance. Local observation of weed species behavior should be given more weight than regional trends, because weed invasiveness and competitiveness varies significantly around the Estuary, especially in relation to salinity and disturbance regimes. Prioritization should address the longevity of seeds (seed banks), and the potential for weed species seed dispersal across the site. Prevention of long-lived seed deposits in soil should be a very high priority.

4.9. General planting guidelines for native plant species in tidal marsh edges

Species-specific propagation and transplanting guidelines for selected, representative key native species of terrestrial-tidal marsh ecotones of the San Francisco Estuary are provided in Appendix 4. These species are generally well-adapted to clay soils typical of most modern tidal marsh edges, which are usually derived from dredged bay mud fill, or similar terrestrial clay soils. A general list of widespread native plants of the vegetation zones evident in most tidal marsh-terrestrial ecotones is presented in Table 4. This is not a universal, all-purpose list for all subregions of the estuary; local planting lists should be based on site-specific soil conditions, slopes, nearby proxy or reference sites, and analysis of local native marsh edge floras.

A full background account of propagation and transplanting methods for native San Francisco Bay plants is beyond the scope of these guidelines, but some essential principles of successful transplanting are reviewed here for emphasis. These factors are often most influential for the success or failure of transplanting.

- **Timing of transplanting and sowing for fall-winter period**. Like most weeding labor, it is easier to get volunteer participation for transplanting in pleasant weather. For optimum transplanting success, transplanting of native perennial and woody plants must occur in wet, cool weather after the soil profile is wetted. Planting days should be scheduled from fall to early winter, preferably during periods of cloud, fog, or drizzle. Seed sowing in the field must occur before the onset of germinating fall/winter rains, because even slight delays in seedling development relative to competing weeds can cause failure of natives to compete. Similarly, transplants must take full advantage of the root growth season. Delays in root development while soil is wet and plant demand for water is minimal, and prior to moisture competition with annuals, can mean inadequate root systems to supply water to shoots during summer moisture stress. Inadequate winter root development can cause injury or mortality in transplants. Spring transplanting (peak root development of nonnative annual grasses, minimal soil moisture, soon followed by summer dry weather) is likely to fail.

- **Local drainage patterns and infiltration of rainfall or runoff.** Most irrigation is generally infeasible and counter-productive for establishing transplants. Most tidal marsh edges are remote from sources of fresh tap water for irrigation. Even where artificial irrigation is feasible, it is seldom advisable to treat native revegetation like native plant landscaping in urban settings. Conventional drip irrigation (sometimes implemented in tidal marsh restoration sites) causes root systems to develop patterns narrowly adapted to the irrigated soil wetting zone in the short-term. Transplants need to adapt root system structure instead to local competition or summer soil moisture profiles, so they can survive in long-term drought conditions without irrigation.

  To ensure that direct rainfall or runoff is adequate for establishment for transplants on gentle slopes, the downslope side of the transplant should be supplied with a very low-relief berm or barrier a few centimeters high. The ground around the transplant should be a level terrace. These microtopographic features help water infiltrate to root systems in clay soils with slow permeability. Where transplanting sites have irregular topography, planting in depressions or swales where rainfall or runoff drain will provide transplants with relatively higher soil moisture for longer in spring.

- **Planting patterns and compatibility.** Native plants do not occur in random distributions, and most native plants can interfere with growth of others. Planting patterns should be based on representative models or reference conditions (see Appendix 1), as well as local reference conditions. Generally, low-growing native plants should not be planted adjacent to taller, dominant species. Species that require seedling regeneration should not be planted in areas surrounded by creeping, clonal perennials that form turfs or litter mats locking out seedlings. Whenever possible, planting patterns modeled after reference sites should be planned and staked or flagged out in the field soon before transplanting dates, to account for contemporary soil and competition conditions.

- **Local on-site experience and training**. Individuals experienced and familiar with native plant horticulture or landscaping should be present on site to provide supervision and training during transplanting, to ensure quality control.

Table 4. **Partial list of recommended candidate native revegetation species for clay soils in terrestrial edges of tidal marshes, western San Francisco Estuary**

See Appendix 6 for botanical and common names. The following species are widespread in tidal marsh edge vegetation of the San Francisco Estuary, but site-specific native species planting lists for revegetation projects should reflect local or subregional variation of the Bay Area's marsh floras.

revegetation function	high marsh zone	high tide line (winter drift-line zone)	above high tide line
matrix vegetation	saltgrass pickleweed alkali-heath	saltgrass marsh baccharis western goldenrod western ragweed meadow sedge wire rush Mexican rush creeping wildrye spikeweed tarplants	creeping wildrye basket sedge meadow sedge (saltgrass in saline/alkaline clay soils)
community diversification (native species diversity, structural diversity)	marsh gumplant smooth goldfields salt marsh owl's-clover muilla (northern estuary)	cressa common aster fiddleneck heliotrope meadow barley poverty-weed slim aster Suisun aster wormwood/mugwort yarrow (northern estuary) bee-plant (northern estuary)	coast live oak coyote-brush valley oak blue elder toyon California bay California rose arroyo willow

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