California Fish and Game 101(2):87-100; 2015

Experimental enhancement of pickleweed, Suisun Bay, California

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As mitigation for habitat impacted by the expansion of a pier on Suisun Bay, California, two vehicle parking lots (0.36 ha and 0.13 ha) were restored by being excavated, graded, and contoured using dredged sediments to the topography or elevation of nearby wetlands. We asked if pickleweed (*Sarcocornia pacifica* L, [Amaranthaceae]) colonization could be enhanced by experimental manipulation on these new wetlands. Pickleweed dominates ecologically important communities at adjacent San Francisco Bay, but is not typically dominant at Suisun Bay probably because of widely fluctuating water salinity and is outcompeted by other brackish water plants. Experimental treatments (1.0-m^2 plots) included mulching with pickleweed cuttings in either the fall or the spring, tilling in the fall, or applying organic enrichments in the fall. Control plots received no treatment. Pickleweed colonization was most enhanced at treatment plots that were mulched with pickleweed in the fall. Since exotic vegetation can colonize bare sites within the early phases of restoration and reduce habitat quality, we concluded that mulching was most effective in the fall by reducing invasive plant cover while facilitating native plant colonization.

Key Words: experimental wetlands, pickleweed, restoration, San Francisco Bay, *Sarcocornia pacifica*

The loss of wetlands worldwide from ca. 1900 to present is roughly estimated at about 50% (Fraser and Keddy 2009). In the conterminous United States (U.S.) wetlands are estimated at about 47% of historical area, with the greatest loss reported for the state of California (91%; Goals Project 1999). Events that have affected wetlands at San Francisco Bay, California, exemplify causes and extent of loss that have plagued wetlands globally. The natural shoreline of San Francisco Bay has been developed for mostly urban or agriculture land use over the past 200 years, where tidal marshes alone have declined nearly 80% from about 77,000 to 16,000 ha (Goals Project 1999).

In the past decade, the second largest wetland restoration in the U.S. has been underway at San Francisco Bay. Certain decommissioned agriculture (mainly commercial salt-production ponds) and military lands have been identified for restoration to tidal marshes to offset historical declines. Thus, effective methods for successful wetland restoration are crucial. Methodologies for restoring west coast salt marshes have improved, but instituted guidelines have outpaced the science necessary for success (Zedler 2000).

In 1996, a shipping pier was expanded on Suisun Bay at the Military Ocean Terminal Concord (MOTCO), Concord, California, and in compliance with California state law (California McAteer-Petris Act of 1965 and amended in 1969) tidal marsh restoration was required as mitigation for the pier expansion project. With larger-scaled wetland restoration projects planned for the San Francisco Bay region, we concluded that the mitigation sites identified were ideal for experimentation of wetland recruitment and succession; such studies have been recommended before large-scale restoration projects are instituted (Callaway et al. 1997).

Suisun Bay forms a complex, hydrological interface between the delta of the Sacramento and San Joaquin rivers (hereafter known as "Delta") and San Francisco Bay. Wetlands in Suisun Bay comprise more than 34,000 ha of tidal marsh, managed wetlands, and waterways in the San Francisco Bay Delta region (BCDC 1976). These wetlands are among the largest remaining contiguous wetlands in that region and include more than 12% of California's remaining natural wetlands (California Department of Water Resources 1995). Suisun Bay wetlands support a diversity of plant, fish, and wildlife, including several rare and endangered species, and provide critically important wintering or breeding habitat for migratory waterbirds and fishes.

Brackish water wetlands exemplify the complexity of biotic and abiotic factors that can affect plant community structure (Callaway and Walker 1997). Elevation, salinity, nutrients, and competition are among factors commonly studied that affect species distribution in such habitats (Traut 2005, Morzaria-Luna and Zedler 2014). Suisun Bay represents a region where tidal salt and fresh water mixing is exacerbated by diversion or controlled release of freshwater inflow, and can be challenging in determining those factors most influential in structuring wetland plant assemblages. Drought, climate change, and ensuing sea level rise will only add to the complexity in this region (Callaway et al. 2007, Watson and Byrne 2009).

Pickleweed (*Sarcocornia pacifica* L*,*[Amaranthaceae]) dominates vegetation expanses of mid-upper tidal elevations in salt marshes along the Pacific coast of North America and the Mediterranean coasts, as well as the main stem of San Francisco Bay (Josselyn 1983). This perennial succulent grows as a low scrub and thrives under saline conditions. In California, pickleweed is essential habitat for species listed as threatened or endangered under state or federal laws, among which are *Reithrodontomys raviventris* (salt marsh harvest mouse), *Rallus longirostris obsoletus* (Ridgway's rail), and *Chloropyron molle* ssp. *molle* (soft bird's beak), a hemiparasitic plant. Loss of habitat is probably the most serious threat to these species (Foin et al.1997, Bias and Morrison 1999). These species were observed and recorded at MOTCO, and their conservation and enhancement were deemed important natural resource management strategies by the U.S. Navy.

Despite the importance of pickleweed to sensitive species, little study has been conducted on factors affecting pickleweed establishment, probably because it is a hardy species (Zedler 1982) that can tolerate a range of salinities but may be more sensitive to increases in inundation (Woo and Takekawa 2012). However, Pennings and Callaway (1992) suggested that pickleweed can occur in higher densities in the lower marsh zone because of higher tolerance to tidal inundation than some marsh plants. Pickleweed seems to thrive at higher salinities (28‰) but can survive at lower salinities (3‰) (Watsonand Byrne 2009). Although it is widespread in salt marsh habitats in San Francisco Bay, pickleweed is not dominant at Suisun Bay possibly because of increased competition in low salinity sites. At MOTCO (Figure 1), vegetation is dominated by a seeming monoculture of sedges (Cyperaceae; mostly *Schoenoplectus* spp. or *Bolboschoenus* spp. [formerly *Scirpus* spp.]), with very limited open areas for scrub vegetation such as pickleweed.

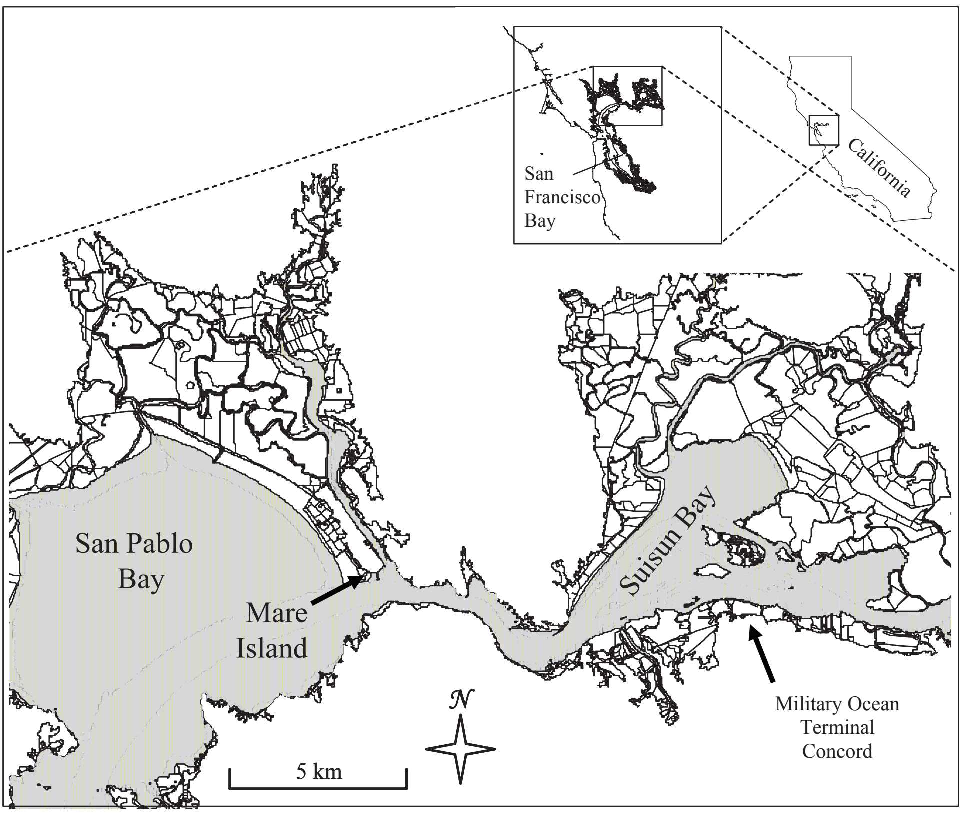


FIGURE 1.—Location of wetlands in Suisun and San Pablo bays (a.k.a., north San Francisco Bay) used in the study for experimental manipulation, California. (Source: San Francisco Estuary EcoAtlas version 1.50b4, San Francisco Estuary Institute, Oakland, California).

Pickleweed apparently can compete with other structurally dominant marsh plants under certain conditions. For example, gaps created in structurally dominant marsh plant patches can facilitate pickleweed colonization (Boyer and Fong 2005). Restoration methods to facilitate pickleweed establishment have not been studied. While unlikely an issue in habitats dominated by pickleweed, physically marginal habitats or physically disturbed habitats prime for colonization by exotic species like hybrid cordgrass (*Spartina alterniflora* × *Spartina foliosa*) or perennial pepperweed (*Lepidium latifolium*), are such that a diverse native plant community may benefit from assisted recruitment following restoration actions. Pickleweed was not the overall dominant vegetation, but pickleweed patches were not uncommon in the vicinity of the Suisun Bay restoration sites.

Pickleweed colonizes or spreads both by seed and rooting of decumbent or broken stems (Josselyn and Perez 1981). Pickleweed produces a high volume of seeds often considered adequate for recruitment. However, seeding to establish pickleweed may be less effective at the point of restoration because seeds disperse by floating. Some factors that affect pickleweed establishment are soil moisture, soil nitrogen, tidal influences, parasitism, and soil salinity (Covin and Zedler 1988, Osborne 1994, Pennings and Callaway 1996, Callaway et al. 1997). Pickleweed dominates San Francisco Bay marshes in soils that contain 20 to 25% organic material, more than was found in most other plant habitats in the area except those dominated by alkali bulrush (*Bulboschoenus robustus*) or cattails (*Typha* spp.). Soil organic matter might enhance pickleweed growth through increased nitrogen fixation (Covin and Zedler 1988).

We built upon a previous greenhouse study (M. Disney, unpublished data) to apply treatments that might enhance pickleweed colonization in an experimental field study. We included study of seasonality because the timing of restoration efforts may affect the rate and, therefore, success of colonization or recruitment. For example, seeding by pickleweed mostly occurs in fall but germination and vegetative expansion peak in early spring (Josselyn 1983). The objectives of this study were to determine if specific treatments might enhance change of severely disturbed areas to pickleweed habitat, and to document early succession of vegetation at MOTCO; hereafter, the Suisun restoration or Suisun sites. We hypothesized that enriching plots on restored sites with compost, mulching with pickleweed, or seasonal application of pickleweed mulch to increase organic content of the soils or recruitment structure (e.g., seeds, plant cuttings), would enhance rapid colonization or recruitment by pickleweed compared to control plots in areas with low soil salinity or dominance by other marsh plants.

We replicated the two MOTCO sites at Suisun Bay at a third site excavated at the south end of Mare Island (hereafter the San Pablo Bay site), about 10 km west of the Suisun Bay sites. Because these three restoration sites were severely perturbed in their history of use as well as by mechanical excavation, we monitored plots on two reference sites, one each in Suisun and San Pablo bays, to document vegetative structure and temporal change on plots at nearby existing marshes. These reference sites were not compared statistically to the experimental sites; rather, they were used to document biotic and physical patterns on adjacent areas of similar topography in order to understand expected mature succession at the restoration sites. Such information facilitated our understanding of development on the restoration sites relative to existing marsh plant structure.

Materials and Methods

Study area.—The study was conducted at MOTCO, Suisun Bay, and at Mare Island at the far eastern edge of San Pablo Bay (hereafter San Pablo Bay sites; Figure 1). The Suisun restoration area (approximately 38° 03' N, 122° 00' W) was located along the southern shore of Suisun Bay between the cities of Martinez and Pittsburgh. Suisun Bay water salinities range from 0.0 to 11.0‰ during periods of high runoff from the Delta, and from 2.0 to 15.0‰ during the dry season. Tidal amplitude averages 1.63 m, compared to 1.78 m at the mouth of San Francisco Bay.

At Suisun Bay, the two restoration sites were former parking lots. The asphalt layer and base material were excavated, the sites were graded and contoured to the topography or elevation of nearby wetlands, and then both sites were covered with fine-textured dredge material to a depth of about 20 cm by fall 1998. Dredge material was obtained from the Port Sonoma Marina on San Pablo Bay. As required for restoration purposes, this material was tested for inorganic contaminants and levels were determined to be acceptable by the San Francisco Bay Regional Water Quality Control Board prior to use. Resulting elevations (ranging from 0.21 to 0.13 m below mean high-high water [MHHW]) and were similar to that of nearby pickleweed habitat. The sites were approximately 0.36 ha and 0.13 ha. Roads or levees and a slough bordered both sites.

The San Pablo Bay restoration site at the southwest end of Mare Island (38° 04' N, 122° 16' W) was part of a former dredge spoils disposal area that also included unexploded ordnance and some contaminated soil. These materials were excavated in 1997 and the area was contoured into a combination of shallow ponds, levees, and gently sloped areas by summer 1998. Additional dredge material was not applied at the San Pablo Bay site because existing sandy soils were not as extensively excavated as at the Suisun sites, and had similar elevations to nearby upland soils. San Pablo Bay salinities near Mare Island range from 0.0 to 18.0‰ during periods of runoff, and from 12.0 to 25.0‰ during the dry season. Tidal amplitude averages 1.75 m. The San Pablo Bay site was approximately 0.15 ha, and elevations ranged from approximately 0.49 to 0.44 m below MHHW, similar to nearby pickleweed habitat.

Plot treatments.—Thirty, 1.0-m^2 plots were established at each of the three restoration sites, 15 plots at lower and 15 at higher tidal elevations. The lower elevation plots were 0.20 to 0.18 m (below MHHW) at the Suisun and San Pablo restoration sites; the higher elevation plots were 0.15 to 0.13 m at the Suisun sites and 0.44 m (below MHHW) at the San Pablo site. At the San Pablo site and at one of the Suisun sites, some lower-elevation plots were commonly inundated except at extreme low tides. In fall 1998, three replicate plots of each of four treatments and a control were randomly assigned to each of the lower and higher tidal elevations at the three restoration sites. Control plots received no treatment following initial site-wide preparation. The treatments were: (1) mulching with pickleweed in the fall (hereafter fall mulch); (2) mulching with pickleweed in the spring (spring mulch); (3) soil enriched with compost in the fall (enriched); and (4) soil tilled in the fall without adding compost (tilled).

Each 1.0-m^2 mulched plot received about 2.4 kg fresh-weight of pickleweed, which had been obtained from a managed wetland at Mare Island. Entire plants were cut into pieces about 20 cm long, applied by hand onto the selected plots, and then covered with jute mesh that was anchored in place. Enriched plots received enough compost to augment soil organic material content by an estimated 8%. This was calculated to be an application of about 12.0 kg (dry weight) compost applied per m^2. Compost, produced by a local municipality from green waste, was cultivated into the soil to a depth of about 15 cm using a gasoline-powered rototiller. Fall-mulched, enriched, and tilled-only plots were established in November 1998 and spring mulched plots in May 1999.

We estimated percent cover on each plot using a 1.0-m^2 sampling frame divided into grids by crossing monofilament lines placed at 10, 30, 50, 70, and 90 cm. The sampling frame was aligned on each plot at each sampling interval. Species, duff (dead or decaying material), or bare soil were tallied under the 25 monofilament crosshairs on the frame. Standing water or other materials also were noted. Percent cover per plot was calculated by multiplying the tally for each species or category by four for a total of 100% cover; if, for example, duff and pickleweed occurred under the same crosshair, only pickleweed was recorded but duff was noted. Any live plant species in the plot not recorded by this procedure were noted as trace. Percent cover per plot was collected seasonally beginning in winter (sampling initiated 21 December 1998) 1999 through spring (May) 2000. Overall sampling of both locations could take up to 60 days to complete; therefore, plots were sampled in the same order each season.

In order to compare soil characteristics on the treatment and control plots, two soil cores (2.5 cm diameter × 15.0 cm deep) or samples were extracted from each plot in spring and summer 1999 and winter and spring 2000. Soil samples were homogenized, weighed, air dried, and reweighed, and then sub-sampled for analyses. Organic matter (OM), nitrogen as ammonia (NH_4-N), and nitrate (NO_3-N) were analyzed by the Division of Agriculture and Natural Resources at the University of California, Davis. Approximate salinity and pH of soils was estimated by mixing fixed weight dried soil and volume distilled water and measuring the slurry with a water quality meter.

We monitored two reference sites of about 0.25 ha in size at existing marshes near the restoration sites. Percent cover on fifteen, 1.0-m^2 plots at each reference site was estimated as described above.

Statistical analyses.—Total cover of pickleweed, marsh native, exotic, and total plants on experimental sites were analyzed for differences related to treatment (four treatments vs. control) and elevation (placement in high vs. low tidal range). Total cover of plots observed at the end of the study in spring 2000 were log-transformed and analyzed using mixed factors ANOVA (PROC MIXED; SAS Institute Inc., Cary, NC). We used this model to test the fixed factors (elevation, treatment, and elevation by treatment interactions), while controlling for variation due to the random factor (site). We graphed the means of total cover versus time to interpret patterns of vegetation succession and soil parameters on the treatment and control plots during the study.

Results

Total vegetation cover at both Suisun and San Pablo Bay restoration sites was greater on fall mulched and enriched plots compared to control plots by the end of the study (spring 2000; Table 1); percent cover of exotic plants was greater on enriched or tilled plots compared to the control. Total native cover, largely pickleweed at both Suisun and San Pablo Bay plots, was greater on the fall-mulched treatment plots than all other plots. Native plants (including pickleweed) apparently colonized or thrived better on the higher than lower elevation plots, but exotic plant cover did not appear to be influenced by elevation (Table 1).

Table 1.—Differences in vegetation percent cover by treatments and elevation, at end of study (spring 2000). Includes all Suisun and San Pablo Bay plots. Treatments: fall (FM) and spring mulched (SM), tilled (T), enriched (E), and control (C); High (H) and low (L) tidal elevation.

Cover	Treatment	Elevation	Treatment Means	Elevation Means
Total	$F_{4,77} = 3.94$; $P = 0.006$	$F_{1,77} = 0.11$; $P = 0.745$	FM > E > T > SM > C	-
Exotic	$F_{4,77} = 2.71$; $P = 0.036$	$F_{1,77} = 3.92$; $P = 0.051$	E > T > FM > SM > C	-
Native	$F_{4,77} = 3.87$; $P = 0.007$	$F_{1,77} = 9.89$; $P = 0.002$	FM > C > SM > T > E	H > L[1,2]
Pickleweed	$F_{4,77} = 7.02$; $P = 0.0001$	$F_{1,77} = 25.4$; $P = 0.0001$	FM > SM > C > E > T	H > L[1,3]

[1] Means of treatment that share line did not differ at the 0.05 level of significance.
[2] Interaction of elevation and treatment: $F_{4,77} = 3.18$; $P = 0.01$; i.e., treatment differences for H: FM > C > SM > T > E were different from those for L: FM > E > T > SM > C; similarly for treatments FM & C: H > L; SM & T: H > L; E: L > H
[3] Interaction of elevation and treatment: $F_{4,77} = 2.54$; $P = 0.05$; i.e., treatment differences for H: FM > C > SM > T > E were different from those for L: FM > E > SM > T > C; similarly for treatments FM, SM, & C: H > L; T & E: H > L

Colonization of total or exotic plants on plots initiated in fall 1998 was substantial by spring 1999 at the Suisun sites (Figures 2a, 2b). Fall pickleweed-mulched, enriched, and tilled plots achieved >70% total cover, whereas total cover on the control (untreated) plots was about 50%. Total and exotic cover on plots treated with pickleweed mulch in spring (1999) was lower than that on control plots until spring 2000. Rabbitsfoot grass (*Polypogon monspeliensis*), brass buttons (*Cotula coronopifolia*), and other grasses were the most common exotic species (Table 2). Brass buttons were purposely planted in the Suisun Bay

Table 2.—Percent cover of common (>1% cover) native and exotic plants on treatment and reference plots, averaged across Suisun and San Pablo Bay restoration and reference sites at final (Spring 2000) sampling interval. Totals sum to ~100 % cover due to rounding.

		Treatments					
Scientific name	Common name	Fall Mulch	Spring Mulch	Enrich	Tilled	Control	Ref-erence
Native taxa							
Sarcocornia pacifica	Pickleweed	20.4	8.7	4.2	3.4	8.5	21.6
Distichlis spicata	Saltgrass	--	--	--	--	--	43.6
Triglochin maritima	Arrowgrass	--	--	--	--	--	5.3
Scirpus spp.	Tule	--	0.4	--	0.6	--	7.1
Typha spp.	Bulrush	0.2	--	0.4	1.1	--	0.2
Spergularia macrotheca	Sand spurry	--	--	--	1.5	6.5	--
Phragmites australis	Common reed	0.8	1.3	0.6	0.4	0.5	--
Other native[1]		0.7	0.7	0.1	0.4	0.3	0.2
Total Native		22.1	11.1	5.3	7.2	15.8	78.0
Exotic taxa							
Cotula coronopifolia	Brass buttons	17.5	16.4	33.5	29.5	16.9	--
Polypogon monspeliensis	Rabbitsfoot grass	14.9	13.3	11.4	6.9	1.6	--
Asclepias sp.[2]	Milkweed	--	0.7	1.1	--	--	0.2
Other exotic[3]		1.1	8.9	0.8	--	--	--
Total Exotic		33.5	39.3	46.7	36.4	18.5	0.2
Total Unknown[4]		15.2	5.3	17.7	20.6	17.3	20.0
Total Abiotic[5]		29.1	43.1	29.3	35.4	48.4	0.4

[1] Common (recorded at least two seasons) native species at < 1 average percent cover on some treatment or reference plots: *Atriplex prostrate*, *Epilobium ciliatum*, *Cuscuta salina*, *Juncus balticus*, and *Grindelia stricta*.
[2] Some species of these genera are native in California but were rare in the study sites and not identified to species.
[3] Common exotic species with < 1 average percent cover on some treatment or reference plots: *Lepidium latifolium*, *Lolium multiflorum*, *Bromus madritensis*, *Bassia* sp., and *Lythrum* sp.
[4] Unidentifiable species (e.g., early plant development) or apparent dormant but unidentifiable plant tissue.
[5] Abiotic includes dead plant tissue, water, bare soil, rock, driftwood, jute, and wrack.

region as forage to support waterfowl. Exotic plants were mainly weedy, *r*-selected (quick growing, high recruitment) species that might competitively exclude native vegetation. However, these plants were uncommon at reference site plots and also at most San Pablo Bay plots, and probably were not dominant to pickleweed or later successional vegetation. For the course of this study, exotic cover remained dominant on treatment plots, but was notably lower on the fall-mulched plots than the enriched or tilled plots.

Colonization by native plants was lower than that by exotic plants on the Suisun restoration sites throughout the study, comprising an average of 15–20% cover on the fall-mulched, tilled, and control plots, and <10% cover on the enriched and spring-mulched plots (Figure 2c). Pickleweed dominated early native cover on fall-mulched plots, whereas fat hen (*Atriplex prostrata*) and sand spurrey (*Spergularia macrotheca*) dominated tilled and control plots. Pickleweed cover was notably higher on the fall-mulched than the reference site plots (Figure 2d). Native plants formed nearly 100% cover on the reference plots, and were dominated by saltgrass (*Distichlis spicata*) (Figure 2c). Control and spring-mulched plots had pickleweed cover similar to that on reference plots by spring 2000 (Figure 2d); tilled and enriched only plots had little established pickleweed cover by that time. Notable on the easternmost restoration site at Suisun Bay during the study was colonization by *Chloropyron molle* ssp. *molle*, which is federally listed as endangered and state listed as rare.

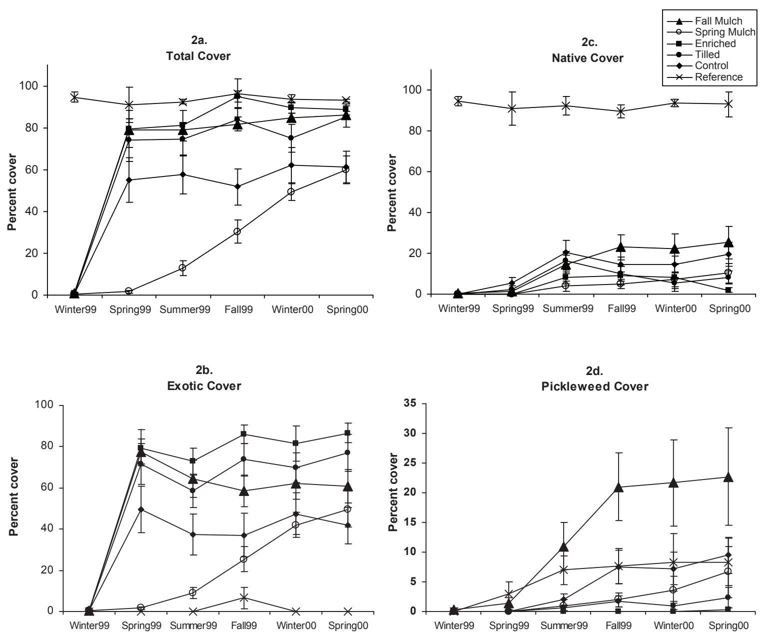


FIGURE 2.—Mean percent cover of marsh vegetation on treatment (fall mulch, spring mulch, enriched only, tilled only) and control plots, and also nearby reference plots, winter 1999 through spring 2000, at Suisun Bay restoration sites excavated to create new wetlands, Military Ocean Terminal, Concord, California. Bars are standard errors.

At the San Pablo Bay site, total cover was substantially reduced compared to Suisun Bay sites, mainly because of low colonization by exotic species (Figures 3a, 3b). Pickleweed was the dominant cover on all plots, regardless of treatment or control. Pickleweed cover was highest on the fall-mulched plots in fall 1999 and spring 2000, but was comparable to the other plots at other observed seasons.

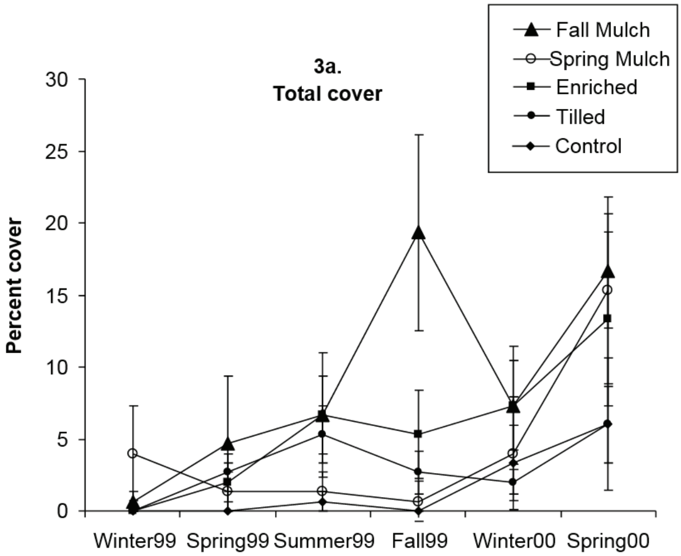
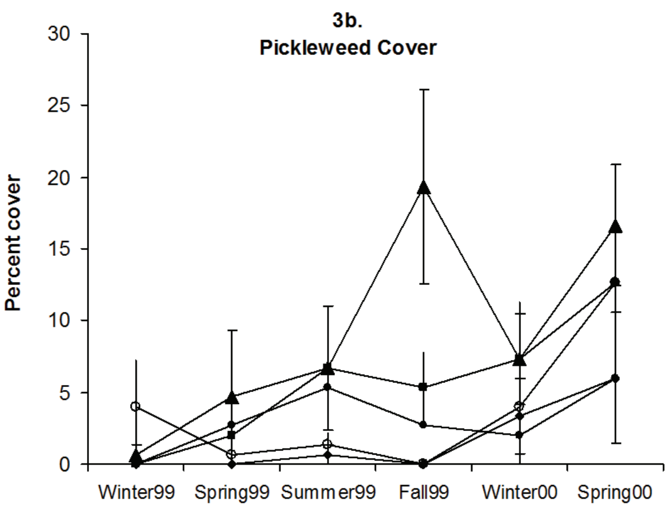


FIGURE 3.—Mean percent cover of marsh vegetation on treatment (fall mulch, spring mulch, enriched only, tilled only) and control plots winter 1999 through spring 2000, at the San Pablo Bay restoration site, Mare Island, California. Bars are standard error. Exotic cover was uncommon on these plots. On reference site plots sampled winter 1999 to spring 2000, mean total cover ranged from 96-100%, of which pickleweed cover ranged from 48-92%.



Levels and changes in soil characteristics generally were similar on all treatment or control plots at both the Suisun and San Pablo Bay restoration sites (Figures 4a-4f). Soil levels for NH_4-N were notably higher at Suisun sites (where dredge-spoil sediments were used) than those at the San Pablo site. Seasonal patterns of change in OM and NH_4-N were similar at both Suisun and San Pablo Bay restoration sites; the exception was that OM on tilled plots was notably greater than that on all other plots at Suisun Bay sites. Nitrogen as NO_3-N was similar in concentration at the Suisun and San Pablo Bay sites, but spiked at different seasons. Approximate soil salinity and pH were similar between treatment and control plots at both Suisun and San Pablo Bay sites; salinity was notably higher at the San Pablo Bay site than the Suisun Bay sites (Figure 4g-4j).

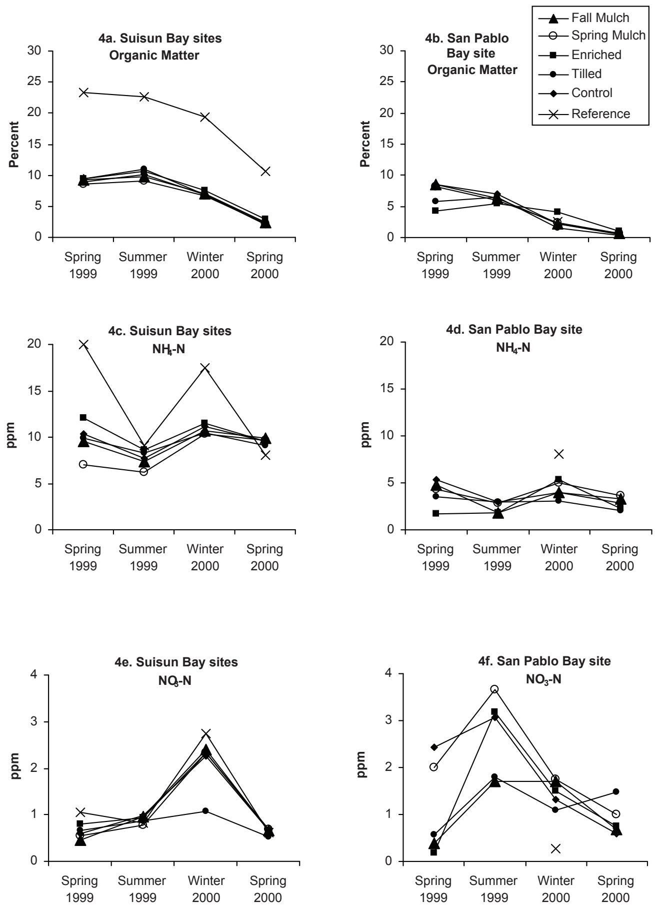


FIGURE 4.—Percent of organic matter and concentrations of nitrogen (ppm) as ammonia (NH_4-N) and nitrate (NO_3-N), and salinity (ppt) and pH on treatment, control, and reference plots sampled seasonally from spring 1999 to spring 2000.

DISCUSSION

We demonstrated that pickleweed colonization was enhanced through mechanical manipulation, and that application of pickleweed mulch in the fall season was influential in expediting colonization. In a subsequent study, we observed a similarly greater cover of pickleweed on fall-mulched plots (approximately 2 m × 10 m) compared to control plots on a small, restored wetland west of Mare Island at Skaggs Island (Miles 2005). Seeding by pickleweed that was applied in fall probably contributed to the gain witnessed in pickleweed colonization in fall compared with spring treatment. Soil chemistry and structure on most treatment and control plots were similar and probably were not influential in the outcome of vegetative cover on these plots.

Composition of dominant plants on the experimental plots differed from that observed on reference plots, indicating that eventually ground cover on the restoration sites

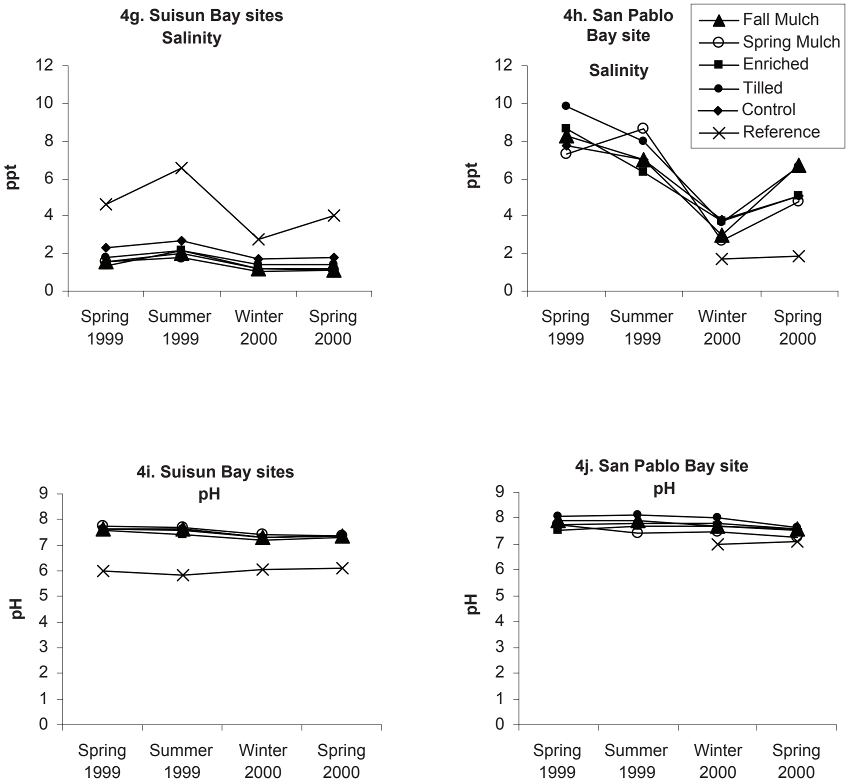


FIGURE 4 (CONTINUED).—Percent of organic matter and concentrations of nitrogen (ppm) as ammonia (NH_4-N) and nitrate (NO_3-N), and salinity (ppt) and pH on treatment, control, and reference plots sampled seasonally from spring 1999 to spring 2000.

could be dominated by saltgrass, and that succession was still in an early state. Subsequent observations (December 2003) at the Suisun Bay sites indicated recruitment of saltgrass on these sites and further colonization by reedy vegetation (e.g., *Typha*, *Phragmites*, *Schoenoplectus*, or *Bolboschoenus*). Surveys of wetlands at the Suisun Bay study area indicated that reed-like vegetation is dominant, with interspersed patches of saltgrass or pickleweed ranging from <1 to about 25 ha based on qualitative surveys we conducted of these wetlands for the U.S. Navy (Miles and Tsao-Melcer 2005). Persistence of patches of plants of lower profile, such as pickleweed and saltgrass, within the higher stature reedy vegetation is probably influenced by the periodic droughts that affect the hydrology of Suisun Bay (Calloway et al. 2007). The resulting higher soil and water salinity at Suisun Bay probably facilitate maintenance of pickleweed and saltgrass, whereas extended occurrence and inundation by freshwater facilitates these reedy species.

Several factors might explain greater colonization or recruitment of exotic vegetation at Suisun Bay restoration sites than at the San Pablo Bay site. The Suisun sites were augmented and graded with dredge-spoil sediments from the Port Sonoma Marina in north San Francisco Bay, whereas the San Pablo Bay site was not augmented. During on-land storage, the dredged sediments may have been inoculated with seeds from plants in the Port Sonoma area. The dredge-spoil was richer in organic matter than the silt-sand sediments observed at Mare Island, although organic matter was not notably greater on plots at Suisun than San Pablo. Exotic plant colonization was greater at Suisun than San Pablo, but pickleweed cover was comparable at both areas. Colonization by early succession, exotic plants probably did not affect that of native plants via competitive exclusion, or by depletion (e.g., N) or enhancement (e.g., OM) of nutrients.

The Wetland Regional Monitoring Program's EcoAtlas (California Wetlands Monitoring Workgroup [2014]) shows ~400 planned, active, or completed wetland restoration efforts in the San Francisco Bay Delta region. Yet, very few studies in this region have published goals desired, procedures followed, milestones established, or have pre-established success criteria for those restoration efforts (e.g., Marcus 2000). In contrast, there have been a number of published studies of restoration efforts in southern California (e.g., Callaway et al. 1997, Zedler and Callaway 1999, Zedler et al. 2003), where remnant tidal marshes occur in small fragments. While many of the methods suggested from southern California may be applicable to San Francisco Bay, unique habitat qualities such as fluctuating salinities due to estuarine mixing and freshwater flows to Suisun Bay are complex, and require investigation and reporting. Furthermore, as Zedler and Callaway (1999) suggested, restoration efforts rarely follow desired trajectories.

Manipulation of wetland restoration lands in late summer and early fall after the reproductive period probably would be least disruptive to plant and wildlife species in the vicinity of restoration. At sites that may require extensive rehabilitation or excavation, such as former dumps or superfund sites, large-scale tilling of pickleweed mulch would be feasible during contouring to establish proper elevation. For example, in San Pablo Bay the Bell Marin Keys Unit 5 (a former military airfield) and Sonoma Baylands were extensively manipulated (San Francisco Bay Area Wetland Regional Monitoring Program 2014), and excavation and contouring apparently were common practices at southern California coastal restoration or wetland mitigation sites (e.g., Callaway et al. 1997). For this study, pickleweed mulch was obtained from wetlands on Mare Island that were disked in late summer by the U.S. Navy to form a buffer around potentially contaminated sites to discourage colonization by endangered salt marsh harvest mice. Annual execution of this practice indicated that patchwork disking above the root system to obtain mulch probably would not impact the survival of donor pickleweed populations. Mulching with pickleweed may be an economically viable method to enhance establishment of pickleweed in areas where it is not typically dominant.

Morzaria-Luna and Zedler (2014) emphasized that experimental manipulations improve our understanding of ecosystem interactions in novel wetland environments. Ultimately, sea level rise and drought and subsequent increased salinity may accomplish the same results witnessed in experimental manipulation at the Suisun Bay restoration sites (Callaway et al. 2007, Watson and Byrne 2009). Colonization at Suisun Bay could more closely resemble changes observed at the San Pablo Bay restoration site, where pickleweed cover on fall mulch plots and control plots was more similar by the end of the study.

Acknowledgments

The U.S Navy (MIPR number N62474-97-MPC7W05) and U.S. Geological Survey supported this study. We thank M. Disney for assistance with design and field data collection, and M. Law and S. Spring who assisted in the field. Thanks also to B. Franklin, J. Hemstock, N. Roster, and R. Rugen (former members of the Naval Facilities, Engineering Field Activity West) for their foresight and support. The U.S. Navy provided the land for these restoration efforts. Any use of trade, product, website, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Received 15 March 2014
Accepted 16 March 2015
Associate Editor was C. Burton