ATTACHMENT 1

VEGETATION MANAGEMENT DESIGNS TO MITIGATE IMPACTS TO RESIDENT CALIFORNIA CLAPPER RAIL POPULATIONS AT SELECTED HERBICIDE-TREATED SALT MARSH SITES

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MEMORANDUM

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From: Peter Baye

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PROJECT: **Invasive Spartina Project – Spartina Control Projects** at **Colma Creek** vicinity (South San Francisco), **Cogswell Marsh** (Hayward), **Arrowhead & MLK marshes** (Oakland)

SUBJECT: **Vegetation management designs to mitigate impacts to resident California clapper rail populations at selected herbicide-treated salt marsh sites**

1.0 Purpose

The purpose of this technical memorandum is to provide designs for vegetation management of herbicide-treated hybrid San Francisco Bay cordgrass stands (*Spartina foliosa* x *alterniflora;* introgressant Pacific and smooth "hybrid cordgrass") at selected salt marsh sites in San Francisco Bay.

The basic purpose of vegetation management in treated marshes is to minimize, to the extent feasible, short-term loss of carrying capacity for federally endangered California clapper rails (*Rallus longirostris obsoletus*) inhabiting existing hybrid cordgrass marshes proposed for eradication. Clapper rails are presumed to act as an "umbrella species" for other salt marsh bird species of concern that utilize similar habitat features (tidal channels with high marsh along banks) in natural tidal marsh vegetation. Salt marsh common yellowthroats and Alameda song sparrows (species of concern for conservation) are expected to benefit from channel-bank high salt marsh revegetation methods described below.

2.0 Locations

The scope of revegetation strategies considered is focused on the following proposed hybrid cordgrass treatment sites, inspected on May 9, 2005 with the Spartina Control Project staff:

(1) Fringing salt marshes of **Colma Creek** (South San Francisco, San Mateo Co.), and cordgrass marsh flats in the vicinity;

(2) **Cogswell Marsh** (Hayward, Alameda Co.);

(3) **Elsie Roemer Marsh** (Alameda, Alameda Co.); and

(4) **Arrowhead Marsh** (Oakland, Alameda Co.).

3.0 Problem/Need Statement

California clapper rails (rails) have colonized recently established, extensive, tall, stands of hybrid cordgrass in hybrid-infested salt marshes and new salt marshes formed by hybrid stands. Rails often occur at high densities where extensive tall stands of hybrid cordgrass border tidal channel banks or mudflat edges. Phasing herbicide or other hybrid cordgrass treatments, to provide transient refuges for rails, would defeat eradication purposes by leaving abundant hybrid seed sources directly adjacent to treated marsh areas. Large-scale treatments effective for local hybrid cordgrass eradication would minimize residual marsh habitat function for rails (carrying capacity; population density of rails supported per unit area). Significant persistence of standing litter (necromass; dead culms of hybrid cordgrass) in the spring following treatment is expected to provide some residual habitat structure for rails. As canopy structure of killed hybrid cordgrass degenerates (decomposition of leaf litter, culms; stem lodging due to flood discharges or storm waves; deposition of litter wracks), residual habitat structure for rails is expected to decline rapidly. Development of native salt marsh vegetation to provide alternative on-site habitat in treated areas is desirable, but is constrained by a number of factors, including:

(a) **Potentially significant local hybrid seed production by native *Spartina foliosa* pollinated by surviving hybrids, a re-infestation and control issue.**

Planting native Pacific (California) cordgrass, *S. foliosa*, in the year following herbicide treatment may complicate follow-up treatments of hybrids. In the year after initial herbicide application, variable frequencies of surviving, regenerating clones and new hybrid seedlings are expected to occur in semi-open, sheltered canopies of killed stands. Planting *S. foliosa* soon after treatment may locally generate seeds originating by hybrid pollination, increasing recruitment of hybrids, and interfering with detection and treatment of hybrids in mixed native/hybrid stands. For this reason, planting of *S. foliosa* for rail habitat rehabilitation would generally need to be delayed until *at least* one full year (second growing season after treatment, or subsequent growing seasons), depending on frequency of hybrid cordgrass recruitment or regeneration.

(b) **Tidal elevation ranges of accreted sediments under hybrid cordgrass stands, a limiting factor for type and structure of native salt marsh vegetation.**

Some hybrid cordgrass stands have accreted sediments to tidal elevations suitable for vegetation other than cordgrass, such as pickeweed (*Sarcocornia perennis*, syn. *Salicornia virginica*) and gumplant (*Grindelia stricta* ssp. *angustifolia*). Pickleweed and gumplant vegetation of sufficient area, height and density, located near tidal channels, may provide useful alternative native rail habitat (high tide/flood refugia, nesting habitat, channel bank cover for movement, foraging) to replace those provided by tall-form hybrid cordgrass, partially compensating for habitat loss. Some hybrid cordgrass stands have accreted sediments to tidal elevations only marginally suitable for pickleweed, or suitable only for Pacific cordgrass. Visually distinguishing suitable high, middle, or low tidal marsh zones under dense hybrid cordgrass can sometimes be difficult, because its dense stands can inhibit colonization by native plants at otherwise suitable tidal elevations. Surface drainage indicators and presence of pioneer native vegetation in gaps, or success of experimental "probe" (phytometer) transplants of pickleweed or gumplant can be used to estimate potential for pickleweed and gumplant establishment (Section 5.1).

(c) **Inherent time lag in developing relatively mature vegetation structure composed of native salt marsh plant species, suitable for rail habitat.**

Even where pickleweed and gumplant can be established within suitable substrate elevations of killed hybrid cordgrass stands, native vegetation structure suitable for clapper rails is not likely to occur until at least one growing season following transplanting, even with early spring transplants at high densities (see discussion, 4.4). Gumplant is likely to remain juvenile (non-flowering, vegetative) for the first growing season after transplanting. Maximum canopy height and density of gumplant occurs with flowering/fruiting branch structure. Planting mature gumplants is not an adequate substitute for a year of juvenile growth; mature container-grown plants with confined root systems would probably result in inferior survivorship and growth, and would be prohibitively expensive.

4.0 Optimum Revegetation Opportunities

Two types of salt marsh structure at treatment sites appear to be most suitable for habitat-compensating revegetation with high marsh species during the first growing season after late summer/fall herbicide treatment of hybrid cordgrass:

(1) Pickleweed-dominated marsh plains with tidal creek beds and banks invaded by tall hybrid cordgrass, but channel banks lacking or deficient in gumplant (e.g. northwest Cogswell Marsh; Fig. 1);

(2) Accreted hybrid cordgrass-dominated fringing marsh persisting at accreted creek banks or prograded marsh plains at upper intertidal elevations suitable for gumplant and tall-form pickleweed (e.g. segments of lower Colma Creek, landward zones of Elsie Roemer Marsh Fig. 2).

Sites of intermediate, suboptimal suitability for vegetation enhancement would include hybrid cordgrass-dominated marsh plains adjacent to tidal creeks or artificial channels, where they have accreted to elevations suitable for pickleweed, but not gumplant (Fig. 3, 4). Cordgrass marsh plains lacking well-defined channels, with only narrow zones at Mean High Water or above, are least suitable for vegetation management to mitigate clapper rail habitat losses (Fig. 5).

Suitability of marsh plains or bank edges for pickleweed or gumplant roughly corresponds with tidal elevation, but is strongly influenced by local drainage. Gumplant generally requires better drainage and longer emergence times than pickleweed; it tends to occur mostly in a narrow (approximately 1.0 to 1.5 m wide) zone along well-drained edges of steep channel banks at elevations Mean Higher High Water (MHHW) or higher. Full expression of gumplant height and shoot density would likely depend on both adequate elevation and local creek bank drainage. Pickleweed is able to establish at elevations near Mean High Water (MHW). The growth form of pickleweed varies along drainage and submergence gradients, with its shrubby, erect, tall growth form best expressed at well-drained higher marsh topography near or above MHHW (higher channel bank edges, low berms, mounds, fills, etc.). The patterning of tall, dense zones of subshrubby gumplant along high, well-drained marsh banks of tidal creeks (Fig. 6) is a characteristic feature of mature salt marshes in San Francisco Bay, and it is a highly important structural feature of clapper rail habitat (Fig. 6).

The dense canopy of hybrid cordgrass at treatment sites makes preliminary topographic data collection problematic. Relative tidal elevations for transplant suitability of pickleweed or gumplant may be inferred indirectly by field indicators such as drift-lines, seedlings or juvenile plants of gumplant, pickleweed, spearscale, or saltgrass in cordgrass vegetation gaps, or superficial substrate indicators such as shrink-swell cracks, dried sediment flakes, etc. Preliminary planting of pickleweed plugs in small (< 1.0 m diameter) artificially created vegetation gaps in hybrid cordgrass prior to herbicide treatment, and tracking growth and survivorship, is a potentially useful empirical method for estimating suitability of growth conditions ("phytometer" method; see 5.1).

5.0 General Revegetation Strategies for Rail Habitat Enhancement or Rehabilitation

The following revegetation strategies apply to one or more of the treatment sites. To minimize duplication, they are discussed generally here, and modified for site-specific needs subsequently.

5.1. Planting existing channel-bank salt marsh with native dominant high salt marsh species

Objectives

The objective of channel-bank (natural levee) planting is to rapidly establish (1) a zone of either dense, tall pickleweed vegetation, with potential for overhanging canopy at steeper channel bank edges, or (2) mixed zones of tall-form pickleweed and gumplant along well-drained crests of relatively high (near MHHW) channel banks, after hybrid cordgrass is killed. Transplanted pickleweed and gumplant would initially grow among decaying, standing litter of herbicide-killed hybrid cordgrass in the growing season following treatment. The revegetation effort is focused on the "riparian zone" (channel-side zone) of salt marsh associated with clapper rail activity: channel beds and banks, and high marsh a few meters from channel banks (natural levees).

The combination of overhanging dense pickleweed canopy along steep channel banks, and extensive cover of tall, evergreen pickleweed and gumplant subshrubs, is aimed at providing partial replacement of tall emergent cover provided by hybrid cordgrass stands. Overhanging pickleweed bank vegetation may provide channel-edge cover for rail movements along channels (supporting foraging in channel banks and beds). Adjacent tall, dense subshrubby gumplant/pickleweed cover would provide additional escape cover for rails responding to disturbances (predators, human entry to marshes) or high tides.

Approach and assumptions

Pickleweed and gumplant would be transplanted to suitably receptive marsh banks in the spring following summer-fall herbicide treatment of hybrid cordgrass. Transplanting would occur only on banks high and well-drained enough to support growth of pickleweed or gumplant, as indicated by either field evidence or direct testing (see phytometer technique, below). The premises of planting are: (1) herbicide-treated hybrid cordgrass would suffer relatively high mortality along accessible, well-drained marsh banks, with only very localized need for re-application of herbicide (or none) the following year; and (2) vegetative transplants of pickleweed and gumplant will significantly accelerate achievement extensive bands of mature high marsh vegetation structure, compared with spontaneous seedling recruitment. Gumplant recruitment in particular may be dispersal-limited at marsh sites where local seed sources are scarce. Pickleweed seeds are presumed to be ubiquitous, but vegetative transplants are able to establish larger sizes sooner in the first growing season.

Pre-treatment phytometer technique to assess suitability for transplanting target species

Before planting is attempted, it would be useful to assess how suitable existing sites are for growing target species. It may be infeasible to acquire accurate and precise topographic data and benchmarks for all sites, and relationships between plant growth rates, vigor and tidal elevations are only loosely correlated. Therefore, a more direct empirical approach may be used to assess the suitability of variable, site-specific salt marsh microtopography for planting target species in advance of treatment. "Phytometer" methods use growth responses of transplants as species-specific indicators of environmental stress or productivity.

If entry into the marsh is allowed in spring-summer 2005 at any parts of the proposed study sites, small numbers of phytometers can be established at targeted locations by introducing plugs (rooted plants in growing medium) of pickleweed and gumplant to existing or artificial gaps in hybrid cordgrass stands near channel banks at representative locations. Gaps should be approximately 1 m in diameter, and can be created by clipping all aboveground biomass to ground level. 3 to 5 plugs can be introduced to each gap. Three replicate gaps along a tidal channel planned for transplants would be desirable. Gaps should be flagged and re-inspected at the end of the growing season (September) for survivorship and plant size (height, spread).

Field indicators of likely suitable microhabitats for testing pickleweed or gumplant along marsh banks include: (1) absence of conspicuous mineral sediment films on green leaves or stems near marsh surface level; (2) shrinkage or superficial cracking of surface sediment or fibrous, filamenttous algae; (3) seedlings or juveniles of high-tide line indicator species such as spearscale (*Atriplex prostrata*, syn. *A. triangularis*), brass-buttons (*Cotula coronopifolia*) or spurrey (*Spergularia* spp.); (4) local accumulation of tidal litter, particularly litter dry at high tide.

Transplanting methods: pickleweed

Transplants of pickleweed would consist only of locally derived divisions of branched, unrooted stems, approximately 20-30 cm long, harvested in late March/early April. Transplants of divisions can be made in fall through winter, but they are subject to higher mortality because of storm disturbance and lack of rooting during the fall- winter season. Transplanting of unrooted divisions later in spring, during warmer weather, would also risk high mortality. Pickleweed would be planted into killed stands of hybrid cordgrass treated the previous fall. If standing density and cover of killed hybrid cordgrass is excessive, dead culms should be pushed aside around the transplant site, or clipped around a 30 cm area. The lower half of pickleweed stem divisions would be planted at a 45^o angle to a maximum depth of approximately 10 cm; green-branched shoot tips would be fully emergent, or may be pressed (with boot) gently into contact with the marsh substrate. Nursery-grown plugs of pickleweed are not necessary for rapid growth and high survivorship of transplants. If they are available, they may be used to the extent they are convenient, but dividing vigorous local stock may be more efficient (reduced transport, weight, handling, trampling).

Planting techniques for pickleweed divisions should be based on partial lifting of marsh substrate rather than digging. Pickleweed divisions can be wedged into a gap opened by pulling/pushing the blade of a tile spade cut into marsh soil, and re-pressing the gap closed after inserting the division. The buried half of the division can be held in place with the toe of a boot while the blade is lifted out. Gently compress marsh substrate after transplanting to ensure complete contact between the division's buried stem and wet marsh soil. Digging and refilling transplant holes in the marsh substrate is generally not justified or recommended; saturated clay-silt bay mud is generally unsuitable for this.

Fertilizer. High nitrogen soluble fertilizer, such as ammonium sulfate or ammonium nitrate) may be placed sparingly at depth, around the buried segment of the pickleweed transplant, approximately 5 to 10 g per transplant. Fertilizer is not essential for growth or establishment, but it can significantly accelerate growth rates and size of target plants during the first growing season. Because middle and high salt marsh zones at the treatment sites lack weeds other than hybrid cordgrass, effects of fertilizer on non-target species would be negligible. No fertilizer should be placed on the marsh surface.

Transplant spacing: Pickleweed transplants should be irregularly spaced at nearest-neighbor distances ranging from 0.5 to 1.0 m within a 2 to 3 m wide band from the channel bank (crest) edge. Regularly spaced, sub-parallel row plantings are not recommended.

Transplanting methods: gumplant

Transplants of gumplant may consist either of bare-root transplants from salvaged sources (disturbed urban-edge high marsh habitats, such as shorelines along trails, artificial fills, parking lots, etc.) or nursery-grown stock in "tall pots" or "tree pots" (long, slender containers). March to early April is the optimum time for transplanting, like pickleweed, but transplants can be made in fall with higher risk of mortality. Bare-root stock of gumplant must be harvested in moist, cool weather only, and kept moist and cool during temporary storage and handling. Bare-root plants should not be handled in dry, windy, or sunny weather, and should not be handled in air temperatures above 10-12^{o}C. Lower leaves of bare-root gumplant transplants should be manually removed prior to transplanting; leaving 3 to 4 youngest leaves.

Gumplant transplants should be located only at well-drained, topographic high areas near channel banks, generally no more than 1.0 m from the channel bank edge (crest). Nearest-neighbor distances of gumplant transplants within a narrow zone of suitable habitat should range from 0.25 to 1.0 m. Channel segments planted with gumplant need not be continuous; segments with 5 to 10 m lengths of gumplant habitat are recommended on at least one bank of planted channels.

Optional mound planting: If channel-edge salt marsh elevations appear to be low or marginal for gumplants (based on field indicators or phytometer performance), planting them on low mounds 10 to 15 cm high, and 30 to 40 cm in diameter, may create microtopography that facilitates early growth and establishment. Borrow material for low mounds may be excavated locally, landward of the mound (away from the tidal creek). Creation of mounds by manual labor would, however, significantly increase labor and time costs for transplanting. Mounds may enable gumplants to establish and thrive where they otherwise would not. Gumplant transplants may be fertilized with high-nitrogen fertilizer as with pickleweed. Soft (herbaceous) growth stimulated by fertilizer should be protected against generalist insect herbivory by natural salt accumulation in shoot tissues.

Delineation of suitable transplant microhabitats

Specific riparian salt marsh areas to be planted would most efficiently be flagged with on-site inspections in fall 2005 immediately before herbicide treatment. In the absence of detailed topographic data, subjective ocular estimates of suitable, receptive topography would guide planting areas. Indicators may be keyed to observations from phytometer plots and adjacent marsh. Delineating subjective estimates of planting areas on current or recent aerial photographs/GIS base maps would require ground-truthing. At least two sites (Elsie Roemer, Colma Creek) exhibited indicators of very rapid recent sediment accretion, so areas of suitable planting conditions may continue to change, and in a favorable trend for establishment of target species.

Planting intensity (total length of channel, area of marsh revegetated) would depend in part on contemporary pre-existing salt marsh vegetation conditions, and the extent of incidental herbicide injury to native vegetation. For example, at northwestern Cogswell Marsh, pickleweed already dominates the marsh plain, but mature gumplant (though vigorous) is very limited in distribution along creek banks, possibly because of seed limitation (small local source population), dispersal limitation, or deficient seedling habitat. Northwest Cogswell marsh therefore would require only gumplant transplanting. At Colma Creek, some segments of the channel banks in spring 2005 were pure stands of hybrid cordgrass, while others supported pickleweed understories. Where hybrid cordgrass dominates the entire vegetation, both pickleweed and gumplant transplants are necessary to provide a complete riparian vegetation gradient along channels.

Revegetation may occur in suboptimal fall post-herbicide conditions, or optimal early spring conditions, depending on accessibility of treated marshes. The extent of incidental herbicide damage to native vegetation (in mixed stands of hybrid cordgrass/pickleweed) may not be fully expressed until the following spring. Therefore, fall post-spray assessments of planting requirements may need to be re-delineated in spring.

5.2. Artificial creation of steep-sided channels in prograded hybrid cordgrass marsh, with native high marsh revegetation

Like the wide, prograded fringing salt marshes along the north shore of San Pablo Bay, some hybrid cordgrass marshes have deficient development of tidal channels, or lack them altogether. Post-herbicide vegetation would likely consist of homogeneous pickleweed plains with poor internal drainage, and a narrow band of gumplant along the high tide line.

Firm, root-stabilized salt marsh soils can support near-vertical banks of natural channels or ditches with relatively high stability. "Ditch-witch" or similar ditch-excavating equipment designed for use in marshes can be used to rapidly excavate ditches over 1 m deep and 1 m wide, at low cost compared with excavators working on mats. Creating a series of shore-perpendicular artificial tidal drainage channels in prograded, killed hybrid cordgrass marsh would establish well-drained channel and bank habitat to support tall, dense gumplant and pickleweed vegetation. *Side casting excavated spoils to slightly above, local MHHW elevation* (approximately) would increase potential habitat of tall-form pickleweed and gumplant, as long as spoils remain subject to inundation by spring tides. Planting sidecast spoils with target species would help pre-empt rapid invasion by non-native invasive plants such as perennial pepperweed (*Lepidium latifolium*). Habitat value of created channels may be increased if slightly irregular, sinuous flow paths (rather than rectilinear ditches) are created, to increase channel density. Rails, song sparrows, and yellowthroats would be expected to utilize the artificial channels with tall native high marsh vegetation on banks.

The long-term stability of created channels is uncertain. High suspended sediment may cause channel bed infilling with sediment, and gradual conversion to marsh (e.g. Highway 37 fringing marsh). Long shore drift of sand at some locations may cause tidal choking of channel mouths, impounding bay water in channels (e.g. Whittell Marsh, Point Pinole; Crissy Marsh, Presidio). The main purpose of channel/channel bank vegetation, however, is to provide a post-herbicide transitional habitat for local resident clapper rails, rather than to ensure long-term, permanent local habitat. Spoil-line ridges would, however, likely persist as high marsh (tall gumplant/pickleweed vegetation) potentially suitable for high tide refugia, nesting by rails, or territories of Alameda song sparrows.

5.3. Pacific cordgrass revegetation

Most of the hybrid cordgrass-invaded marshes have exhausted local populations of native Pacific cordgrass (Cogswell), or never supported significant native cordgrass in historic times (South San Francisco, Elsie Roemer, MLK, and most of Arrowhead). Hybrid cordgrass appears to be a superior colonizer of bare sites, and currently has numerical advantage for long-distance seed dispersal ("seed swamping" native cordgrass). If native cordgrass is to re-establish at treated South Bay sites where hybrids have dominated, it will likely need new, genetically "pure" founder populations in ample numbers.

Pacific cordgrass replanting should be attempted only after seedling recruitment rates of hybrids are confirmed to occur at minimal, manageable, detectible levels. Before Pacific cordgrass is planted in mass as founders, test plantings should be grown to flower and seed on the site. Progeny tests of locally grown Pacific cordgrass seed should be made to determine whether background hybrid pollen loads are causing excessive local production of hybrid seed. Pacific cordgrass planting should be postponed until progeny tests confirm that hybrid seed are not being produced at detectible levels.

Pacific cordgrass should be planted in wave-sheltered, accreting high mudflats near the lower edge of pickleweed marshes. Planting may be done by sod plugs (fragments of natural marsh "sod" consisting of rhizome network fragments and shoots embedded in cohesive marsh substrate) or individual shoot clusters. Sod plugs are far more resilient and mechanically stable than bare-root sprigs (shoot clusters). Collection of wild-grown plugs, and transport to transplant sites, is more labor-intensive than harvest and transplanting of sprigs. Borrow areas of pure Pacific cordgrass in the South Bay are limited. Collecting multiple genotypes of Pacific cordgrass (multiple collection sites within source marshes, or multiple source marshes within a region) is desirable for planting founder populations to ensure adequate outcrossing (avoiding Allee effects; pollen limitation due to self-incompatibility) and relatively high seed set.

Wild-grown plugs should be genetically tested for hybridity if collected from remnant native clonal stands in the South Bay. Costs of cultivating tested clones of wild-collected Pacific cordgrass may be prohibitive, and few wetland nurseries are equipped to produce cordgrass in significant numbers.

Cordgrass transplanting should occur close to the time of leaf elongation in early spring, before new roots elongate significantly. This stage usually occurs in March to early April. Transplants can be made during the growing season, but transplanted shoots generally die back and regenerate from tillers (branch shoots emerging from basal buds). Mechanically stabilizing unrooted sprigs in soft bay mud is a challenge for Pacific cordgrass, as is access to suitable planting sites in mudflats. Pacific cordgrass can be planted primarily at the upper end of its tidal range, near or slightly below MHW, and can spread by rhizomes to intertidal elevations near MSL. Planting cordgrass sprigs into banks of tidal channels large enough to navigate can be done by low-draft boats (inflatables) that allow frequent approach to shallow mud shoreline edges at mid-tide stages.

Planting intensities and patterns of Pacific cordgrass can emulate natural patterns of colonization. Unlike stabilization plantings that require continuous zones of minimal width and density, founder populations of Pacific cordgrass can consist of scattered, small colonies. One Pacific cordgrass colony per 100 to 200 m of marsh/mudflat edge or channel bank is reasonable as a founder colony density. Founder colonies may consist of 5 to 10 sprigs of transplants, with at least two (presumed) distinct genotypes per founder colony. Unlike natural seedling-grown pioneer colonies, transplanted founder populations should contain multiple clones (genotypes) from different source populations in the region, to ensure high levels of local outcrossing and seed set. Springs may be spaced at least 0.5 m apart. Placing coarse, non-buoyant "mulch" on the mud surface (such as oyster shells or gravel) around the base of springs should help prevent washouts in less sheltered positions (erosion and transport of springs).

5.4 Pace of plant development and vegetation change (directed succession)

The following is an outline of expected potential vegetation change within revegetated marsh areas at treated sites. It suggests the timing of structural vegetation development relevant to rail habitat conditions, and indicates gaps or "bottlenecks" in habitat function (lags in development of suitable rail habitat). Descriptions focus on channel and adjacent bank and marsh plain. Rates of development are based on observed rates of pickleweed and gumplant growth at many salt marsh restoration sites from the mid-1990s to the present in the San Francisco Estuary (pers. observ.). Estimates do not (and cannot) account for natural disturbance events such as severe droughts or storms, or climate-driven short-term rapid increases in sea level.

Year 0: Fall herbicide treatment. Full development of hybrid cordgrass vegetation. Extensive, mostly continuous stands of tall, dense cordgrass cover. Persistent winter cover of standing litter (culms, foliage), not significantly different from naturally senesced stands. Variable incidental kill of pickleweed where mixed stands occur around hybrid cordgrass clones or ramets. Potential fall transplants of pickleweed, gumplant, where spring access to marsh is prohibited. No growth or establishment of transplants in fall-winter; potentially high mortality of transplants.

Year 1: Assume over 90% mortality of hybrid cordgrass in middle marsh zone. *Degeneration of marcescent (persistent after senescence/death) standing hybrid cordgrass culms*, semi-open litter canopy, increased frequency of lodged culms (bent, broken) and litter wrack patches within stands. Degree of cover degeneration depends on initial pre-herbicide vigor (plant size, density), and exposure to high-energy waves, currents, and litter deposition; expect range of 20%-70% reduction in cover during rail breeding season following herbicide treatment, depending on winter storm conditions.

Initial *pickleweed seedling colonization occurs* in areas MHW elevation and above, where litter cover of ground surface (shading, litter matting) is less than about 50% at 1 meter scale. No seedling colonization under dense litter shade or matting. Surviving fall transplants of pickleweed, gumplant grow rapidly in vegetation gaps. *Pickleweed transplants* (fall or spring) spread to 0.5 to 0.75 m diameter, up to 0.5 m height (mostly 0.3 m or lower), depending on elevation above MHW. *Juvenile gumplant transplants* may spread up to about 0.3 m diameter, only 0.5 to 0.7 m height; no flowering branch structure first year. *Overall vegetation structure*: semi-open, patchy cover, deficiency in tall vegetation sufficient for cover during solstice high tides. Litter (standing or wracks) provides majority of cover by fall of year 1. Low cover persists through winter of Year 2.

Year 2: Killed hybrid cordgrass degenerates to sparse persistent culm bases, insignificant cover from standing litter. Low, patchy vegetation cover through winter rail mating/spring breeding season. Litter wracks re-form and persist locally. Patchy re-treatment of regenerated hybrid cordgrass or seedling recruits. *Pickleweed transplants* expand rapidly in late spring through summer; spread up to 1.5 m laterally or more by end of second growing season; height up to 0.5 or 0.6 m at higher banks, near 100% cover within occupied patches. Overall pickleweed cover may approach 50-60% in planted areas where prescribed initial transplant densities and high survivorship occur at optimal marsh elevation and drainage conditions. Higher percent cover by pickleweed may occur where pre-existing pickleweed, or pickleweed seedling establishment following hybrid cordgrass eradication, is prevalent. Prediction of background levels of pickleweed recruitment is difficult, and would vary significantly within sites. Patches of overhanging bank canopy may develop under some pickleweed patches, but overhanging canopy would be patchy. *Gumplant transplants* in optimal conditions would reach 0.7 m height by mid-summer to late summer, flowering branch structure; individuals spread about 0.5 to 0.7 m wide. Significant, wide distribution of tall, emergent cover is achieved by end of year 2 growing season, along channel banks. Vegetation height (maximum cover for highest tides) would be similar to natural gumplant-bordered tidal marsh creeks, but total area of high tide cover would be less abundant and discontinuous. Mature bank vegetation (pickleweed-gumplant)

Year 3: Above-ground necromass of killed hybrid cordgrass provides negligible cover, but pickleweed dominates killed hybrid cordgrass stands in planted and unplanted channel bank areas above MHW, providing essentially continuous cover, potential overhanging bank canopy. Original gumplant transplants along banks near MHHW maintain or slightly increase mature size, and variable seedling recruitment of gumplant (from year 2 seed production) occurs, mostly within 1 – 2 meters from parent plants. Gumplant cover becomes mix of juvenile and mature plants. Site may be ripe for first re-vegetation with native Pacific cordgrass if hybrid recruitment is insignificant.

Year 4: Relatively mature pickleweed vegetation with potential overhanging canopy would prevail along channel banks near MHW, and pickleweed-gumplant vegetation would prevail along channel banks near MHHW. Founder colonies of Pacific cordgrass (year 3 transplants) may establish isolated patches up to several meters in diameter, spreading laterally about 1.0 m/yr.

Year 5: Some seedling establishment of Pacific cordgrass, derived from seed of founder colonies, may occur at low frequency. Bank salt marsh vegetation would be similar to Year 4, with greater potential for overhanging bank canopy cover by pickleweed

Years 5-10: Gradual recolonization of lower channel banks and upper mudflats by Pacific cordgrass. Pickleweed-gumplant vegetation is matures with salt marsh accretion.

6.0 Descriptions of recommended site-adapted revegetation strategies.

6.1. Elsie Roemer Marsh, Alameda

Existing conditions: Mostly planar, prograded hybrid cordgrass fringing marsh. High vigor cordgrass. Some sandy shoals offshore; relatively high wave energy at marsh edge. Slight landward dip (higher elevations accreting at outer marsh edge) restricts drainage at landward edge of marsh in places. Locally abundant cordgrass drift-lines and wrack mats. Narrow band of backshore gumplant. Sparse, local pickleweed and saltgrass colonize barren areas left in wake of wracks.

Prescription: Excavate a minimum of 3 shore-perpendicular, slightly sinuous channels (see 4.2) at intervals across the prograded, high hybrid cordgrass marsh in fall, after applied herbicides are fully translocated to below-ground parts, and during the rail non-breeding season. Allow side-cast spoils to consolidate during neap tides of fall. In early spring, plant side-cast spoils with pickleweed and gumplant at relatively high density (ca. 0.5 to 1.0 m nearest neighbor distance) for rapid revegetation and high percent cover. If spring entry to marsh is prohibited because of clapper rail breeding, plant as late in fall as possible after herbicide treatment. Plant intervening marsh plain (killed cordgrass) with pickleweed divisions at much lower density (ca. 2 to 3 m nearest neighbor distance, or greater), allowing seedling recruitment to fill gaps. Alternatively, marsh plain revegetation may rely wholly on seedling recruitment, but attainment of high cover will be slightly delayed. Channel banks should become more than 50% vegetated by the end of the first growing season, and should exceed 80% cover by the end of the second growing season. Gumplant should become tall, branched and flower by the end of the second growing season.

6.2. Arrowhead Marsh, Oakland

Existing conditions: Middle marsh zone prevails on marsh plain: saltgrass, jaumea, pickleweed (pickleweed not currently dominant) prevalent, but relatively short, diffuse hybrid cordgrass is widespread across marsh plain. Hybrid cordgrass dominates beds and banks of many tidal creeks. Marsh bank edges (channels, San Leandro Bay) often forms overhanging canopy of saltgrass-pickleweed turf. Limited distribution, low abundance of gumplant, congested along bank edges in a few areas, mostly outer marsh.

Prescription: Protect existing overhanging vegetation canopy (pickleweed, saltgrass, jaumea) along marsh edges as much as possible during herbicide treatment. Because of high clapper rail densities and phased approach to hybrid cordgrass eradication, suboptimal fall transplanting should be assumed unless otherwise authorized. Transplant clusters of gumplant along high, well-drained banks of salt marsh channels or open bay marsh scarps, in a zone 1.0 m from the top of bank. Nearest neighbor density of gumplants within transplant patches should be 0.5 to 1.0 m. Patches should run approximately 5 to 10 m along banks. Patches of gumplant should be established if possible before herbicide treatment, with transplanted colonies protected by tarps or drop-cloths during spraying. Pre-establishing mature gumplants would minimize the gap in high tide cover during the first growing season after herbicide treatment within a phase. Otherwise, gumplant transplants will require two growing seasons to develop mature structure that serves as high tide cover.

The majority of Arrowhead Marsh marsh plain in 2004 and 2005 supported only sparse pickleweed, and abundant saltgrass, with locally abundant jaumea. No pickleweed transplanting is recommended.

6.3. Cogswell Marsh, Hayward

Existing conditions: Extensive pickleweed marsh plain with sinuous tidal channels occurs in northwest corner, with hybrid cordgrass infestation within channel beds, banks, and locally above banks and adjacent marsh plain. Vigorous gumplants are present locally in very few areas, suggestive of suitable environmental conditions, but lag in gumplant colonization (potential limitation by seed source, dispersal, or safe sites for seedlings). Extensive hybrid cordgrass marsh plains (very dense, tall stands) occur in eastern (inland of N-S levee) and southern reaches of site, obscuring small tidal channels or eliminating them. Limited areas of transitional hybrid cordgrass-pickleweed marsh are evident, but dense hybrid cordgrass stands may mask marsh areas accreted to MHW or above. (Wave-cut hybrid cordgrass marsh scarps occur west of the pedestrian bridge; accelerated marsh shoreline retreat may follow hybrid cordgrass eradication.)

Prescription: Revegetation should focus on gumplant transplants in the northwest corner of the marsh where pickleweed marsh plains and steep-sided tidal channel banks prevail. Use phytometer method if possible in Year 0 (pre-herbicide growing season) to assess growth potential of gumplant along channel banks. Gumplant should be transplanted primarily within 1 m of the channel bank edge outside of hybrid cordgrass treatment areas. Where extensive vegetation gaps may occur along banks treated with herbicide, creation gumplant "refuges" should be attempted by post-spray transplanting into treated areas. Working hypothesis is that lack of gumplant high tide/nesting cover in pickleweed-dominant salt marsh may be critical limiting sub-habitat for rails; supplemental extensive channel-bank gumplant may increase rail carrying capacity of marsh, compensating partially for marsh loss in other sectors of Cogswell Marsh.

In hybrid cordgrass-dominated marsh areas, transplant pickleweed divisions into treated hybrid cordgrass marsh areas within 3 m of channel bank edges, where marsh surface soil shows indicators of prolonged emergence (shrinkage cracks or films, dried algal films, during neap tide periods, consistent with local MHW elevations).

6.4. Colma Creek vicinity marshes.

Existing conditions: Along Colma Creek flood control channel, hybrid cordgrass marshes have extensive segments accreted to elevations at which pickleweed has established within hybrid cordgrass canopies, or is establishing in gaps within cordgrass stands. North of the mouth of Colma Creek, nearly pure hybrid cordgrass marsh has established on mudflats with minimal drainage (lack of defined channel topography); marsh-mudflat edge is defined by leading edge of expanding cordgrass vegetation rather than topographic/drainage pattern. Almost all of the marsh north of Colma Creek is low marsh, not suitable for conversion to pickleweed in current/anticipated conditions. The existing fringing pickleweed marsh zone is planar and poorly drained, with decumbent, low growth forms. Because of the low gradient and lack of "arterial" slough channels, potential for creation of persistent artificial channels (ditches) in pickleweed marsh to establish tall-form pickleweed stands is poor. South of Colma Creek, salt marsh is dominated by homogeneous fringing low marsh composed of pure stands of hybrid cordgrass.

Prescription: Existing pickleweed sub-canopies or stands should be protected from incidental herbicide damage as much as possible along Colma Creek. Transplant pickleweed divisions into treated hybrid cordgrass marsh areas within 3 m of herbicide-treated channel banks where marsh surface soil shows indicators of prolonged emergence (shrinkage cracks or films, dried algal films, during neap tide periods, consistent with local MHW elevations). Use gumplant phytometers to assess potential areas for gumplant establishment, in Year 0 (pre-treatment) if possible. Transplant gumplant into areas indicated suitable by phytometers. No feasible revegetation actions are identified for areas of prevalent low marsh (below MHW, marsh/mudflat progradation sites) until year 3 or 4, when Pacific cordgrass revegetation may be feasible for the upper intertidal zone.

Figures

Figure 1. Northwestern Cogswell Marsh. Relatively mature marsh microtopography along channel banks: small slump-blocks, local areas of high elevation and drainage, associated with shrubby, tall-form pickleweed patches. Note lack of gumplants. This condition is suggestive of suitable gumplant transplant habitat, but may be resistant to natural seedling colonization by gumplant. Small gaps in pickleweed, or mounds, may facilitate gumplant seedling or transplant establishment at bank edges. Photo: author; May 2005.

Figure 2. Colma Creek. Overhanging canopy of matted pickleweed below hybrid cordgrass on relatively high elevation salt marsh banks. Periodic flood events are likely the cause of bank undercutting and overhanging canopy. Note clapper rail resting on cordgrass wrack suspended on pickleweed, partially screened by cordgrass stems. Photo: author; May 2005.

Figure 3. Northwestern Cogswell Marsh. Hybrid cordgrass dominates channel beds, choking with sediment, and depressions in pickleweed-dominated marsh plain. Note overhanging pickleweed canopy at bank edges. Limited marsh plain elevation, microtopography are indicated by lack of tall-form pickleweed, sediment film on much of pickleweed canopy. Small planting mounds may be necessary to establish gumplant where microtopography and marsh elevation are limiting. Photo: author; May 2005.

Figure 4 . Central-eastern Cogswell marsh, near channel bank edge. Highest vegetation cover provided by low marsh (hybrid cordgrass); middle marsh zone vegetation is decumbent, low pickleweed (<0.3 m tall). Pickleweed is likely to establish spontaneously by seedling colonization in herbicide treated stands like this, but with reduced cover for rails. Small planting mounds may be necessary to establish gumplant (equivalent in local high tide cover, plant height) where microtopography and marsh elevation are limiting. Photo: author; May 2005.

Figure 5. Coalescing hybrid cordgrass colonies form low salt marsh on mudflats, north of Colma Creek mouth. Note lack of tidal drainage channels. No short-term revegetation strategy with native plants is feasible to offset loss of clapper rail habitat in this existing condition. Photo: author; May 2005.

Figure 6. Natural reference site model for pattern of gumplant high marsh cover along mature tidal channel bank edges, providing high tide cover and nesting for rails. Modern reference condition, and historic naturalist accounts of clapper rail distribution and habitat preferences in pre-reclamation salt marshes of SF Bay, form basis for revegetation design. Note that the pattern of gumplant follows local drainage gradients of both large sloughs and small tidal creek banks. (photo courtesy of U.S. Fish and Wildlife Service, San Francisco Bay NWR, kite aerial photography)