



**Impacts of Non-native Perennial Pepperweed (*Lepidium latifolium*)
on Abundance, Distribution and Reproductive Success
of San Francisco Bay Tidal Marsh Birds**



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ABSTRACT

San Francisco Bay tidal marshes have been reduced in area by more than 85% in the last 200 years due to the direct impact of human activities: primarily industrial and urban development, and conversion to agriculture and salt ponds. Human activities continue to threaten estuarine ecosystem health indirectly, especially via contaminants in the aquatic food chain and the spread of invasive, non-native species of plants and mammalian predators. One such plant, *Lepidium latifolium*, is displacing native tidal marsh plant species and altering habitat for wildlife. We investigated whether *Lepidium* was associated with variation in populations of birds breeding in tidal marshes in the Estuary, and with variations in their reproductive success. First, we examined bird point count survey data collected during the spring of 2000 and 2001 for relationships between *Lepidium* percent cover at each survey point, and the abundance of three endemic subspecies of tidal marsh Song Sparrow (*Melospiza melodia samuelis*, *M. m. pusillula*, and *M. m. maxillaris*), and Marsh Wren (*Troglodytes palustris*); the presence of the California Black Rail (*Laterallus jamaicensis coturniculus*) and Salt marsh Common Yellowthroat (*Geothlypis trichas sinuosa*); and overall species richness and species diversity. We looked for relationships at several scales while controlling for variation among Bays (i.e., Suisun Bay, San Pablo Bay and San Francisco Bay), and among marshes, and for variation in other habitat characteristics potentially associated with *Lepidium* distribution. We showed that there were generally positive associations between *Lepidium* and all bird metrics except Black Rail; but that when controlling for variation among Bays or among marshes, and when controlling for other local habitat scale characteristics, these relationships were not significant, except with Common Yellowthroat. Thus only the Common Yellowthroat was associated specifically with unique traits of *Lepidium*, and this response led to a higher probability of Yellowthroat presence where

Lepidium cover was highest. Song Sparrow nests at five sites in San Pablo and Suisun Bay were less likely to be successful, more likely to be depredated, yet less likely to fail due to high tides, when built in *Lepidium*. Nests were built in *Lepidium* only at the two sites in Suisun. When controlling for variation among sites, nests built in *Lepidium* were neither more nor less likely to fail for any reason or due specifically to predation or flooding. We examined Song Sparrow territory density at Rush Ranch (one of the invaded sites in Suisun Bay) for evidence of a relationship with *Lepidium* cover. Territories with more *Lepidium* were closer together, implying that *Lepidium* may actually be associated with higher habitat quality as perceived by the Song Sparrows. We lacked information on the endangered California Clapper Rail (*Rallus longirostris obsoletus*) abundance and associated habitat characteristics, so we were unable to explore the relationship between this species and *Lepidium*. It is clear that there is significant overlap in distribution of Clapper Rails and *Lepidium*, but more information is needed to determine whether *Lepidium* is likely to invade areas currently of high quality for Clapper Rails, and what the impacts are likely to be. We also recommend additional studies of the impacts of *Lepidium* on the Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*), on invertebrates, on native plants and on the tidal marsh food chain in marshes across the estuarine salinity gradient.

INTRODUCTION

San Francisco Bay wetlands have been highly impacted by human activities over the last two hundred years. Tidal marshes have been reduced by over 85 percent, and the remaining habitat is highly fragmented, the hydrology is altered and the flora and fauna are threatened by contaminants, invasive species and sea level rise (Goals Project 1999; Takekawa et al in review). Due to this habitat loss and degradation, several endemic species have become increasingly rare, and some, including the California Clapper Rail (*Rallus longirostris obsoletus*) and Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*), are classified as endangered at the Federal and State level (US Fish and Wildlife Service 1999; California Department of Fish and Game 2004). Numerous current restoration projects around the Bay, such as the Napa Sonoma Marsh and the South San Francisco Bay salt pond restoration plans, promise to increase overall habitat acreage and potentially lead to the recovery of these and other tidal marsh dependant species. However, these new marshes will take years to develop into mature high marsh, and may never look like, or, more importantly, function as, natural mature marsh if non-native, invasive plant species are allowed to take hold in the developing habitat. In the South San Francisco Bay, non-native *Spartina alterniflora* (smooth cordgrass) has invaded many marshes, interbreeding with native *Spartina foliosa* (California cordgrass). This cordgrass and its intergrades displace native plants, alter sedimentation processes and grow out further onto mudflats than the native plants, potentially reducing mudflat area for foraging shorebirds (Stralberg et al. 2004) and altering marsh plain habitat for tidal marsh species (California State Coastal Conservancy & US Fish and Wildlife Service 2003).

In San Pablo Bay and Suisun Bay in particular (referred to collectively as the North Bay), another non-native species is taking hold: *Lepidium latifolium* (hereafter referred to as *Lepidium*), also known by its common name, perennial pepperweed. While *S. alterniflora* has captured attention of the scientific community and eradication efforts are underway, detailed studies of the autecology of *Lepidium* and of potential control methods in tidal marsh habitats are just beginning. This species is invading a range of habitat types in California and throughout the western U. S., including freshwater wetlands and riparian areas (Renz 2000). Little is known about how *Lepidium* directly or indirectly impacts tidal marsh ecosystems. It has the potential to change marsh soil characteristics, out-compete native plants, and alter habitat structure to the detriment native marsh fauna.

In this paper, we describe for the first time how the presence of *Lepidium* is related to the abundance and distribution of tidal marsh birds in San Francisco Estuary, California, during the avian breeding season (March through June) and how it may impact reproductive success. We describe patterns of *Lepidium* distribution from the literature and from our own field studies, at the scale of the Estuary down to the marsh level. We test hypotheses relating to how *Lepidium* might affect breeding birds, and examine how those effects might be related to *Lepidium*'s particular structure and distribution patterns. And finally, we look at failure rates of nests built in *Lepidium* compared to those built in other marsh plants, also examining how *Lepidium* structure may contribute to any differences.

BIRDS IN TIDAL MARSHES OF THE SAN FRANCISCO ESTUARY

The San Francisco Estuary is home to significant numbers of birds: some breeding in its marshes and resident year round, some, such as waterfowl and shorebirds, passing through on

migration and stopping briefly to forage on mudflats, and some remaining in the Bay throughout the winter, but breeding elsewhere (Goals Project 1999). Resident breeding birds are the main focus of this paper, including several species of songbirds and rails. The focal songbirds include three subspecies of Song Sparrow, hereafter referred to as tidal marsh Song Sparrows or simply Song Sparrows: San Pablo Song Sparrow (*Melospiza melodia samuelis*), Suisun Song Sparrow (*M. m. maxillaris*); and Alameda Song Sparrow (*M. m. pusillula*); the Salt Marsh Common Yellowthroat (*Geothlypis trichas sinuosa*) and the Marsh Wren (*Troglodytes palustris*). The Song Sparrows and Yellowthroat are State Species of Special Concern (California Department of Fish and Game 1992; Chan in review; Spautz & Nur in review; Evens in review). The two species of rail we consider here are the State and Federally Endangered California Clapper Rail and the State Threatened California Black Rail (*Laterallus jamaicensis coturniculus*). All but the Marsh Wren are local endemic, distinct subspecies with limited ranges and limited population sizes. We also consider, in our measures of species richness and species diversity, the entire suite of birds using marshes during the breeding season, including some that do not breed in marshes but go there to feed or roost. Other species commonly detected in marshes and included in our measures of species richness and diversity include Red-winged Blackbird (*Agelaius phoeniceus*), Northern Harrier (*Circus cyaneus*), Snowy Egret (*Egretta thula*), Virginia Rail (*Rallus limicola*), Mallard (*Anas platyrhynchos*), and many others.

Each tidal marsh bird species has a unique set of habitat requirements. Clapper Rails tend to be associated with *Spartina foliosa*, and are found in highest numbers in marshes closer to the Bay, where the tidal prism is highest (Collins et al. 1994). We have shown elsewhere that the tidal marsh Song Sparrows, Marsh Wren, Common Yellowthroat and Black Rail are associated with particular plant species and general vegetation characteristics (local habitat scale

measures), as well as with landscape level measures including distance to habitat edge, marsh patch size and perimeter-area ratio, marsh isolation and type of surrounding land use (Spautz & Nur 2002; Spautz et al. in review). We previously determined that at least one species (the Common Yellowthroat) is positively associated with the presence of *Lepidium*, even while controlling for other marsh plant species and marsh habitat structure, including landscape level characteristics. Here, we tested each species (except for Clapper Rail), along with additional measures of species richness and diversity, explicitly for a relationship with *Lepidium*. If there was a significant positive or negative relationship, we wanted to find out why. What characteristics of *Lepidium* might be attracting or displacing birds? Will the spread of *Lepidium* result in changes in distributions and densities of tidal marsh obligate birds? For the Clapper Rail for which we do not have abundance and vegetation data, we use current information about the species range (California State Coastal Conservancy and US Fish and Wildlife Service 2003) and species habitat requirements (Collins et al 1994), and the range and requirements of *Lepidium* (Grossinger et al. 1998), to draw inferences regarding how the spread of *Lepidium* might impact Clapper Rails.

DISTRIBUTION OF LEPIDIUM IN THE SAN FRANCISCO ESTUARY

Lepidium latifolium L. (perennial pepperweed) is native to southern Eurasia. It has spread throughout North America, probably via contaminated seed, invading a range of disturbed habitats, wetlands, tidal marshes and riparian areas, particularly west of the Rocky Mountains (Renz 2000). It is a member of the mustard family and can reach heights of 1.5 m (Renz 2000). It displaces native vegetation, and through several mechanisms that are not completely understood (including the production of allelopathic compounds in the soil), it has the capacity to spread via underground roots and form vast monocultures (K. Boyer pers. comm.; Renz 2000)

Lepidium has the capacity to produce over 16 billion seeds per year per acre; however the dominant method of spread in most ecosystems is via transfer of root fragments, particularly via water (Renz 2000). This at least partly accounts for its initial establishment along tidal channels in the tidal marshes off San Francisco Estuary.

Given these patterns in *Lepidium* distribution, and its potential to expand into new areas, it is important to understand current impacts on the tidal marsh ecosystem and to develop predictive models for impacts were *Lepidium* allowed to spread uncontrolled. It is clear that *Lepidium* displaces native vegetation, but the limits to its distribution in terms of parameters such as salinity and elevation is poorly understood; thus its capacity to further invade the estuary is unknown (Renz 2000).

STUDY OBJECTIVES

In light of the potential for *Lepidium* to greatly expand its distribution and to further displace native plants and animals in Bay Area tidal marshes, we believe that it is critical to determine the presence of any potentially detrimental effects as soon as possible. Our objectives in this study include the following:

- Summarize distribution patterns of *Lepidium* within marshes (local scale), and within the Estuary (regional scale), using existing published data as well as data collected for this study.
- Look for correlations between *Lepidium* and other habitat variables at the local and landscape levels using PRBO habitat survey data and available land use data.

- Determine whether *Lepidium* is associated with the abundance or presence of tidal marsh breeding birds, overall species richness and overall species diversity (hereafter referred to collectively as bird metrics) at several spatial scales: across the Estuary, within each Bay, and within a marsh. Are birds attracted to (or do they tend to avoid) an entire marsh containing *Lepidium*, or only the portions of a marsh covered in it?
- If there is a negative or positive relationship, look for the causal basis. Determine whether any association between bird metrics and *Lepidium* is likely to be related to its general relative distribution within marshes (e.g. its association with channels), or its structure (e.g. height or stem density).
- Examine patterns of tidal marsh Song Sparrow nest failure: are nests built in *Lepidium* more or less likely to be successful, depredated or to be destroyed by high tides?
- If there is an association between *Lepidium* and nest success or failure, could it be due to patterns of *Lepidium* distribution at the Estuarine or marsh scale? Within a marsh with *Lepidium*, are nests built in *Lepidium* built higher or lower than in other plant substrates? Is the level of visual concealment from potential predators greater or lesser?
- Is tidal marsh bird territory density associated with the presence of *Lepidium*? If so, is the implication that territories with *Lepidium* are of greater or lesser quality than average at that marsh?
- Given the above patterns of response to *Lepidium*, are we in a position to say whether the overall impact of *Lepidium* is detrimental, favorable or neutral? Is there evidence of a threshold over which *Lepidium* effects are greater or lesser? That is, if *Lepidium*

distribution increases, are the patterns that we have observed with moderate *Lepidium* infestation likely to change?

- What kind of additional information needs to be collected to determine whether the patterns we describe here will impact tidal marsh breeding birds in the longer term? Are particular populations in parts of the Estuary particularly vulnerable? Do we have sufficient information to recommend particular control measures?

METHODS

POINT COUNT SURVEY METHODS

We conducted point count surveys at 421 locations in 54 tidal and muted tidal marshes, distributed fairly evenly across the San Francisco Estuary (Figure 1; Table 1; Spautz et al. in review). Surveys were conducted within 4 hours of sunrise, two times during the breeding season in 2000 between March 20 and May 31 (some sites were sampled only once), and twice in 2001 between March 20 and May 29. Successive survey rounds were conducted at least 3 weeks apart. The goal was to estimate the number of each bird species using each site during the breeding season. Many species detected during the breeding season were assumed to be breeding, although others such as swallows (e.g. Barn Swallow, *Hirundo rustica*), Red-winged Blackbirds, and most waterbird and raptor species, were assumed to be using the marsh for foraging and roosting, but not for breeding.

We placed survey points about 200 m apart (sometimes only 150 m) along transects, with a randomly chosen start location and one to 20 (usually 10) points per site, depending on marsh size. In the smallest marsh fragments there was only room for one point. Transects were often placed along levees or boardwalks to decrease impact to marsh habitat. At each point, a trained

observer recorded all birds detected by sight and sound for five minutes. For detections within 100 m from the observer, distance was estimated within 10 m bands; detection type (visual or auditory) was also recorded for each bird. Juvenile songbirds (because they were not part of the breeding population), and birds flying high over the site were recorded but excluded from the analyses.

An abundance index for each focal passerine species (Song Sparrow, Common Yellowthroat and Marsh Wren) at each survey point for each survey period was calculated using detections within 50 m of the observer to correspond with the area used for habitat measurements (see below). Abundance was adjusted to the actual area of marsh within a 50 m radius of each survey point, which was first calculated from the EcoAtlas modern baylands layer (SFEI 1998) and then manually adjusted as necessary based on our familiarity with each site on the ground.

Species richness was calculated as the total number of species detected at each point at each round within 100 m of the observer, excluding birds flying over. Species diversity was calculated using detections of all species (excluding flyovers) within 100 m at each point for each round of surveys using the Shannon-Wiener species diversity index (Krebs 1989).

BLACK RAIL SURVEY METHODS

Black Rail surveys were conducted at 216 points in 28 San Pablo and Suisun Bay marshes (Table 1) during the breeding season of 2001, between April 18 and May 29. We did not survey San Francisco Bay sites because Black Rails are not usually found during the breeding season in those marshes. We established 1 to 20 (usually 10) survey stations in each marsh, depending on marsh size. In several marshes rail survey stations were previously established by Evens et al. (1991), but most marshes were surveyed from points we established

for landbird point count surveys discussed above. Survey stations were placed at least 100 m apart but at most sites they were 200 apart, as was the case for point count stations.

Surveys were conducted following a standardized tape call/response protocol (Evens et al. 1991). The observer listened passively for 1 minute after arriving at the listening station, then broadcasted tape-recorded black rail vocalizations: 1 minute of "grr" calls followed by 0.5 minutes of "ki-ki-kr" calls. The observer then listened for another 3.5 minutes for a total of 6 minutes per listening station. At each station, rails heard calling $<30^\circ$ apart were considered the same bird (unless the calls were simultaneous), and those $>30^\circ$ apart were considered different birds. We summarized the data by counting the number of rails detected within 50 m of the observer to correspond with the area in which we collected vegetation measurements (see below); this is also the maximum distance at which Black Rails can be reliably counted (Spear et al. 1999).

We determined whether rails were present during any rail survey or breeding season point count survey in 2000 or 2001 (coded "absent" if never detected during any survey in either year) and included in our analysis only the sites where rail tape-playback surveys were conducted in 2001.

NEST MONITORING METHODS

We monitored tidal marsh Song Sparrow nests at 5 different marshes in the northern San Francisco Bay between 1996 and 2002 (Table 2, Figure 1). In San Pablo Bay our sites were China Camp State Park (and adjacent private marsh habitat; monitored 1996 through 2003), Petaluma River Mouth (1996 to 2001); Black John Slough (1999 through 2002). In Suisun Bay, we had two sites: Benicia State Park (1996 to 2003) and Rush Ranch (1996 to 2002). Within

each marsh site, one or two study plots were established, each including two smaller subplots where 10 to 20 pairs were followed intensively throughout the season and every effort made to find all nesting attempts.

We searched for nests between March 1 and July 30 of each year, using published protocols (Martin and Geupel 1993). Methods that minimized potential increases in predation risk were emphasized. Nests were marked with flagging at least 10 m away and were not checked when cowbirds or potential predators were in the area. We checked each nest at intervals of 2 to 4 days until fledging, recording the number of eggs and young and parental behavior. After the nest was no longer active, we determined the outcome (successfully fledged, depredated, abandoned, lost due to weather conditions, or lost due to tidal flooding) based on parental behavior and nest condition.

VEGETATION AND LOCAL HABITAT SURVEY METHODS

Point count and Black Rail points

At each point surveyed, vegetation and other local habitat data were collected in the field (Table 3); most sites were surveyed in 2000 or 2001, although several were surveyed in 1997 or 1998. These data were limited to the habitat within 50 m of each point. We visually estimated the percent of marsh habitat, and percent cover of tidal channels, shrub and non-woody vegetation (and of each individual plant species), and pannes or ponds. We measured vegetation density by counting the number of times vegetation hit a 6 mm-diameter pole at 10 cm intervals from the ground at five sample points. We summed all hits, and also summed those under and over 30 cm, a height previously determined to be important for ground-nesting birds in marshes and grasslands (Rotenberry and Wiens 1980, Collins and Resh 1985). For analysis we calculated

mean hits for each density-height category. We measured the distance to the nearest tidal channel and that channel's width; we also developed a channel index by counting the number of channels under 1 m, under 2 m, and over 2 m width along two 100-m transects intersecting the survey point at right angles.

Nest locations

At each nest site, we collected detailed information about the nest and its immediate surroundings (Table 4). Variables collected included the two most dominant plant species contributing each to the nest support and concealment, the height of the nest plant, the proportion of the nest concealed (from above and from standing height at 1 m from nest, from four positions placed at 90° angles; all of which were averaged for analysis), dimensions of the vegetation clump the nest was built in (length, width, and height), the dimensions of the nest itself, the number of stems supporting the nest and the nest's height from the ground. We also measured the distance of the nest to the closest channel and the width of that channel.

GIS METHODS

Lepidium distribution

We used three sources of information on *Lepidium* distribution:

- A published map of *Lepidium* distribution, based on the knowledge of a group of marsh vegetation experts (Grossinger et al. 1998). A point on the map indicated a remembered sighting of at least one *Lepidium* plant. This map was not verified in the field, and relative densities are not reflected. Many areas with *Lepidium* in 1998 were undoubtedly

not accounted for, so the range of *Lepidium* distribution was incomplete (R. Grossinger pers. comm.)

- PRBO point count vegetation data collected at point count and Black Rail survey points between 1997 and 2001 (see above for field methods). We averaged *Lepidium* cover across points at each marsh site and then calculated cover categories based on the distribution of the data. We used these categories to code for general *Lepidium* cover to generate a shapefile in ArcView GIS 3.2a (ESRI 2000). Because vegetation data were collected only around survey points, many sites coded for 0 (zero) *Lepidium* may actually have had significant *Lepidium* cover during this time period. Thus the distribution on this map should also be considered incomplete.
- An ArcView shapefile containing vegetation information for Suisun Bay (Keeler-Woolf 2000). Polygons classified as *Lepidium* or a mixture of *Lepidium* and another plant species were merged for mapping and analysis of *Lepidium* cover within Song Sparrow territories as Rush Ranch.

Clapper Rail distribution

We made a map of Clapper Rail distribution using an existing GIS layer of known Clapper Rail detections in the estuary (California State Coastal Conservancy and US Fish and Wildlife Service 2003). This layer was developed for use in decision-making for eradication of invasive *Spartina* species, and does not necessarily reflect the actual location of Clapper Rails in any one year (K. Zaremba and J. Evens, pers. comm.). Clapper Rails were considered present if any were detected at a marsh within the last 10-14 years, based on recorded data and on the knowledge of regional Clapper Rail experts (J. Evens, J. Albertson, PRBO unpubl. data).

Point count and Black Rail points

For each point count location, we used ArcView GIS 3.2a (ESRI 2000) and extensions to derive a set of landscape parameters characterizing that point and the surrounding marsh. GIS data for bayland habitats were obtained from the San Francisco Estuary Institute's (SFEI) EcoAtlas modern baylands GIS layer (version 1.50b4, SFEI 1998). To characterize upland habitats, we derived a composite land use layer for the San Francisco Bay area consisting of the most recent 1:24,000 land use GIS layers from the California State Department of Water Resources (DWR; 1993-1999) where available, and 1:24,000 land use GIS layers from the United States Geological Survey (USGS) Mid-continent Ecological Science Center (1985) elsewhere.

We generated two general classes of landscape metrics (Table 5):

- Edge proximity metrics; and
- Landscape composition metrics

Edge proximity metrics were calculated for each point count location in ArcView 3.2a using the Alaska Pak (NPS 2002) extension's "closest feature" function.

Landscape composition metrics were calculated for each point count location by creating circular buffers of 1000 m and using the "tabulate areas" function of ArcView's Spatial Analyst (ESRI 1999) to calculate the area of each land use category within the buffer distance of interest.

Territory mapping

We used Song Sparrow territory data collected at Rush Ranch in 2002, where we found the highest *Lepidium* cover (and for which a vegetation map was available; Keeler-Woolf 2000

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[see below]). We mapped Song Sparrow territory locations in two study plots of approximately 8.5 ha each using standardized spot-mapping methods (Ralph et al. 1993): singing males were observed at each territory at least four times between March 1 and June 30, although most were observed more than 10 times. We manually digitized approximate territory boundaries in ArcView as a polygon shapefile. Using an aerial photo as a guide, we manually digitized channel locations and then added smaller channels not visible in the photo based on geographic coordinates collected in the field using a hand-held Global Positioning System.

We developed an index of territory density (nearest neighbor estimates) by calculating the mean distance from the centroid of each territory to the centroids of each of its closest two neighboring territories, excluding territories at the edge of our mapped area, using Nearest Features v 3.6d extension (Jenness 2004). Thus, the shorter the distance between centroids, the higher the local density and the smaller the territories on average. We also used this extension to calculate the shortest distance of each territory center to the nearest channel. We used existing GIS coverage of Suisun Bay vegetation types produced by the California Department of Fish and Game (Keeler-Woolf 2000) to determine boundaries of *Lepidium* patches. The proportion of *Lepidium* within each territory was calculated using the “tabulate areas” function of ArcView’s Spatial Analyst (ESRI 1999).

STATISTICAL METHODS

We began by summarizing the abundance of the focal bird taxa and bird community metrics (hereafter referred to collectively as bird metrics), as well as key habitat metrics, by bay.

To elucidate the ecological relationships between *Lepidium* and other habitat variables (which could potentially be confounding variables with respect to bird metrics) we calculated

pairwise Pearson correlation coefficients between *Lepidium* and the habitat variables and their associated *P*-values; we did this for local scale (by bay and pooled) and landscape level variables associated with point count stations and with local scale variables associated with nest locations.

Relationships between Lepidium and bird distribution and abundance

To test the hypothesis that *Lepidium* had an impact on tidal marsh bird distribution and abundance, we conducted separate regression analyses with *Lepidium* as an independent variable and each of the bird species, overall species richness and species diversity as the dependant variables.

For all bird metrics but Black Rail and Common Yellowthroat (which are rare and absent from many marshes) we averaged the number of detections for each point first by year and then between years. We used a square-root transformation to improve the normality of regression model residuals for Song Sparrow and Marsh Wren. Relationships between these metrics and the habitat variables were analyzed using linear model analysis (Neter et al 1990) in Stata 8.0 (Stata Corp. 2003). For the less common Salt Marsh Common Yellowthroat and Black Rail, we evaluated presence/absence per survey point (the species was considered present if detected during any survey period) with logistic regression analysis (Hosmer and Lemeshow 1989) using the logit function in Stata.

To test for trends in the relationship between the bird metrics and *Lepidium* cover that might not be linear with percent cover, we examined the effect of transforming *Lepidium* cover, to determine if a transformation “linearized” the relationship. We examined the significance of the effect of various *Lepidium* transformations (untransformed, inverse, log, and exponential) on each of the bird metrics.

We examined the hypothesis that the relationship might not be positively or negatively monotonic and that there could be a point beyond which increased *Lepidium* cover might actually have an effect opposite to the effect seen at lower levels of cover. To test this hypothesis, we examined the fit of a quadratic model (including *Lepidium*-squared as a term in a linear model) for each bird metric, to determine the presence of an interior *Lepidium* maximum or minimum.

We constructed linear or logistic regression models (Neter et al. 1990) in order to assess the separate and combined effects of *Lepidium* cover and other local habitat variables on each bird metric. Because we were explicitly testing the impact of *Lepidium* on birds alone and in relation to potentially confounding variables, percent cover of *Lepidium* was retained, even if it was not statistically significant in the presence of the other variables.

To determine the scale at which birds are responding to *Lepidium*, we constructed models examining the relationship with *Lepidium* among and within marshes: 1) looking at all survey points across the entire Estuary, a) first while controlling for variability among Bays, b) and then controlling for Bay and other potentially confounding habitat variables; and finally c) while controlling for variability among marshes; and 2) looking at the mean values for each marsh of the bird metrics, *Lepidium*, and other habitat variables: a) while controlling for variability first only between Bays, and then, if there was a significant relationship, b) while controlling for Bay and other potentially confounding habitat variables. Models in 2a and 2b looked only variation among marshes, while models in 1c looked only at variation within marshes. In contrast, models in 1a and 1b examined variation both among and within marshes.

For each bird metric, we analyzed the relationship between the variable and *Lepidium* cover either controlling for variation among bays or among marsh sites. We also tested for interactions between *Lepidium* and Bay to determine if the effect of *Lepidium* differed among Bays. Then we examined each bird variable separately for each Bay, first looking at *Lepidium* alone (to elucidate any *Lepidium**Bay interactions) and then controlling for marsh (to detect whether birds are responding to patterns of *Lepidium* distribution within a marsh). The latter analysis considered only marshes for which there was variability among survey points within that marsh. Marshes with only one survey point, or where birds were either absent from all points or present at all points, were dropped from analysis.

For each bird variable we developed multiple-variable local scale linear or logistic regression models, testing the significance of other local scale variables while retaining *Lepidium* and controlling for variability among Bays. We used a reverse stepwise procedure to remove the least significant variables, retaining in the final model only those variables for which Wald's $P < 0.05$. For logistic regression models we used a likelihood ratio test to determine the significance of the final variables. For linear and logistic models we calculated a partial R^2 for each of the final variables.

We hypothesized that birds using *Lepidium* might use it because it tends to be found near channels, where most marsh birds tend to forage and establish territories. We also hypothesized that birds might be attracted to *Lepidium* because of its height and high stem density, both of which could make it good cover for foraging, roosting, and nesting, and a good perch for singing songbirds. We also hypothesized that birds might be attracted to other local habitat variables associated indirectly with *Lepidium*, e.g. characteristics such as vegetation diversity, which is directly related to the environmental salinity and elevation gradients also directly effecting

Lepidium cover. Thus, we selected the following variables: vegetation species richness, vegetation species diversity, distance to closest channel, width of closest channel, percent cover of all vegetation, shrubby vegetation, and channels, total stem density, stem density under 30 cm, and stem density over 30 cm.

We analyzed marsh to marsh variation in bird metrics with respect to *Lepidium* using the means of the values at the survey points within each marsh. We calculated the log of the mean of *Lepidium* cover, but left the dependent variables untransformed, because those means were more likely to be normally distributed than the original values. For both the Common Yellowthroat and Black Rail we used the presence or absence of the species at the entire site and used logistic regression as with the point by point database. We repeated the modeling process above with this database, first controlling for variability among Bays and then, for bird metrics significantly associated with *Lepidium* at this scale, controlling for variability in the means of the local habitat variables as well as Bay.

Impacts of Lepidium on Song Sparrow reproductive success

We determined which nests were built with *Lepidium* as a substrate plant species or nest concealment plant species. We coded each nest as “1” if *Lepidium* was used either as a substrate for the nest or contributed to nest concealment, and coded the nest as “0” if not. We did the same for 14 other common plant nest-substrate species. Up to 2 plant species could be coded as “nest substrate plants” and up to 2 plant species could be coded as nest concealment plant species. Thus, each nest could have up to four plant species coded “1”. Remaining nests for which none of the 15 plant species were present, was coded for a final category, “other.”

We tabulated and graphed nest outcome by site. Each nest fell into only one category with respect to 6 possible outcomes: successful, or failed due either to predation, flooding, abandonment, weather, or structural problems.

We then examined the Pearson correlation coefficient for *Lepidium* substrate with clutch initiation date and 10 nest structural variables, to determine general characteristics of nests built in *Lepidium*.

For each Song Sparrow nest with known outcome, we created three dependent variables for analyzing reproductive outcome: 1) success: coded 1 if nest fledged at least one young (not including cowbirds), 0 if nest failed for any reason; 2) depredated: coded 1 if nest failed due to depredation, 0 if nest succeeded, or if it failed for another reason; 3) flooded: 1 if nest failed due to flooding, 0 if nest did not fail due to flooding; if the nest was successful (whether flooded or not) it was excluded from the analysis.

For each reproductive outcome variable, we determined the significance of the relationship with *Lepidium*, first alone and then controlling for marsh site and year, using logistic regression analysis. Using a backwards stepwise procedure we tested for the significance of the following additional nest variables: clutch initiation date, nest concealment, distance to closest channel, width of closest channel, plant substrate height, and nest clump height, controlling also for year and marsh site. Variables other than *Lepidium*, year, and site were removed sequentially if the Wald's *P*-test of the significance of that variable was > 0.05 .

Impacts of Lepidium on Song Sparrow territory density

Using a linear model, we analyzed the relationship between percent *Lepidium* cover within each territory and an index of territory density (see GIS methods). We tested for a

relationship between the two with and without controlling for the distance of each territory to the closest channel.

RESULTS

We found *Lepidium* more commonly in Suisun Bay and San Pablo Bay than in San Francisco Bay (Figure 1, Figure 3; Table 6). Because there is no current intensively field-documented map of *Lepidium* distribution in the region, it is not clear whether the relatively lower levels of *Lepidium* in San Francisco Bay in our data reflect realities in the field. It is clear however, that *Lepidium* has extensively invaded more of the brackish marshes in Suisun Bay, such as Rush Ranch, than it has PRBO's study sites in the South San Francisco Bay.

Tidal marsh focal species (Song Sparrow, Common Yellowthroat, Marsh Wren, Black Rail and Clapper Rail) were found throughout the Estuary (Table 6, Figure 4). One exception is that the California Black Rail rarely breeds in San Francisco Bay, and the main populations in California are found in San Pablo and Suisun Bay (Trulio & Evens 2000; Spautz and Nur 2002). Yellowthroats and Marsh Wrens were most abundant in Suisun Bay, while Black Rails and Song Sparrows are most abundant in San Pablo Bay (Table 6). In San Francisco Bay and San Pablo Bay, survey stations with more Song Sparrows tended to have lower overall species richness and species diversity (Table 7). Stations with more Common Yellowthroats and Marsh Wrens (which respond more strongly to habitat structure than do Song Sparrows; Spautz et al. in review) had overall higher species richness and diversity.

California Clapper Rails were most commonly found in San Francisco Bay and San Pablo Bay (Figure 4). In some years Clapper Rails were detected in northern Suisun Bay, and usually those detections were not during the rail breeding season.

There were differences among Bays in the distribution of most tidal marsh plant species, and other marsh habitat characteristics, as well as in *Lepidium*'s relationships to each (Table 6; Table 8). *Lepidium* tended to be positively associated with *Baccharis pilularis* in San Pablo Bay, which is usually found on marsh edges or on levees (Table 8A); also with *Juncus*, most *Scirpus* species, and with higher levels of plant species richness and diversity (Table 8B). *Lepidium* tended to be negatively associated with plants found in the high marsh, including *Salicornia virginica*, *Distichlis spicata*, *Frankenia salina*, and *Grindelia stricta*, all of which were most abundant in the more saline portions of San Pablo and San Francisco Bay. Depending on the Bay, *Lepidium* showed a range of responses to channels: it was positively associated with more channel cover (Suisun), wider channels (San Pablo and Suisun) or smaller channels (San Francisco; Table 8B), although the relationships were not evident when all Bays were considered together. Due primarily to strong associations in San Pablo Bay, *Lepidium* tended to be associated with areas that had a lower overall stem density below 30 cm and a higher density over about 40 cm (Table 8B).

At the landscape level, *Lepidium* was significantly positively correlated with distance to water edge (i.e., it was found away from the Bay or river edge of a marsh); and negatively correlated with distance to nearest upland or urban edge (i.e., it was more abundant at marsh upland edges, Table 9). It tended to be in areas with more surrounding marsh (larger marshes), and with more natural upland or agriculture in the surrounding 1000 m.

RELATIONSHIP BETWEEN *LEPIDIUM* COVER AND BIRD ABUNDANCE OR PRESENCE

Song Sparrow

The relationship between Song Sparrow abundance and *Lepidium* was best explained using a linear model; a quadratic model was not significant (Table 10). When looking at all

survey points across the Estuary, there was a significant relationship between Song Sparrow abundance and *Lepidium* (log-transformed) when controlling for Bay or marsh, and there were significant interactions with Bay (Table 11). The relationship was positive in Suisun and San Francisco Bay (where the response was strongest) but there was no significant relationship in San Pablo Bay (Table 12; Figure 5). Within a marsh, Song Sparrows were more abundant in areas with more *Lepidium*, although the relative contribution of *Lepidium* to the variability in abundance among and within marshes was small (partial $R^2 = 0.01$).

When other potentially predictive local habitat variables were added to the model, the relationship with *Lepidium* was no longer statistically significant, but there was still a positive trend (Table 13A). However, as before, there was a significant interaction between *Lepidium* and Bay. The local variables that Song Sparrows responded to more directly than to *Lepidium* were percent shrub cover, total vegetation cover and number of vegetation stems over 30 cm high (Table 13A).

We looked at the variation solely among marshes to clarify the scale of the relationship between *Lepidium* and Song Sparrow. The relationship with *Lepidium* was not significant when controlling for Bay, although there was a positive trend (Table 14).

Common Yellowthroat

There was no evidence of a quadratic relationship between *Lepidium* and Common Yellowthroat (Table 10).

Common Yellowthroats had a positive association between yellowthroat presence and *Lepidium* (log transformed) whether or not marsh was included in the model (Table 11). There was a significant interaction between *Lepidium* and Bay: a strong positive relationship in Suisun,

but only a weak positive trend in San Pablo Bay (San Francisco Bay could not be analyzed separately due to insufficient sample size; Table 12; Figure 5). As with the Song Sparrow, Common Yellowthroat response to *Lepidium* was better predicted with a linear model than a quadratic model (Table 10).

Even when controlling for variation in other local habitat variables, yellowthroats still showed a positive response to *Lepidium* (Table 13A). While controlling for amount of *Lepidium*, yellowthroats were also positively associated with vegetation species richness, percent shrub cover, and number of stems over 30 cm.; and negatively associated with vegetation species diversity, channel cover, and distance to closest channel (i.e. they preferred to be close to smaller channels, Table 13A).

Analyzing variation among marsh mean values, there was no evidence of a positive relationship with *Lepidium* (Table 14).

Marsh Wren

There was no evidence of a quadratic relationship between *Lepidium* and Marsh Wren (Table 10). Marsh Wrens showed no relationship with *Lepidium* when controlling for Bay (Table 11). There was no apparent interaction between *Lepidium* and Bay, and separate Bay models were not significant (Table 12; Figure 5). However, when controlling for marsh, i.e. looking at variability within marshes where there was variability in *Lepidium* cover, there was a non-statistically significant negative trend (Table 11).

When controlling for other local habitat variables, *Lepidium* was not significant (Table 13A). Other local variables retained in the model that were significantly related to Marsh Wren abundance were total vegetation cover, width of closest channel, and total number of stem hits

(all positive); and distance to closest channel (i.e. evidence of channel affinity), and number of stems under 30 cm (both positive).

Analyzing for a relationship between Marsh Wrens and *Lepidium* in terms of variation among marshes, there was a trend towards a positive relationship between Marsh Wrens and *Lepidium*, but it disappeared when Bay was included (Table 14).

Black Rail

Of all the bird metrics, Black Rail presence showed the least association with *Lepidium*, and this was consistent across all models. There was no relationship whether controlling for Bay or marsh (Table 11; Figure 5); or when looking individually at Suisun and San Pablo Bay (Table 12; Black Rail surveys were not conducted in San Francisco Bay because the rails were rarely detected there during the breeding season). Of all the bird metrics, Black Rail's relationship with *Lepidium* was the best fit to a quadratic model, although the fit was not statistically significant (Table 10).

Two local scale habitat variables were significant when examined together with *Lepidium* and Bay (although neither Bay nor *Lepidium* were significant): percent shrub cover (positive) and distance to closest channel (negative; Table 13).

Analyzing variation among marshes, there was no evidence of a relationship between Black Rail and *Lepidium* (Table 14).

Bird Species Richness and Species Diversity

We detected no relationship between bird species richness or species diversity and *Lepidium* when controlling for differences among Bays or marshes (Table 11). However, the relationship with species richness was weakly positive (but not significant) in San Pablo Bay,

when Bays were analyzed separately (Table 12; Figure 5). There was no evidence of increased or decreased species richness or diversity at points with more *Lepidium* within a marsh (Table 11).

The relationship of both metrics with *Lepidium* was not significant when controlling for variability in other local variables; vegetation species richness remained statistically significant in both models (a positive relationship); and shrub cover and number of stems under 30 cm, only in the species diversity model, were both negative (Table 13B).

There did not appear to be a relationship of bird species richness or diversity with *Lepidium* among marshes (Table 14).

EFFECTS OF *LEPIDIUM* ON SONG SPARROW REPRODUCTIVE SUCCESS

Lepidium was significantly correlated with a number of habitat variables we might hypothesize to impact nest success (or its converse): including nest concealment, nest height, nest clump dimensions (Table 15). It was not correlated with distance to channel or width of channel.

When considered alone, and when considering all nests across all marshes, *Lepidium* presence in the nest substrate was associated with higher rates of nest depredation and lower rates of nest flooding (but not with any trend in overall nest success, Table 16). We suspected the relationship with depredation and flooding was due to the fact that *Lepidium* was only found at two of the nest plots, Rush Ranch and Benicia State Park (Figure 6), which were the sites with the highest predation rates and lowest flooding rates (Figure 7). Hence, we repeated the

analyses controlling for both site and year; and there was no longer a relationship with between *Lepidium* and either depredation or flooding (Table 16).

When we tested for an effect of *Lepidium* while controlling for variation in other local habitat variables as well as for year and site, there was no trend at all for *Lepidium* (Table 17), for any of the three measures of nest success.

The variables that were significantly associated with increased overall nest success were greater distance from channel, earlier clutch completion date and year (Table 17). For the model best predicting the probability of predation, the significant variables were distance to channel (negative), nest height (positive), plant height (positive) and clutch completion date (positive). Nests built closer to channels, in higher vegetation and later in the season were most likely to get depredated (Table 17).

The variables that were significantly associated with nest failure due to flooding were height from ground (negative), nest substrate height (also negative) and later clutch completion date, site and year (Table 17).

EFFECTS OF *LEPIDIUM* COVER ON SONG SPARROW TERRITORY SIZE

Examining an aerial photo of Rush Ranch, *Lepidium* was often associated with channels (Figure 8). Song Sparrows territories were also associated primarily with channels, so there was significant overlap between bird territories and *Lepidium*. Territories in areas with more *Lepidium* were closer together, with or without controlling for distance from channel, although when controlling for channel distance the relationship was not statistically significant (Table 18).

DISCUSSION

We have shown that at a given survey point, there was a general overall positive relationship between *Lepidium* cover and tidal marsh bird abundance or presence, at least for the bird metrics examined. The only exception was Black Rail, for which no relationship was evident at all at the scale at which we measured *Lepidium*. The overall positive relationship was primarily due to the fact that both *Lepidium* and bird abundance were higher in the same marshes, particularly for Suisun Bay compared to other bays. For Marsh Wren, bird species richness, and bird diversity, the relationship with *Lepidium* became non-significant (although still positive) when taking into account variability among Bays. In contrast, for Song Sparrow, the relationship actually became positive when controlling for Bay (and was shown to be positive in only San Francisco and Suisun Bay); and for the Common Yellowthroat, the relationship remained strongly positive and significant, particularly in Suisun Bay.

Both Song Sparrow and Common Yellowthroat were apparently attracted to the areas within a marsh where *Lepidium* was found, although this trend was apparent only in San Pablo and Suisun Bay. For the Marsh Wren, there was an aversion within Suisun Bay, the only evidence of a negative effect in these analyses. Given the existence of a significant relationship between Song Sparrow abundance and Common Yellowthroat presence and *Lepidium* among points and within marshes, the question arose: were birds selecting *Lepidium* (or avoiding it) because of some aspect of its structure or growth form, or because it was near channels, where birds tended to establish territories and forage regardless of vegetation type? And at what scale was the choice taking place?

To answer the first question, we looked at a suite of local habitat variables that were associated with *Lepidium*. We hypothesized that these characteristics of points with higher

Lepidium cover might also be important to birds, and that these characteristics of *Lepidium*-dominated areas were the driving force behind any relationship to bird responses. For Common Yellowthroat, there was a positive relationship with *Lepidium* even when controlling for these other habitat measures; thus there is something about *Lepidium* that seemed to be related to increases in yellowthroats that was not reflected in the variability of any of our other habitat measurements. However, for the other species, the relationship with *Lepidium* (if there was one) could be explained by other habitat characteristics. For the Song Sparrow, there was still evidence of a positive trend, but it was not significant. For the Marsh Wren, bird species richness and species diversity, there was already little evidence for a relationship, and adding other habitat variables did not change this.

The second question involved looking at the means of marsh site variables, to see if the variability among sites could explain any relationship between bird metrics and *Lepidium*. For the Marsh Wren, Black Rail, bird species richness and bird species diversity, no significant patterns emerged, indicating that there was no relationship at the among-marsh level (as with the among-point analyses). For the Song Sparrow and Common Yellowthroat, again, there was a positive but not significant trend when controlling for marsh and other significant habitat variables. Due to the apparent lack of a relationship with any bird metric, we did not further explore the relationship with *Lepidium* and local habitat scale variables at the among-marsh level.

Although these analyses failed to show any evidence of an overall decrease in numbers of birds, bird species richness and bird species diversity associated with *Lepidium*, this does not mean that there is no reason for concern about a further spread in the plant's distribution. There may be a non-linear relationship, i.e., there may be an overall increase associated with low to

moderate levels of *Lepidium*, but over a certain threshold, there may be a deleterious effect. At the level of *Lepidium* currently in the bay, we found no evidence of a non-linear relationship with *Lepidium*; however at higher level of infestation there is potential for finding such a relationship.

The existence of a positive relationship with *Lepidium* for the Common Yellowthroat and Song Sparrow can be explained by looking at habitat relationships of these species in other parts of North America. Both of these species are found in a range of wetland types and other habitats with a thick understory (Arcese et al. 2002; Guzy & Ritchison 2002). Thus a thick stand of *Lepidium* could seem an attractive place for establishing a territory and nesting, especially if there is a good food source nearby.

If there is a positive effect on numbers of Song Sparrows and Common Yellowthroats, that in itself is also not sufficient to say that *Lepidium* is beneficial to those populations. It will be important to explore how *Lepidium* impacts adult or juvenile survivorship by directly altering cover throughout the year (P. Baye, pers. comm.), directly or indirectly alters food supply (P. Baye and K. Boyer, pers. comm.), alters overall habitat suitability, and how it impacts reproductive success. We do not currently have the data to assess most of these impacts, but we do have the ability to assess impacts on overall habitat suitability (by measuring effects on territory sizes) and impacts on reproductive success by measuring nest survivorship.

When we looked for evidence of an effect of *Lepidium* on reproductive success in the Song Sparrow, we found that nests built in *Lepidium* were more likely to be lost to predators (when considering all nests across all sites). However, nests in *Lepidium*-invaded sites were just as likely to be depredated whether or not built in *Lepidium*. Similarly, there was evidence that nests built in *Lepidium* were less likely to be lost due to flooding during high spring tides, but

very few nests in the *Lepidium*-infested sites were likely to be flooded at all due to a combination of muted tidal prism and higher elevations. Thus, there was no measurable impact of *Lepidium* on reproductive success within a particular marsh.

When we looked for evidence of an effect of *Lepidium* on Song Sparrow territory density at Rush Ranch, we found that territories with more *Lepidium* were actually smaller than those in parts of the marsh with less *Lepidium*. This would suggest that, at least for Song Sparrows, higher levels of *Lepidium* may actually increase habitat value, if an individual can have all its needs met defending a smaller area.

Although we did not analyze impacts on territory density at our other nest-monitoring site with *Lepidium*, (i.e., Benicia State Park), or for other taxa for which we have territory data, we suggest that the pattern seen with Song Sparrows would be similar to that found with Common Yellowthroats. Yellowthroats had a stronger positive relationship to *Lepidium* cover than did Song Sparrows, so their territory density would probably also increase in areas of higher *Lepidium* cover. Based on the lack of a significant relationship with *Lepidium* in the point count data, Marsh Wren and Black Rail territory densities are not likely to vary with *Lepidium* cover, but this should be investigated further. We also did not conduct analyses of *Lepidium* effects on the reproductive success of other species. Our sample sizes are much smaller for taxa other than Song Sparrows, so it is not expected that analyses would have sufficient statistical power to make a definitive statement.

We have only distributional data for Clapper Rails, and no data on territory sizes or reproductive success in marshes with *Lepidium*, and therefore can only make statements about potential interactions based on personal observations of our own and of other biologists familiar with Clapper Rails and/or *Lepidium* in the San Francisco Estuary. Suisun Bay, the area with

apparently the highest level of *Lepidium* invasion, is also the area with the smallest overall Clapper Rail population in any given year. Rails are found regularly during the breeding season in the marshes on the southern edge of Suisun Bay in Martinez (J. Evens pers. comm.), but not in high numbers, and rails are rare in northern Suisun around Rush Ranch. *Lepidium* itself may make these areas less suitable for Clapper Rails, but the more likely explanation is that the characteristics of these marshes that make it suitable for *Lepidium* also make it less suitable for rails, i.e., lower salinity, smaller tidal prism and higher elevations (Collins et al. 1994). The fact that *Lepidium* is first invading those areas that do not support large populations of rails on a regular basis may be cause for concern: these areas may actually become even less likely to support rails with increases in *Lepidium* cover (J. Evens pers. comm.).

It is useful to look at the distribution of *Lepidium* within marshes that regularly support significant Clapper Rail populations, e.g. the Petaluma River area. Sanderson et al. (2000) found that *Lepidium* tended to be associated with mid-order channels. Kathy Boyer (pers. comm.) noted that *Lepidium* and *Spartina foliosa* tend to not be found together along channels (confirming our results), and that banks of channels with *Lepidium* tend to be relatively steep. Thus channels with *Lepidium* are less likely to be good Clapper Rail habitat. Either *Lepidium* does not preferentially establish in channels where *S. foliosa* does best, or *Lepidium* may change channel morphology, by increasing erosion and making banks steeper and less suitable for *S. foliosa*, as it does in other habitats due to its relatively low root density (Renz 2000). More information is needed related to the range of elevation and salinity conditions that are favorable to *Lepidium* establishment, and its impact on hydrological and geomorphic processes in tidal marshes (P. Baye, pers. comm.).

Lepidium may or may not be attractive as cover for nesting Clapper Rails, but because Clapper Rails are relatively specific in their requirements (relative to the widely distributed Song Sparrow and Common Yellowthroat) it is likely to be less attractive than vegetation typically used (*Spartina* spp. and *Salicornia virginica*) due to the vast differences in its structure during the breeding season.

RECOMMENDATIONS

Although we have not demonstrated that *Lepidium latifolium* has a detrimental impact on tidal marsh Song Sparrows, Common Yellowthroat, Marsh Wren, California Black Rails, overall species richness and species diversity, its impacts on native flora and fauna are still poorly understood. Its impacts on Clapper Rails are entirely unknown and given the level of existing data, can only be speculated. The same can be said for its impact on the Salt Marsh Harvest Mouse. We suggest that studies specifically addressing impacts to these species should be of the highest priority.

We also recommend that additional work be done on impacts to reproductive success and habitat use of tidal marsh landbirds and rails in general, continuing the work we presented here, addressing specifically impacts to food resources and energy budgets. We also recommend that studies of a similar nature be conducted in other habitats around San Francisco Bay with high potential for *Lepidium* invasion, e.g. riparian areas and freshwater wetlands.

Bay researchers are concentrating on studies of control measures, mechanisms of invasion, impacts on soil composition and associated invertebrates (K. Boyer pers. comm.) and competition with native species, and with improved mapping (C. Rogers pers. comm.). We support all these measures for understanding the invasion of *Lepidium* and methods to reduce the impacts, and encourage future integration with our results. This information will improve our

understanding of how *Lepidium* impacts the entire tidal marsh ecosystem, especially over the long term.

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FIGURE 1. MAP OF PRBO BIRD SURVEY SITES IN THE SAN FRANCISCO ESTUARY, 2000-2001.

Nest plots are indicated by name. Marsh sites are categorized by mean percent *Lepidium* cover calculated within 50 m of bird survey points. Habitat spatial data courtesy SFEI (1998).

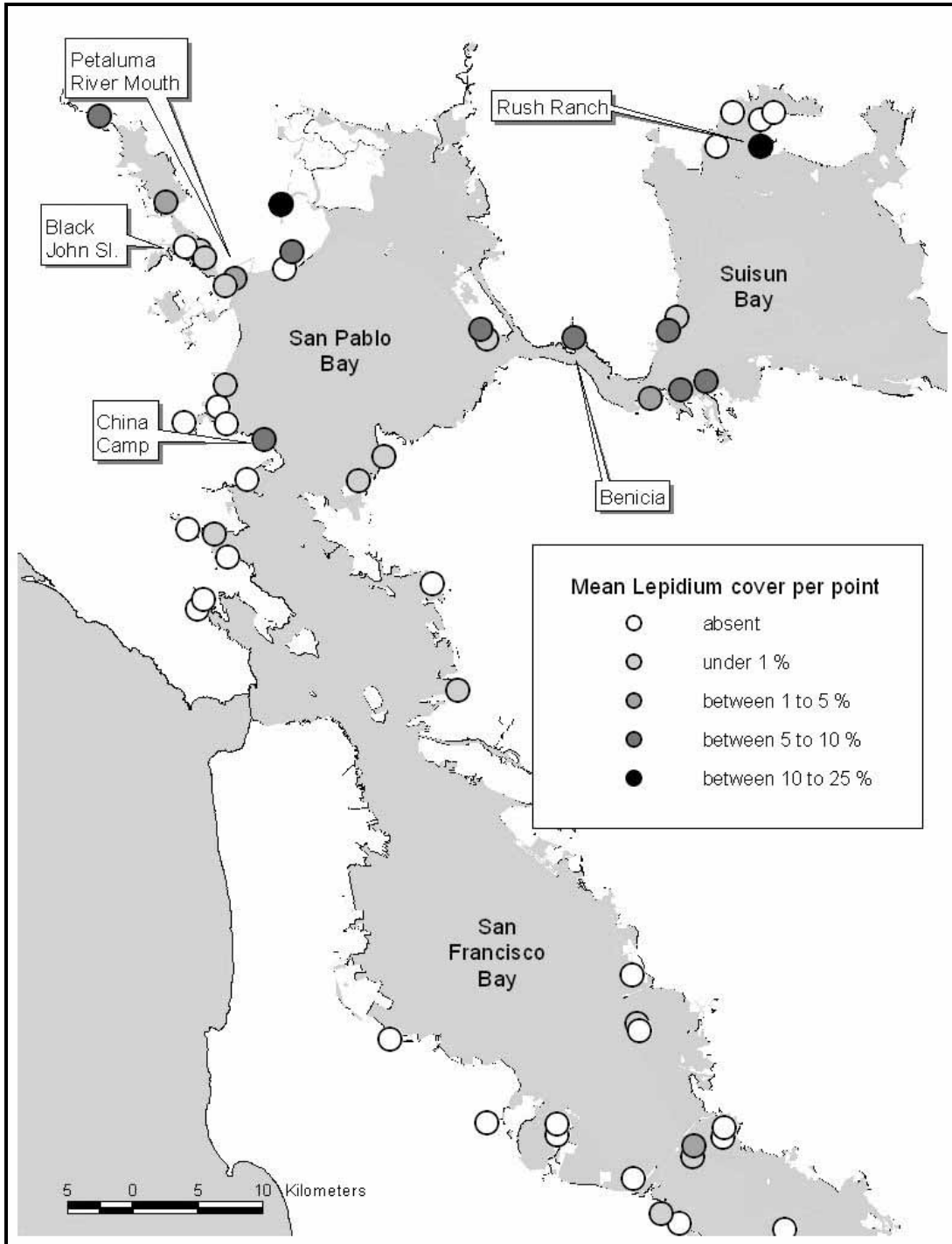
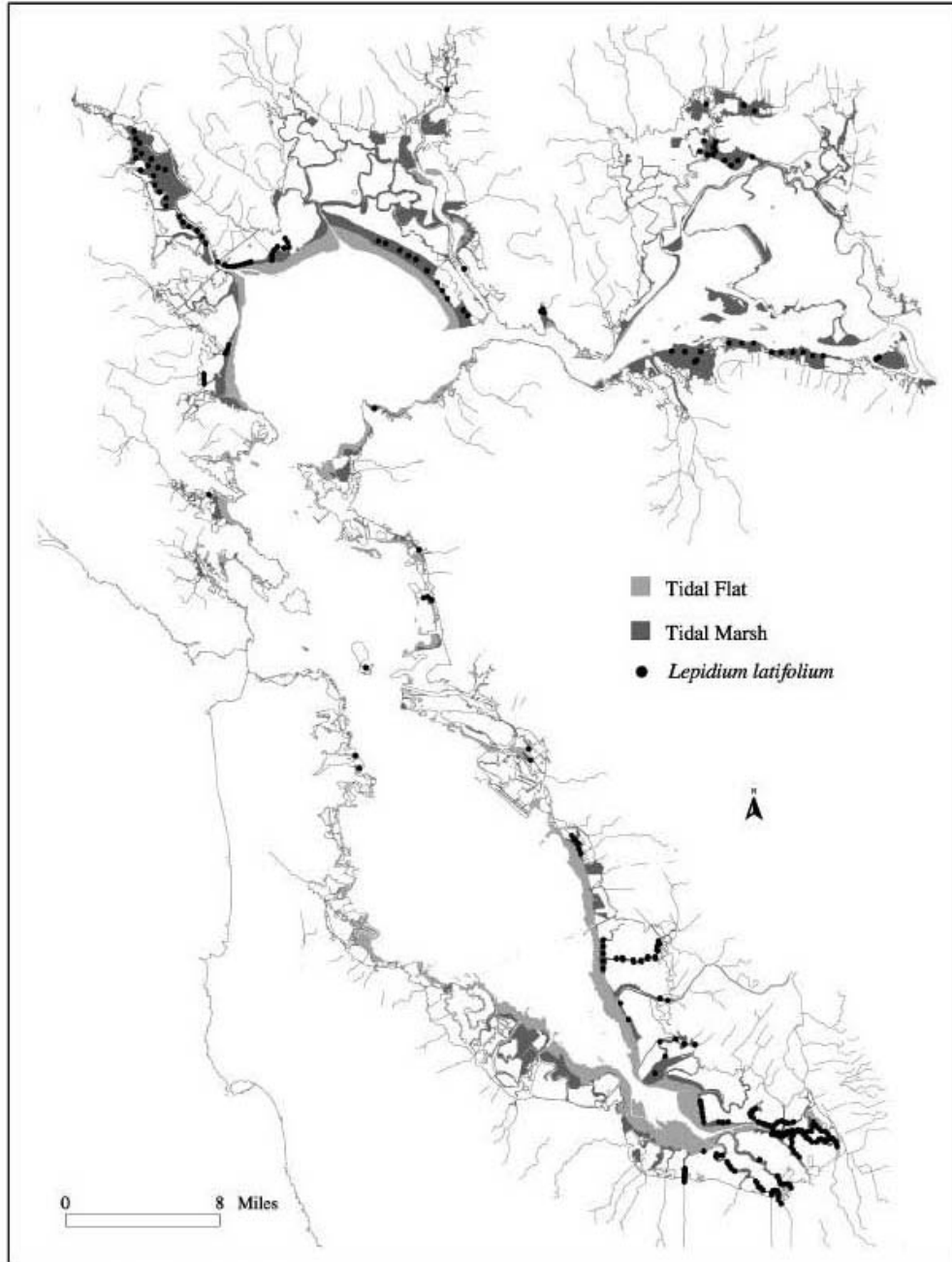


FIGURE 2. MAP OF KNOWN *LEPIDIUM LATIFOLIUM* LOCATIONS IN THE SAN FRANCISCO ESTUARY, 1998 (Grossinger et al. 1998). This map is not a complete representation of *Lepidium* distribution in 1998; locations where no *Lepidium* is indicated were not necessarily *Lepidium*-free.



Compiled by SFEI, 1998 (Basemap: Bay Area EcoAtlas Version 1.50)

FIGURE 3. RELATIVE PERCENT COVER OF *LEPIDIUM* AT PRBO POINT COUNT STATIONS, BY BAY. 2000-2001.
Distribution of percent cover at individual survey points.

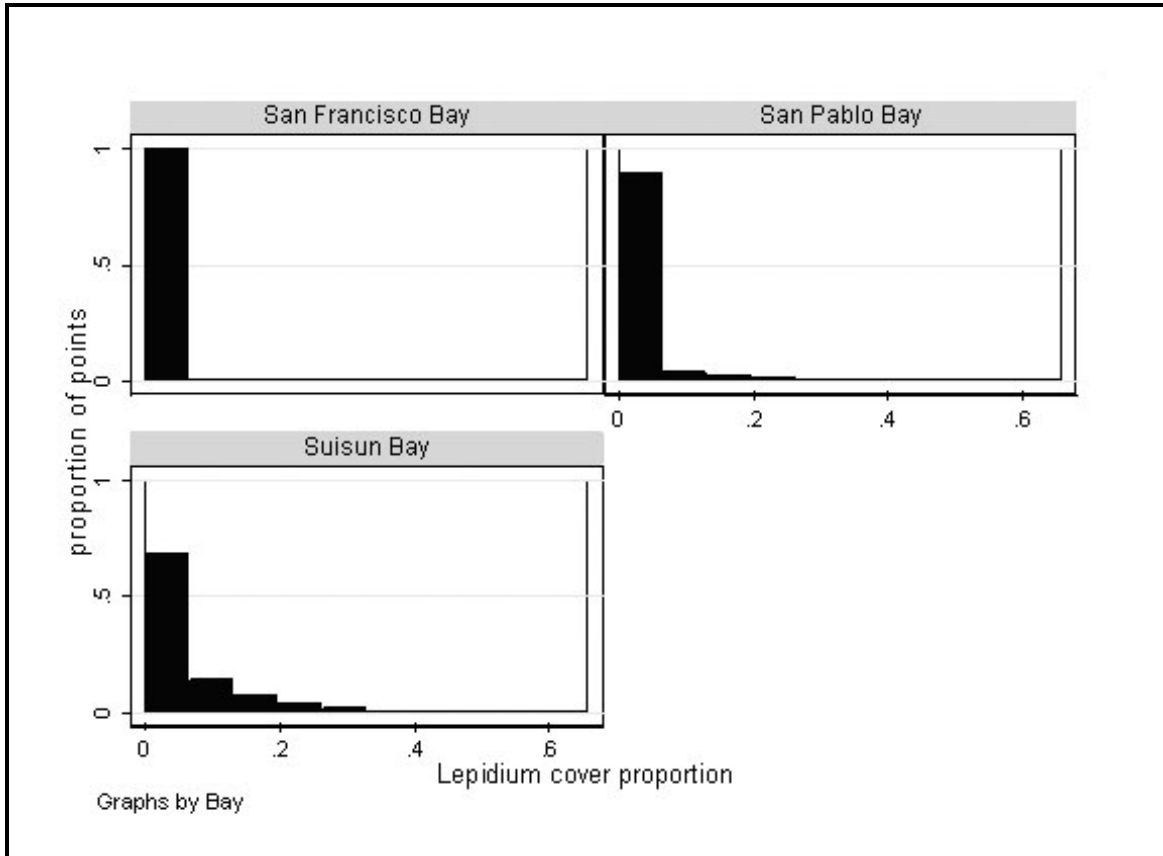


FIGURE 4. DISTRIBUTION OF CALIFORNIA CLAPPER RAILS IN THE SAN FRANCISCO ESTUARY.

Clapper Rail data courtesy California State Coastal Conservancy (2003).

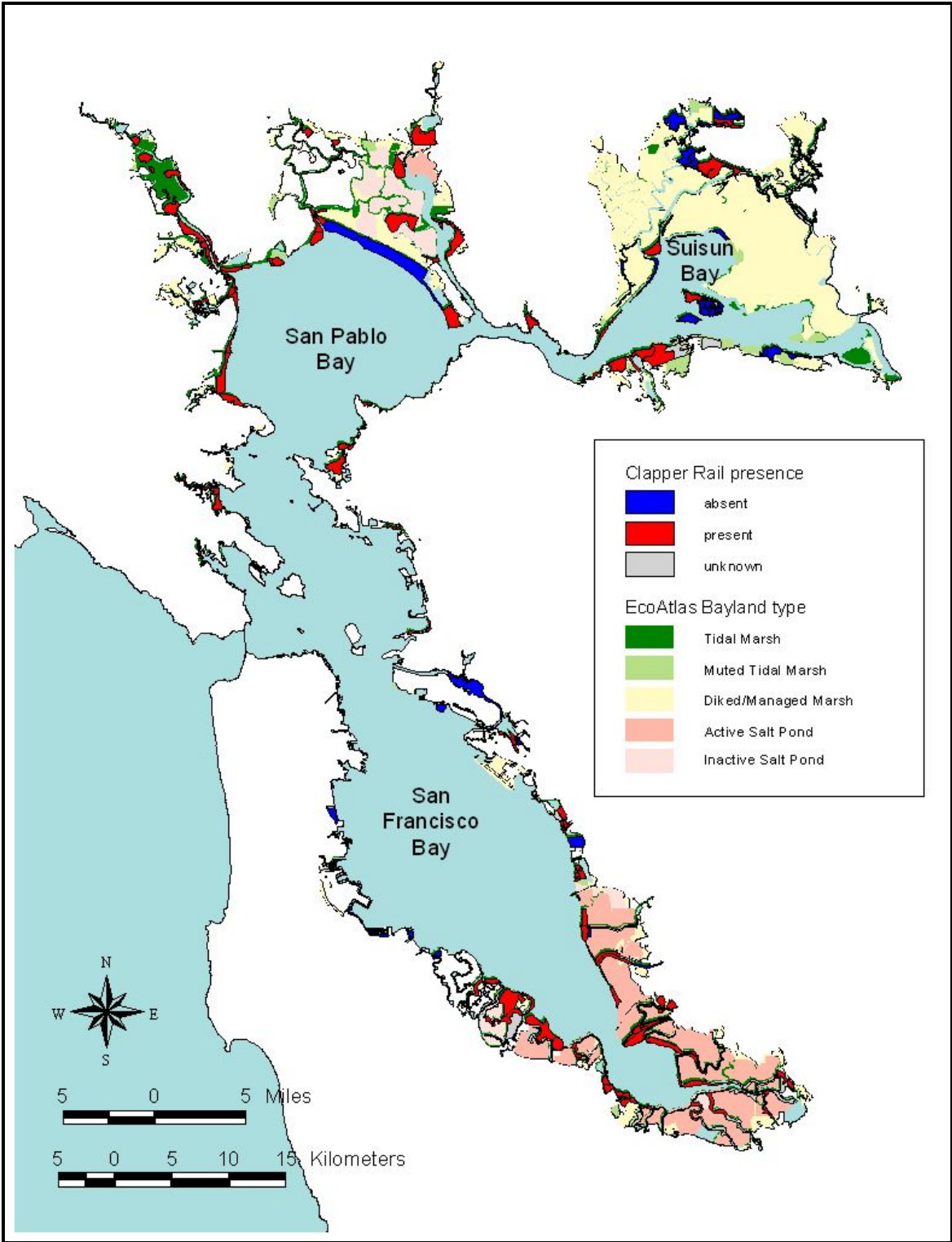


FIGURE 5A. PREDICTED VALUES OF SONG SPARROW ABUNDANCE ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12. Song Sparrow abundance is untransformed.

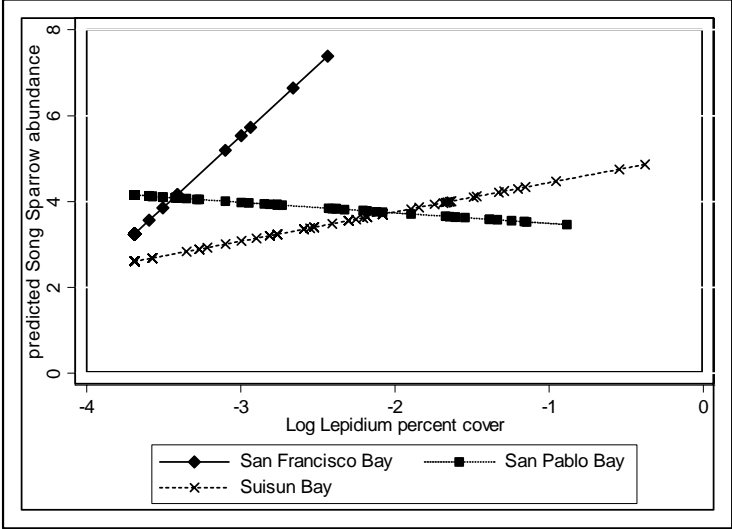


FIGURE 5B. PREDICTED COMMON YELLOWTHROAT PRESENCE ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12.

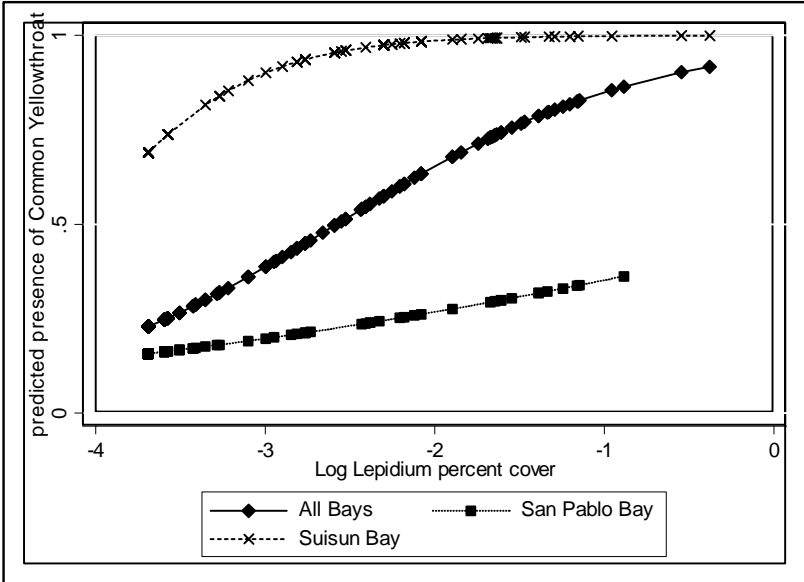


FIGURE 5C. PREDICTED VALUES OF MARSH WREN ABUNDANCE ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12. Marsh Wren abundance is untransformed.

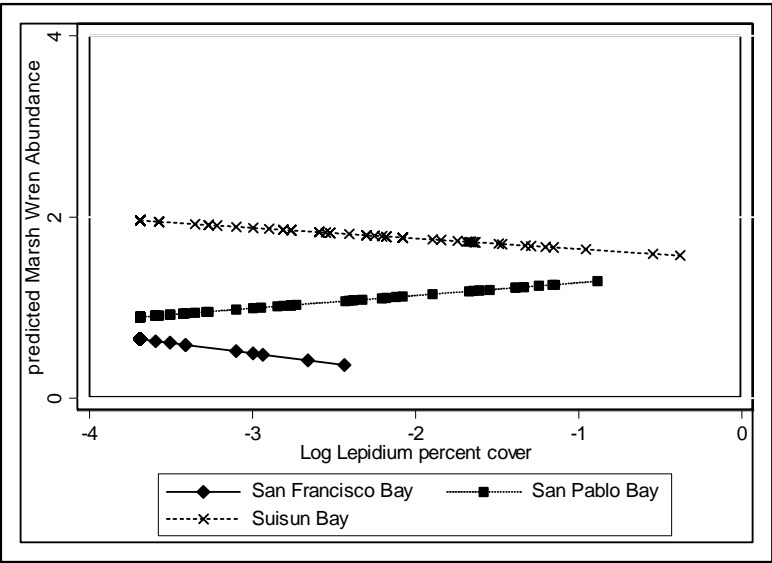


FIGURE 5D. PREDICTED BLACK RAIL PRESENCE ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12.

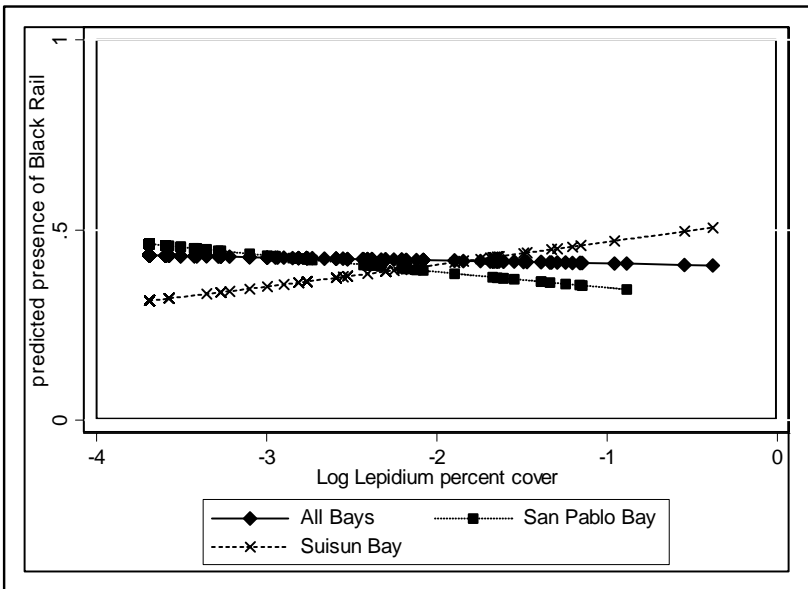


FIGURE 5E. PREDICTED VALUES OF SPECIES RICHNESS ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12.

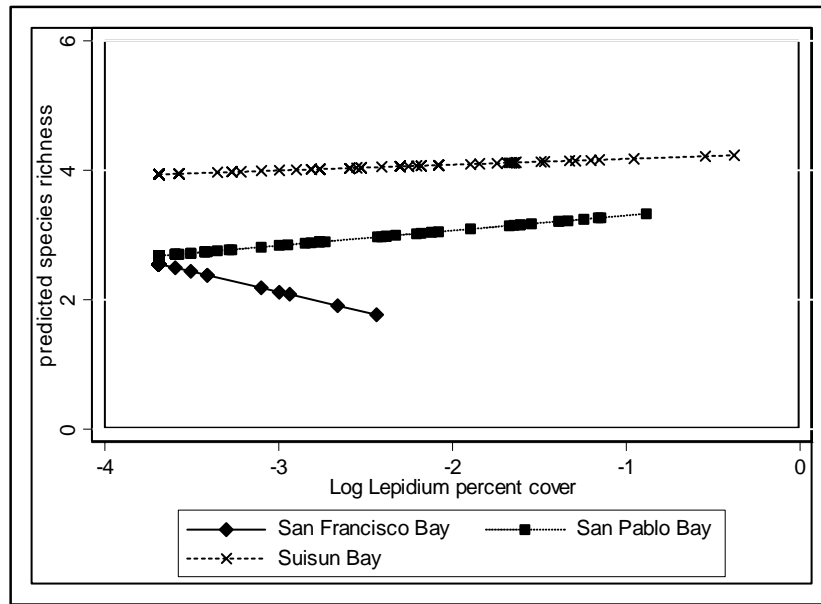


FIGURE 5F. PREDICTED VALUES OF SHANNON DIVERSITY INDEX ASSOCIATED WITH LOG *LEPIDIUM* COVER, BY BAY. 2000-2001. Predicted values are based on models shown in Table 12.

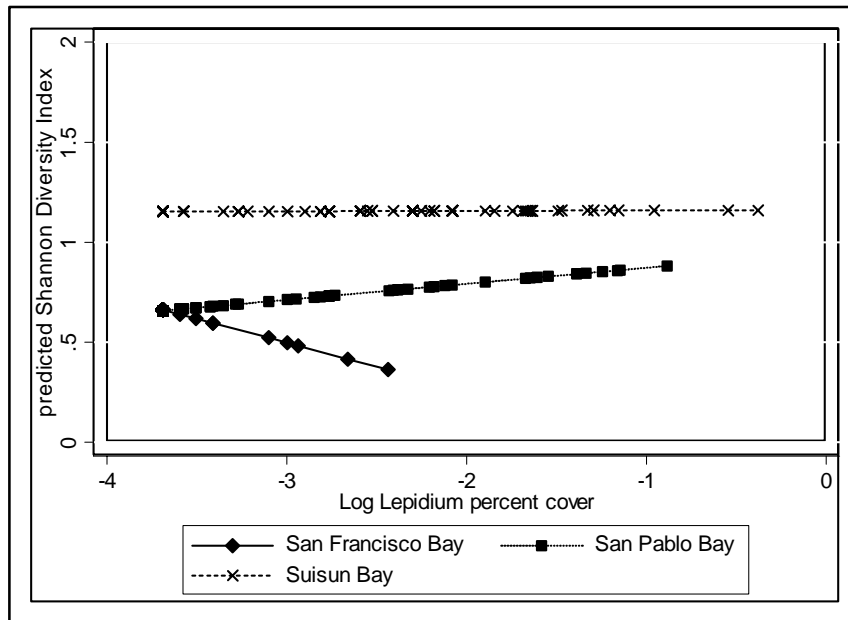


FIGURE 6. PROPORTION OF SONG SPARROW NESTS BUILT WITH MAJOR PLANT SPECIES AS SUBSTRATE OR COVER, BY SITE. SAN PABLO AND SUISUN BAY, 1996 TO 2003.

Up to four different plant species could be recorded for each nest: two contributing to support and two to concealment, so each nest may be represented up to 4 times in these data.

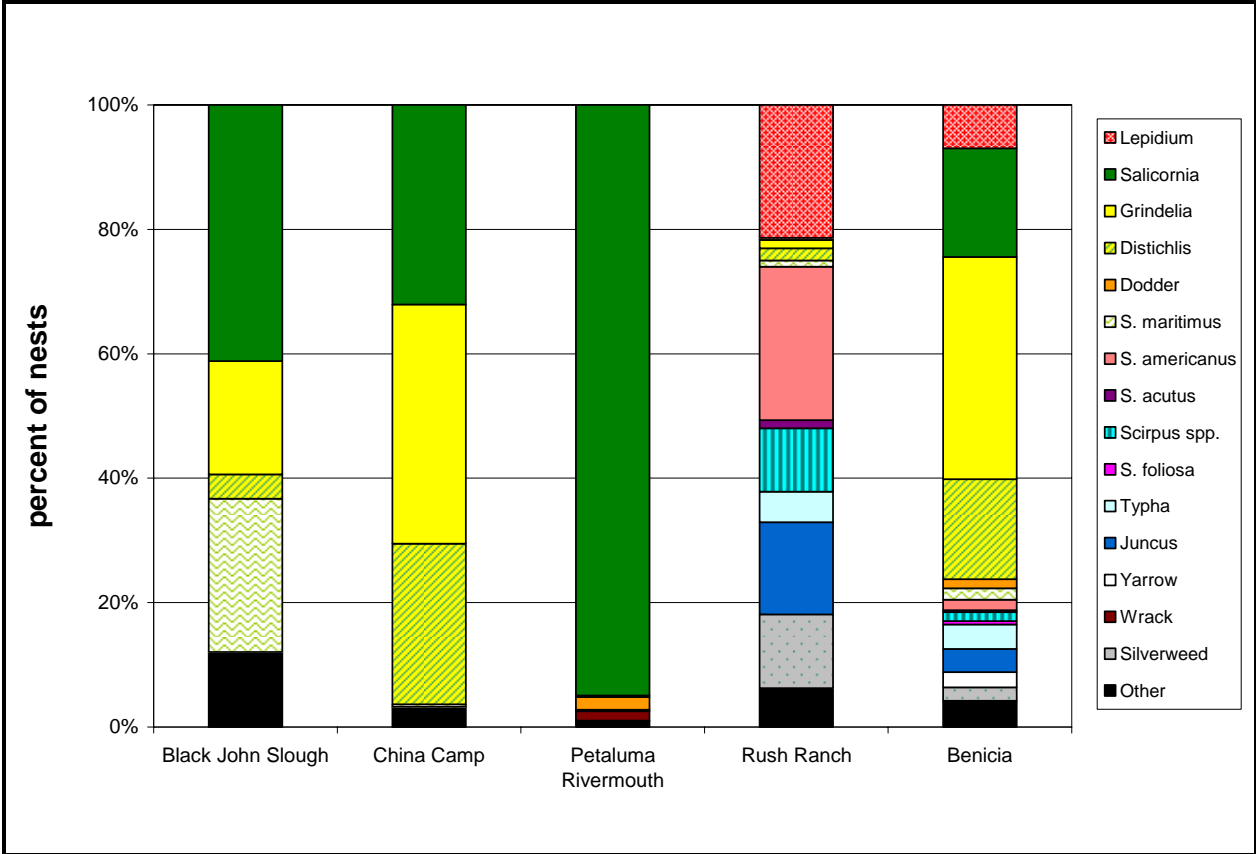


FIGURE 7. SONG SPARROW NEST OUTCOMES AT EACH OF FIVE STUDY SITES. SAN PABLO AND SUISUN BAY, 1996-2003.

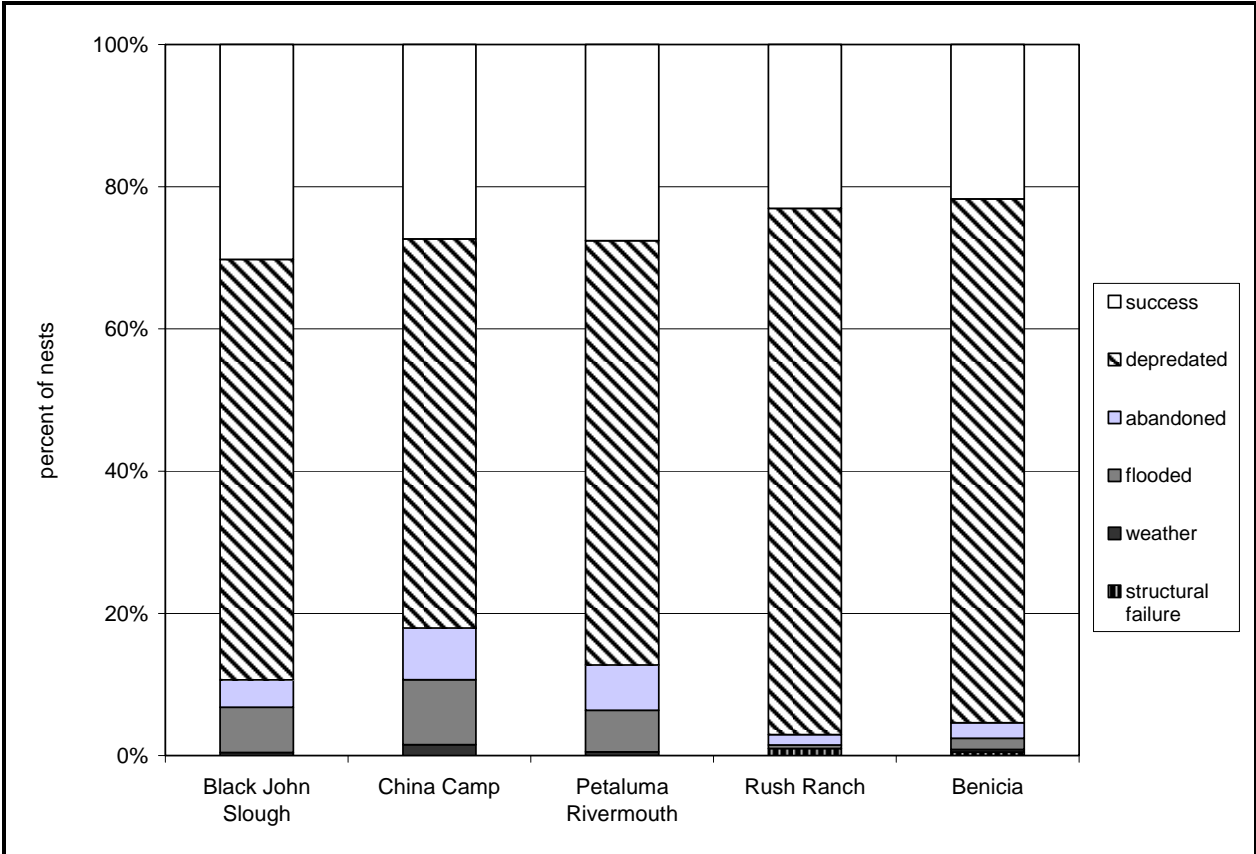


FIGURE 8. DISTRIBUTION OF *LEPIDIUM* AND 2002 SONG SPARROW TERRITORIES AT RUSH RANCH, SOLANO COUNTY, SUISUN BAY.

Vegetation data courtesy of California Department of Fish and Game (Keeler-Woolf 2000).

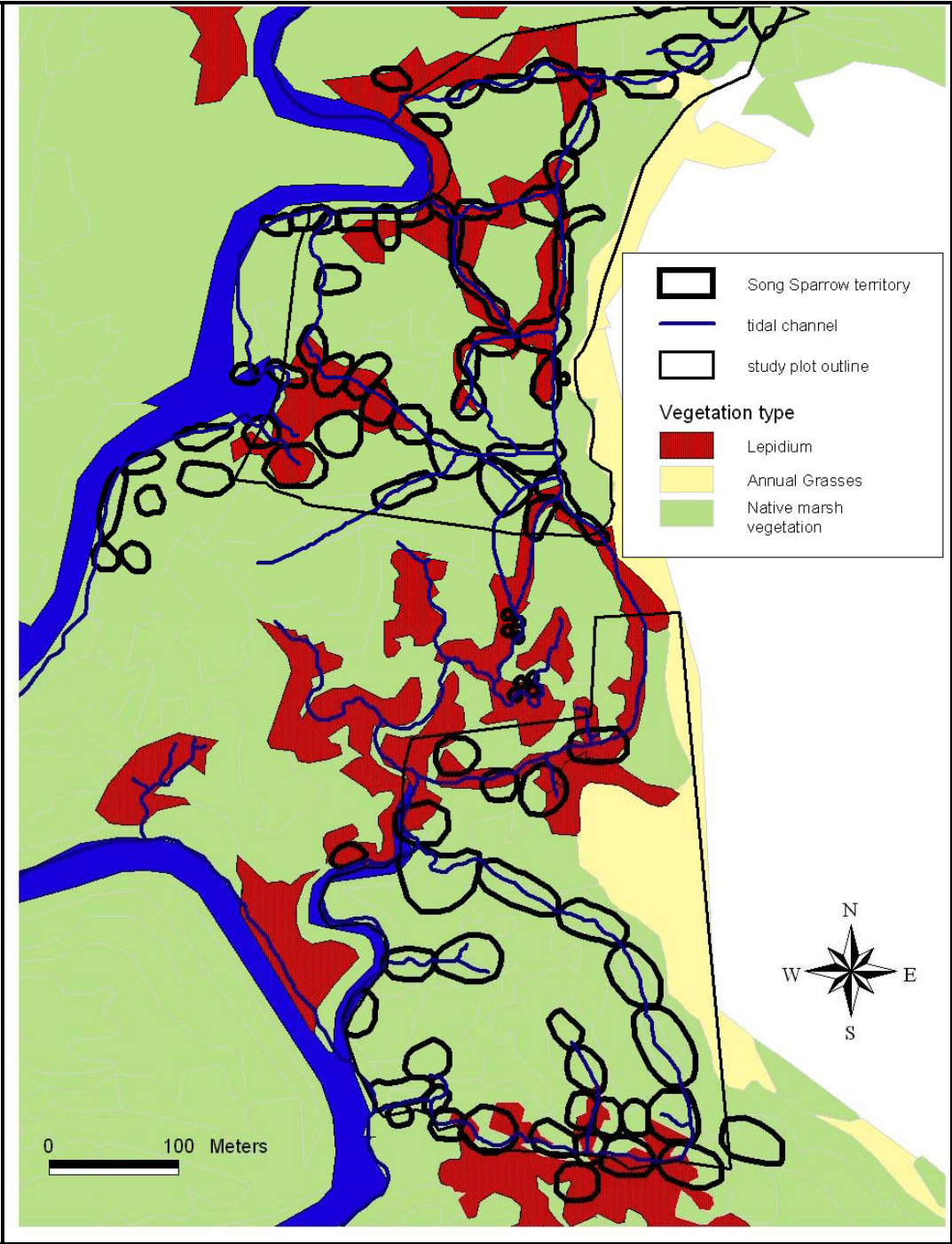


TABLE 1. LIST OF TIDAL MARSH BIRD SURVEY SITES IN THE SAN FRANCISCO ESTUARY, MARCH TO MAY, 2000-2001.

Point counts were conducted at all sites. Sites in Suisun and San Pablo Bays also surveyed for California Black Rails are indicated with asterisks.

SITE NAME	Number of Survey Points	Patch Size (ha)
SAN FRANCISCO BAY		
Alameda Creek	6	234.5
Hetch-Hetchy East	5	446.2
Hetch-Hetchy West	7	446.2
Dumbarton Marsh	14	446.2
Emeryville Crescent	5	20.1
Faber-Laumeister Tract / East Palo Alto	7	124.5
Hayward Regional Shoreline	11	100.8
Hoffman Marsh (El Cerrito)	5	14.8
Mouth of Alviso Slough	6	10.0
Middle Bair Island West	5	1283.8
New Chicago Marsh	6	1768.9
Newark Slough	7	446.2
Oral B Fragment	1	-
Outer Bair Island West	3	1283.8
Palo Alto Baylands	9	124.5
Park Plaza Fragment	1	2.0
Ravenswood Slough	8	35.7
Whaletail	12	234.5

SITE NAME	Number of Survey Points	Patch Size (ha)
SAN PABLO BAY		
* Beach Fragment	1	1.3
* Black John Slough	20	1806.5
* Day Island	8	1132.8
* China Camp Fragments	2	0.4
* China Camp State Park	16	1132.8
* Corte Madera Ecological Reserve	10	104.6
* Green Point Centennial Marsh	7	1806.5
* Mare Island	20	1428.7
Mitchell Fragment	3	11.8
* McInnis Marsh	10	1132.8
Hamilton South / McInnis North	10	1132.8
Petaluma Dog Park	4	-
* Petaluma Ancient Marsh	9	1806.5
Piper Park	5	58.8
* Point Pinole South	3	9.3
Pond 2A Restoration	10	5767.8
San Pablo Creek	9	60.6
Petaluma River Mouth (Carl's Marsh)	10	393.0
Sears Point	10	123.2
Tolay Creek	11	393.0
* Tam High School (Richardson Bay)	5	38.5
* Travelodge Fragment	1	2.4
* Lower Tubbs Island (muted marsh)	8	393.0
* Triangle/MCDS Fragment	1	5.0

SITE NAME	Number of Survey Points	Patch Size (ha)
White Slough Marsh	5	265.2
SUISUN BAY		
* Bullhead Marsh	10	205.8
Cordelia	3	7.8
* Grey Goose	6	61.4
Goodyear Slough North	10	77.5
* Goodyear Slough South	10	230
* Hill Slough East	6	28.3
Hill Slough West	5	12.8
Martinez Regional Shoreline	10	40.8
* Point Edith	10	1034.5
* Rush Ranch	10	557.9
* Southampton Bay/ Benicia State Park	10	71.3

TABLE 2. SONG SPARROW NEST SAMPLE SIZES. SAN PABLO AND SUISUN BAY, SAN FRANCISCO ESTUARY. 1996-2003.

Number of Song Sparrow nests found active with known outcome at each site.

site	Petaluma					Total
	Black John Slough	China Camp	River mouth	Rush Ranch	Benicia	
1996	0	29	59	41	124	253
1997	0	159	40	9	210	418
1998	0	120	56	23	44	243
1999	53	158	54	30	72	367
2000	50	144	97	37	93	421
2001	39	130	69	22	75	335
2002	93	131	0	42	106	372
2003	0	145	0	0	99	244
all years	235	1,016	375	204	823	2,653

TABLE 3. LOCAL SCALE HABITAT VARIABLES EXAMINED AT BIRD SURVEY POINTS IN THE SAN FRANCISCO ESTUARY. 2000-2001.

Variable	Description
Percent cover of dominant native and non-native plant species within 50 m of point:	Relative percent cover of each plant species (in relation to all vegetation), for all species with at least 1 % cover.
<i>Distichlis spicata</i> (saltgrass)	Short dense grass found in upper marsh, in saline soils
<i>Grindelia stricta</i> (gumplant)	Leafy, composite woody shrub with many stems; found on channel banks, in more saline marshes. Mean height 1 m.
<i>Juncus balticus</i> (rush)	Short rush found in brackish to fresh water areas
<i>Lepidium latifolium</i> (perennial pepperweed; non-native invasive)	Tall perennial herb (> 1 m) found in brackish to fresh areas, channel banks and upper marsh. Forms dense tangled canopy mid-season, falls to near-horizontal when foliage is densest. Replacing native vegetation.
<i>Phragmites australis</i> (common reed)	Tall grass up to 2 m high, forms dense stands; found in brackish to fresh areas; may be non-native
<i>Salicornia virginica</i> (pickleweed)	Short often dense perennial, found in upper marsh, saline soils; dominant in San Pablo Bay and San Francisco Bay. Typically 30 – 40 m height but can grow taller.
All <i>Scirpus</i> species	
<i>Scirpus acutus</i> / <i>californicus</i> (<i>tule</i>)	Tall, rounded perennial sedge (> 2 m) found in brackish to fresh areas, often on channel banks, often submerged.
<i>Scirpus americanus</i>	Short to medium height triangular perennial sedge found in saltier areas than <i>acutus</i> . Old stems form dense structure used for nesting

Variable	Description
	birds
<i>Scirpus maritimus</i> (alkali bulrush)	Medium height triangular perennial sedge found in saltier areas than <i>S. americanus</i> . Old stems form dense structure used for nesting birds
<i>Spartina alterniflora</i> (salt-water cord grass; non-native invasive)	Tall cordgrass (> 1 m) forms denser stands in lower and higher elevations than native <i>foliosa</i> ; interbreeds and outcompetes native; greatest problem in San Francisco Bay.
<i>Spartina foliosa</i> (California cord grass)	Tall native cordgrass found in narrow band in low marsh and in channels.
All <i>Spartina</i> spp.	Primarily <i>S. foliosa</i> and <i>S. alterniflora</i>
<i>Typha</i> spp. (cattails)	Tall (> 1 m) perennial in fresh water areas.
Vegetation species richness	Total number of plant species counted within 50 m,
Vegetation species diversity	Shannon Diversity index ^a
Percent ground cover within 50 m of point	Visually estimated ground cover
Marsh habitat	All focal marsh habitat including internal levees. Points on or near marsh edges have < 100% marsh habitat.
Shrub cover	Shrubs including: <i>Grindelia</i> and <i>Baccharis</i>
Total vegetation cover	All herbaceous and woody marsh vegetation
Pond/panne cover	Tidal or non-tidal open water or dry pannes
Channel cover	Tidal channels or sloughs
Distance to closest channel	Closest channel > 0.2 m in width
Width of closest channel	Width of that channel
Channel density; channels under 1 m in width	Number of channels of under 1 m width crossed on two 100 m transects centered on survey point and set at right angles; divided by total length of transects

Variable	Description
Channel density; channels under 2 m in width	As above but using channels of under 2 m width
Number of stems at:	Mean count of stems touching 6 mm dowel
<10 cm	placed at 5 sample points at predetermined
10-20 cm	distances from center survey point, in a
20-30 cm	randomly selected direction.
>30 cm	
<30 cm	
Total stems	Sum of all stems counted

^a Krebs 1989

TABLE 4. LOCAL SCALE HABITAT VARIABLES EXAMINED AT BIRD NEST SITES. SAN PABLO AND SUISUN BAY SITES. SAN FRANCISCO ESTUARY. 1996-2003.

Variable	Description
Nest support plant	Plant species to which nest is attached or which offers support; can be up to 2 species
Nest concealment plant	Plant species to which provides concealment to nest; may or may not be same as support plant; can be up to 2 species
<i>Lepidium</i> nest support	<i>Lepidium</i> is present as at least one of the above species of nest support or nest concealment
Height of nest plant	Height of nest support plant
Number of support branches	Number of plant stems directly supporting nest from beneath or on sides.
Height, length & width of nest clump	Dimensions of discrete clump in which nest is built.
Distance from edge of clump	Distance of edge of nest from edge of nest clump
Nest concealment	Average of percent concealed from above, below and from 4 cardinal directions
Nest dimensions	Outside and inside depth and width.
Nest height from ground	Distance from ground to bottom of nest

TABLE 5. LANDSCAPE METRICS CALCULATED FROM GIS DATA AT EACH BIRD SURVEY POINT.

Landscape Metric	Unit of Analysis	Data Source
Edge Proximity		
Distance to nearest water edge	Point	EcoAtlas
Distance to nearest non-marsh edge	Point	EcoAtlas
Distance to nearest upland edge	Point	EcoAtlas
Distance to nearest urban edge	Point	EcoAtlas, DWR, USGS
Landscape Composition		
Percent tidal and muted marsh within 1000 m	Point	EcoAtlas
Percent non-tidal wetland within 1000 m	Point	EcoAtlas, DWR, USGS
Percent urban within 1000 m	Point	EcoAtlas, DWR, USGS
Percent agriculture within 1000 m	Point	EcoAtlas, DWR, USGS
Percent natural upland within 1000 m	Point	EcoAtlas, DWR, USGS
Percent all natural habitat (wetlands and uplands) within 1000 m	Point	EcoAtlas, DWR, USGS

TABLE 6. MEAN ABUNDANCE INDEX OF TIDAL MARSH BIRD SPECIES PER HA AT BIRD SURVEY POINTS, PRESENCE (PROPORTION OF SURVEY STATIONS WITH ONE OR MORE DETECTIONS OF THAT SPECIES) AND SELECTED LOCAL HABITAT VARIABLES BY BAY. SAN FRANCISCO ESTUARY. 2000-2001. (Modified from Spautz et al., in review).

Variable	San Francisco	SD (N)	San Pablo Bay	SD (N)	Suisun Bay	SD (N)
	Bay					
Song Sparrow abundance	3.39	2.37 (122)	4.15	2.37 (199)	3.01	1.66 (100)
Common Yellowthroat abundance	0.08	0.266 (122)	0.16	0.419 (199)	1.06	1.06 (100)
Common Yellowthroat presence	0.12	0.33 (122)	0.17	0.38 (199)	0.76	0.49 (100)
Marsh Wren Abundance	0.635	1.168 (122)	0.918	1.45 (199)	1.84	1.30 (100)
Marsh Wren presence	0.45	0.50 (122)	0.48	0.50 (199)	0.94	0.24 (100)
Black Rail abundance	-	-	0.099	0.256 (124)	0.065	0.151 (58)
Black Rail presence	-	-	0.44	0.50 (146)	0.38	0.49 (63)
Overall species richness	2.52	1.14 (122)	2.72	1.20 (199)	3.84	0.895 (100)
Overall species diversity	0.65	0.385 (122)	0.67	0.412 (199)	1.11	0.266 (100)
<i>Lepidium latifolium</i> proportion cover	0.002	0.008 (120)	0.020	0.059 (199)	0.066	0.113 (91)
<i>Distichlis spicata</i> proportion cover	0.027	0.061 (120)	0.056	0.116 (199)	0.075	0.094 (91)
<i>Grindelia strict</i> proportion cover	0.041	0.065 (120)	0.049	0.063 (199)	0.021	0.034 (91)
<i>Salicornia virginica</i> proportion cover	0.681	0.230 (120)	0.660	0.266 (199)	0.141	0.228 (91)

Variable	San Francisco Bay	SD (N)	San Pablo Bay	SD (N)	Suisun Bay	SD (N)
All <i>Scirpus</i> spp proportion cover	0.017	0.078 (120)	0.118	0.217 (199)	0.203	0.163 (91)
<i>Scirpus maritimus</i> proportion cover	0.016	0.079 (120)	0.112	0.204 (199)	0.036	0.088 (91)
Total vegetation percent cover	81.03	32.65 (120)	88.82	11.70 (198)	88.34	11.02 (91)
Channel percent cover	14.01	16.48 (120)	5.70	5.82 (198)	5.49	6.81 (91)
Distance closest channel	16.78	17.11 (96)	19.57	32.62 (181)	24.29	29.34 (90)
Stems under 30 cm	7.40	3.84 (79)	6.86	3.06 (199)	7.90	4.09 (90)
Stems over 30 cm	0.797	1.760 (84)	1.57	1.466 (199)	5.24	3.44 (90)
Total stems	7.40	3.84 (79)	6.86	3.06 (199)	7.90	4.09 (90)

TABLE 7. PAIR-WISE CORRELATION BETWEEN BIRD SPECIES AND SPECIES METRICS AT BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

Sign of Pearson's correlation coefficient (r) and associated P-value are shown.

	Song Sparrow	Common Yellowthroat	Marsh Wren	Black Rail	Species Richness
Common Yellowthroat	$r = + 0.103$ $P = 0.035$				
Marsh Wren	$r = - 0.022$ $P = 0.654$	$r = + 0.311$ $P < 0.001$			
Black Rail	$r = + 0.128$ $P = 0.008$	$r = + 0.089$ $P = 0.069$	$r = + 0.108$ $P = 0.027$		
Overall Species Richness	$r = - 0.256$ $P < 0.001$	$r = + 0.368$ $P < 0.001$	$r = + 0.383$ $P < 0.001$	$r = + 0.180$ $P < 0.001$	
Shannon Diversity Index	$r = - 0.331$ $P < 0.001$	$r = + 0.385$ $P < 0.001$	$r = + 0.447$ $P < 0.001$	$r = + 0.131$ $P = 0.007$	$r = + 0.945$ $P < 0.001$

TABLE 8A. CORRELATIONS BETWEEN *LEPIDIUM* COVER AND COVER OF OTHER DOMINANT PLANT SPECIES, OVERALL AND BY BAY: ASSOCIATIONS WITH OTHER PLANT SPECIES. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

Sign of Pearson's correlation coefficient (r) and associated P -value are shown. Variables where $P > 0.2$ are marked NS. Sample sizes shown are a range, due to some missing values for some variables.

Local scale habitat variable	All Bays		San Pablo Bay		Suisun Bay		San Francisco Bay	
Sample size	331-410		174-199		82-91		75-120	
	r	P	r	P	r	P	r	P
PERCENT COVER PLANT SPECIES:								
<i>Baccharis pilularis</i>	+ 0.156	0.002	+ 0.128	0.063		NS		NS
<i>Distichlis spicata</i>	- 0.067	0.176	- 0.113	0.093	- 0.173	0.102		NS
<i>Feonicum vulgare</i>		NS	+ 0.125	0.062		NS		NS
<i>Frankenia salina</i>	- 0.001	0.026	- 0.100	0.137		NS		NS
<i>Grindelia stricta</i>	- 0.083	0.095		NS		NS	+ 0.144	0.068
<i>Juncus spp.</i>	+ 0.124	0.012		NS		NS		Absent
<i>Phragmites australis</i>		NS		NS		NS		Absent

Local scale habitat variable	All Bays		San Pablo Bay		Suisun Bay		San Francisco Bay
<i>Salicornia virginica</i>	- 0.303	< 0.001	- 0.133	0.048	- 0.155	0.143	NS
All <i>Scirpus</i> species	+ 0.098	0.047		NS		NS	NS
<i>Scirpus acutus/californicus</i>	+ 0.100	0.043		NS		NS	NS
<i>Scirpus americanus</i>	+ 0.188	< 0.001		NS		NS	Absent
<i>Scirpus maritimus</i>		NS		NS		NS	NS
<i>Spartina alterniflora</i>		NS	Absent			Absent	NS
<i>Spartina foliosa</i>	- 0.052	0.294		NS		Absent	NS
All <i>Spartina</i> spp.	- 0.115	0.020		NS		NS	NS
<i>Typha</i> spp.	+ 0.114	0.021		NS		NS	Absent

TABLE 8B. CORRELATIONS BETWEEN *LEPIDIUM* COVER AND OTHER LOCAL SCALE HABITAT VARIABLES, BY BAY. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

Sign of Pearson's correlation coefficient (r) and associated P -value are shown. Variables where $P > 0.2$ are marked NS. Sample sizes shown are a range, due to some missing values for some variables.

Local scale habitat variable	All Bays		San Pablo Bay		Suisun Bay		San Francisco Bay	
Sample size	331-410		174-199		82-91		75-120	
	r	P	r	P	r	P	r	P
Vegetation species richness ^a	+ 0.178	< 0.001	+ 0.087	0.199		NS	+ 0.190	0.016
Vegetation species diversity ^a	+ 0.282	< 0.001	+ 0.262	< 0.001		NS	+ 0.130	0.101
% marsh habitat	+ 0.115	0.020	+ 0.086	0.203		NS	+ 0.102	0.199
% shrub cover ^a		NS		NS		NS	+ 0.142	0.073
% total vegetation cover ^a		NS		NS	- 0.240	0.022		NS
% pond/panne cover		NS		NS		NS		NS
% channel cover ^a		NS		NS	+ 0.339	0.001		NS
% drift cover		NS		NS		NS		NS
% bare ground	+ 0.120	0.027	+ 0.096	0.155		NS		NS
Distance to closest channel ^a		NS		NS		NS		NS

Local scale habitat variable	All Bays	San Pablo Bay	Suisun Bay	San Francisco Bay			
Width of closest channel ^a	NS	+ 0.156	0.028	- 0.181	0.098	- 0.115	0.208
Channel density < 1m	NS	- 0.141	0.053		NS		NS
Channel density < 2m	NS	- 0.156	0.031		NS		NS
Channel density > 2m	NS		NS		NS	+ 0.178	0.121
Number of stems at							
Under 10 cm	- 0.080	0.126	- 0.169	0.012		NS	NS
10-20 cm		NS	- 0.202	0.002	+ 0.144	0.175	NS
20-30 cm	+ 0.067	0.120	- 0.125	0.063		NS	NS
Under 30 cm ^a		NS	- 0.217	0.001		NS	NS
Over 30 cm	+ 0.240	< 0.001		NS		NS	NS
30-40 cm	+ 0.163	0.003		NS		NS	NS
40-50 cm	+ 0.279	< 0.001	+ 0.295	< 0.001		NS	NS
50-60 cm	+ 0.283	< 0.001	+ 0.266	< 0.001		NS	NS
60-100 cm ^a	+ 0.356	< 0.001	+ 0.144	0.044	+ 0.175	0.115	NS
Over 100 cm	+ 0.071	0.195		Ns		NS	NS
Total number of stems ^a	+ 0.123	0.019	- 0.165	0.014	+ 0.145	0.173	NS

^a Potentially confounding local habitat variable selected for multiple-variable regression analyses.

TABLE 9. CORRELATIONS BETWEEN *LEPIDIUM* COVER AND LANDSCAPE LEVEL HABITAT VARIABLES. POINT COUNT STATIONS. SAN FRANCISCO ESTUARY. 2000-2001.

Sign of Pearson's correlation coefficient (r) and associated P value are shown. Variables where $P > 0.2$ are marked NS; exceptions include key variables that are tested elsewhere.

Landscape level variable	r	P
Distance to nearest water edge	0.313	<0.001
Distance to nearest non-marsh edge		0.846
Distance to nearest upland edge	- 0.149	0.003
Distance to nearest urban edge	- 0.098	0.051
Percent tidal and muted marsh within 1000 m	0.131	0.009
Percent non-tidal wetland within 1000 m		0.384
Percent urban (as defined by each of the three data sources used) within 1000 m		0.723
Percent agriculture (as defined by each of the three data sources used) within 1000 m	0.137	0.006
Percent natural upland within 1000 m	0.305	< 0.001
Percent all natural habitat (wetlands and uplands) within 1000 m	0.222	< 0.001

TABLE 10. EXAMINATION OF A QUADRATIC MODEL FOR THE RELATIONSHIP BETWEEN BIRD METRICS AND *LEPIDIUM*. POINT COUNT AND BLACK RAIL SURVEY DATA. SAN FRANCISCO ESTUARY. 2000-2001.

Bird Species Index	Quadratic $a \text{ Lepidium}^2 + b \text{ Lepidium} + c$
Song Sparrow ^a	$a = - 2.16 \pm 2.15; P > 0.3$
Common Yellowthroat ^b	$a = + 5.21 \pm 24.26; P > 0.8$
Marsh Wren ^a	$a = - 0.79 \pm 2.33; P > 0.7$
Black Wren ^b	$a = - 12.55 \pm 10.32; P = 0.17$
Species Richness ^a	$a = - 0.45 \pm 3.81; P > 0.9$
Species Diversity ^a	$a = + 0.12 \pm 1.28; P > 0.9$

^a Linear regression results

^b Logistic regression results; likelihood-ratio *P*-value

TABLE 11. RELATIONSHIP BETWEEN *LEPIDIUM* COVER (LOG *LEPIDIUM*) AND BIRD ABUNDANCE OR PRESENCE AT BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY, 2000-2001. Summary of regression analysis results. Each model was run separately. Log *Lepidium* was run with Bay (column 3) and with Marsh as a categorical variable (column 5). *P*-values are shown for β coefficients; sign and value of coefficients is shown for continuous variables, and for categorical variables where significant. Partial R^2 values are shown where calculable, and likelihood ratio test *P*-statistics are shown for variables in logistic models, except where indicated as Wald's *P*. Bay**Lepidium* interactions are explored in Table 12.

	Bay only	<i>Lepidium</i> & Bay	Bay* <i>Lepidium</i> interactions	<i>Lepidium</i> & Marsh ₃
		LELA:+ 0.10; <i>P</i> = 0.048 Partial $R^2 < 0.001$		LELA: + 0.17, <i>P</i> = 0.001 Partial $R^2 = 0.010$
Song Sparrow ^a	Overall: <i>P</i> < 0.001 $R^2 = 0.041$ N = 421	Bay: <i>P</i> = 0.001 Partial $R^2 = 0.034$	<i>P</i> = 0.001 N = 403	Marsh: <i>P</i> < 0.001 Partial $R^2 = 0.537$
		Model $R^2 = 0.040$ N = 403		Model $R^2 = 0.534$ N = 403
		LELA: + 0.643, LRT <i>P</i> = 0.002 Partial $R^2 = 0.020$		LELA: +1.83, Wald's <i>P</i> = 0.003
Common Yellowthroat ^b	LRT <i>P</i> < 0.001 $R^2 = 0.294$ N = 421	Bay: <i>P</i> < 0.001 Partial $R^2 = 0.062$	<i>P</i> = 0.001 N = 403	Marsh: <i>P</i> < 0.001
		Model pseudo- $R^2 = 0.314$ N = 403		Model pseudo- $R^2 = 0.291$ N = 172

	Bay only	<i>Lepidium</i> & Bay	Bay* <i>Lepidium</i> interactions	<i>Lepidium</i> & Marsh ₃
Marsh Wren ^a		LELA: $P > 0.4$ Partial $R^2 < 0.001$		LELA: -0.10 , $P = 0.073$ Partial $R^2 = 0.01$
	overall $P < 0.001$ $R^2 = 0.167$ N = 421	Bay : $P < 0.001$ Partial $R^2 = 0.129$	$P = 0.220$ N = 403	Marsh: $P < 0.001$ Partial $R^2 = 0.605$
		Model $R^2 = 0.166$ N = 403		Model $R^2 = 0.642$ N = 403
		LELA: $P = 0.636$ Partial $R^2 < 0.001$		LELA: Wald's $P = 0.507$
Black Rail ^b	LRT $P > 0.4$ Model pseudo- $R^2 = 0.002$ N = 209	Bay: LRT $P = 0.244$ Partial $R^2 = 0.005$	LRT $P = 0.388$ N = 145	Marsh: $P > 0.5$ Partial $R^2 = 0.002$
		Model pseudo- $R^2 = 0.005$ N = 186		Pseudo $R^2 = 0.108$ N = 165
		LELA: $+0.142$, $P = 0.102$ Partial $R^2 = 0.044$		LELA: $P > 0.9$ Partial $R^2 < 0.001$
Overall species richness ^a	overall $P < 0.001$ $R^2 = 0.172$ N = 421	Bay: $P < 0.001$ Partial $R^2 = 0.157$	$P = 0.264$ N = 403	Marsh: $P < 0.001$ Partial $R^2 = 0.597$

	Bay only	<i>Lepidium</i> & Bay	Bay* <i>Lepidium</i> interactions	<i>Lepidium</i> & Marsh ₃
		Model R ² = 0.220 N = 403		Model R ² = 0.659 N = 403
		LELA: + 0.04, <i>P</i> = 0.235 Partial R ² = 0.061		LELA: <i>P</i> > 0.4 Partial R ² = 0.008
Shannon Diversity Index ^a	overall <i>P</i> < 0.001 R ² = 0.202 N = 421	Bay: <i>P</i> < 0.001 Partial R ² = 0.188	<i>P</i> = 0.133 N = 403	Marsh: <i>P</i> < 0.001 Partial R ² = 0.642
		Model R ² = 0.238 N = 403		Model R ² = 0.697 N = 403

^a Linear regression P-value; ^b Logistic regression; likelihood-ratio *P*-value

TABLE 12. RELATIONSHIP BETWEEN LOG *LEPIDIUM* COVER AND BIRD ABUNDANCE OR PRESENCE, BY BAY. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

Summary of regression analysis results. Regression coefficient and *P*-value are shown. For regression models where the *P*-value for *Lepidium* ≤ 0.30 , variable coefficients and model R^2 values (general linear models) or pseudo- R^2 values (logistic regressions) are shown.

	San Pablo Bay	Suisun Bay	San Francisco Bay
Song Sparrow ^a	- 0.053, <i>P</i> > 0.4 $R^2 = 0.003$	+ 0.21, <i>P</i> = 0.001 $R^2 = 0.152$	+ 0.86, <i>P</i> = 0.012 $R^2 = 0.052$
Common Yellowthroat ^b	+ 0.40, <i>P</i> = 0.122 Pseudo $R^2 = 0.012$	+ 2.04, <i>P</i> = 0.012 Pseudo $R^2 = 0.183$	Insufficient data
Marsh Wren ^a	+ 0.132, <i>P</i> = 0.115 $R^2 = 0.013$	<i>P</i> > 0.3 $R^2 = 0.009$	<i>P</i> > 0.9 $R^2 < 0.001$
Black Rail ^b	<i>P</i> > 0.6 Pseudo $R^2 = 0.001$	<i>P</i> > 0.3 Pseudo $R^2 = 0.010$	No data
Overall Species Richness ^a	+ 0.232, <i>P</i> = 0.085 $R^2 = 0.010$	+ 0.089, <i>P</i> = 0.29 $R^2 = 0.013$	- 0.622, <i>P</i> = 0.28 $R^2 = 0.010$
Shannon Diversity Index ^a	+ 0.080, <i>P</i> = 0.082 $R^2 = 0.016$	<i>P</i> > 0.9 $R^2 = 0.001$	- 0.222, <i>P</i> = 0.22 $R^2 = 0.013$

^a Linear regression results ^b Logistic regression results

TABLE 13A. RELATIONSHIP BETWEEN LOG *LEPIDIUM* COVER AND BIRD ABUNDANCE OR PRESENCE, BY BAY, WHILE CONTROLLING FOR OTHER HABITAT VARIABLES. FINAL LOCAL HABITAT SCALE MODELS. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

We developed the best-fitting model for each bird metric containing log-*Lepidium*, Bay and ten additional local scale variables using backwards step-wise regression models (see text). We tested for interactions between *Lepidium* and Bay. We show the coefficient and *P*-values for the final significant variables and the partial R^2 for each; for logistic models we show likelihood-ratio test *P*-values.

Variable	Song Sparrow ^a		Marsh Wren ^a		Common Yellowthroat presence ^b		Black Rail presence ^b	
R^2 (1) / Pseudo R^2 (2)	0.170		0.280		0.412		0.080	
	β Coefficient <i>P</i>	Partial R^2	β Coefficient <i>P</i>	Partial R^2	β Coefficient <i>P</i>	Partial R^2	β Coefficient <i>P</i>	Partial R^2
Log (percent cover <i>Lepidium</i>):	$\beta = + 0.082$ <i>P</i> = 0.079	0.007	$\beta = + 0.048$ <i>P</i> = 0.361 ^c	0.002	$\beta = + 0.610$ <i>P</i> = 0.009	0.016	$\beta = + 0.395$ <i>P</i> = 0.130	0.010
Vegetation species richness	NS		NS		$\beta = + 1.550$ <i>P</i> = 0.032	0.011	NS	
Vegetation species diversity	NS		NS		$\beta = - 0.179$ <i>P</i> = 0.009	0.016	NS	
% shrub cover	$\beta = + 0.035$ <i>P</i> < 0.001	0.082	NS		$\beta = + 0.085$ <i>P</i> = 0.004	0.020	$\beta = + 0.075$ <i>P</i> = 0.028	0.211
% total vegetation cover	$\beta = + 0.005$ <i>P</i> < 0.001	0.027	$\beta = + 0.005$ <i>P</i> = 0.012	0.015	NS		$\beta = + 0.072$ <i>P</i> < 0.001	0.053
% channel cover	NS		NS		$\beta = - 0.062$ <i>P</i> = 0.001	0.032	NS	
Distance to closest channel	NS		$\beta = - 0.004$ <i>P</i> = 0.002	0.022	$\beta = - 0.023$ <i>P</i> = 0.003	0.037	$\beta = - 0.018$ <i>P</i> = 0.055	0.025

Variable	Song Sparrow ^a		Marsh Wren ^a		Common Yellowthroat presence ^b		Black Rail presence ^b	
Width of closest channel	NS		$\beta = + 0.013$ $P = 0.007$	0.007	NS		NS	
Number of stems under 30 cm	NS		$\beta = - 0.114$ $P < 0.001$	0.079	NS		NS	
Number of stems over 30 cm	$\beta = + 0.042$ $P = 0.003$	0.045	NS		$\beta = + 0.284$ $P < 0.001$	0.045	NS	
Total number of stems	NS		$\beta = + 0.070$ $P < 0.001$	0.045	NS		NS	
Bay	$P < 0.001$	0.038	$P = 0.013$	0.021	$P < 0.001$	0.070	$P = 0.452$	0.003
Significant interactions	Lepidium * Bay $P = 0.024$ Slopes: SF: + 0.392 SP: + 0.129 SU: + 0.194		NONE		Lepidium * Bay $P = 0.001$ Slopes: SF: ^d SP: + 0.419 SU: + 3.020		NONE	
Sample size	N = 364		N = 315		N = 329		N = 168	

^a Linear regression results

^b Logistic regression results

^c Model without log-*Lepidium*: this is the best-fitting model and retains all other variables shown here.

^d Slope for San Francisco Bay interaction with *Lepidium* could not be calculated for Common Yellowthroat limitations of logistic regression;; absence of *Lepidium* predicted absence of Common Yellowthroats perfectly.

TABLE 13B. RELATIONSHIP BETWEEN LOG *LEPIDIUM* COVER AND BIRD ABUNDANCE OR PRESENCE, BY BAY, WHILE CONTROLLING FOR OTHER HABITAT VARIABLES. FINAL LOCAL HABITAT SCALE MODELS. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

We developed the best-fitting model for each bird metric containing log-*Lepidium*, Bay and ten additional local scale variables using backwards step-wise regression models (see text). We tested for interactions between *Lepidium* and Bay. We show the coefficient and *P*-values for the final significant variables and the partial R^2 for each; for logistic models we show likelihood-ratio test *P*-values.

Variable	Bird species richness ^a		Bird Species diversity ^a	
R ² (1) / Pseudo R ² (2)	0.242		0.289	
	β Coefficient	Partial R ²	β Coefficient	Partial R ²
	<i>P</i>		<i>P</i>	
Log (percent cover <i>Lepidium</i>):	$\beta = + 0.074$	0.001	$\beta = + 0.003$	< 0.001
	<i>P</i> = 0.400 ₃		<i>P</i> = 0.920 ₃	
Vegetation species richness	NS		NS	
Vegetation species diversity	$\beta = + 0.408$	0.022	$\beta = + 0.186$	0.033
	<i>P</i> = 0.001		<i>P</i> > 0.001	
% shrub cover	NS		$\beta = -0.010$	0.015
			<i>P</i> = 0.009	

Variable	Bird species richness ^a		Bird Species diversity ^a	
% total vegetation cover	NS		NS	
% channel cover	NS		NS	
Distance to closest channel	NS		NS	
Width of closest channel	NS		NS	
Number of stems under 30 cm	NS		$\beta = -0.014$	0.021
			$P = 0.009$	
Number of stems over 30 cm	NS		NS	
Total number of stems	NS		NS	
Bay	$P < 0.001$	0.072	$P > 0.001$	0.062
Significant interactions	NONE		NONE	
Sample size	N = 403		N = 360	

^a Linear regression results

^b Logistic regression results

TABLE 14. AMONG-MARSH RELATIONSHIP BETWEEN *LEPIDIUM* COVER (LOG *LEPIDIUM*) AND BIRD ABUNDANCE OR PRESENCE. BIRD SURVEY POINTS. SAN FRANCISCO ESTUARY. 2000-2001.

Summary of regression analysis results. These models were run with a database of the mean values for each marsh of the dependent variables (bird metric) and independent variable (*Lepidium*). Each model was run separately. *Lepidium* was run alone (column 2), and with Bay (column 3). *P*-values are shown for β coefficients. Likelihood ratio statistics are shown for variables in logistic models. For Common Yellowthroat, there was no variability in presence in Suisun Bay (i.e. birds were present at all sites) so Suisun Bay was excluded from the analysis.

	Bay only	Log <i>Lepidium</i> & Bay
		<i>Lepidium</i> : + 0.27; <i>P</i> = 0.139
		Partial $R^2 < 0.015$
Song Sparrow Mean ^a	<i>P</i> > 0.2 $R^2 = 0.048$	Bay: <i>P</i> = 0.231 Partial $R^2 = 0.019$
		Model $R^2 = 0.080$
		<i>Lepidium</i> : + 0.339, <i>P</i> > 0.2
		Partial $R^2 = 0.024$
Common Yellowthroat ^b	<i>P</i> = 0.004 Pseudo- $R^2 = 0.105$	Bay: <i>P</i> = 0.212 Partial $R^2 = 0.028$
		Model pseudo- $R^2 = 0.039$

	Bay only	Log <i>Lepidium</i> & Bay
		<i>Lepidium</i> : $P > 0.6$ Partial $R^2 < 0.001$
Marsh Wren mean ^a	$P = 0.001$ $R^2 = 0.224$	Bay : $P = 0.008$ Partial $R^2 = 0.0588$ Model $R^2 = 0.222$
		<i>Lepidium</i> : $P > 0.7$ Partial $R^2 = 0.005$
Black Rail ^b	$P = 0.36$ pseudo- $R^2 = 0.033$	Bay: $P > 0.5$ Partial $R^2 = 0.014$ Model pseudo- $R^2 = 0.038$
		<i>Lepidium</i> : $P > 0.8$ Partial $R^2 = 0.040$
Mean Overall species richness ^a	$P < 0.001$ $R^2 = 0.229$	Bay: $P = 0.001$ Partial $R^2 = 0.214$ Model $R^2 = 0.269$

	Bay only	Log <i>Lepidium</i> & Bay
		<i>Lepidium</i> : $P > 0.8$
		Partial $R^2 = 0.028$
Mean Shannon Diversity Index ^a	$P = 0.002$ $R^2 = 0.268$	Bay: $P = 0.003$ Partial $R^2 = 0.255$
		Model $R^2 = 0.296$

^a Linear regression P -value; ^b Logistic regression P -value.

TABLE 15. PEARSON PAIRWISE CORRELATIONS BETWEEN *LEPIDIUM* PRESENCE OR ABSENCE IN SONG SPARROW NEST SUBSTRATE AND NEST SITE CHARACTERISTICS, INCLUDING HABITAT STRUCTURAL VARIABLES AND NEST INITIATION DATE. SAN PABLO AND SUISUN SITES. SAN FRANCISCO ESTUARY. 1996-2003.

Nest characteristics	Correlation coefficient (r)	P-value
Mean nest concealment	+ 0.039	0.050
Distance to closest channel	+ 0.012	0.610
Width of closest channel	+ 0.026	0.269
Height of nest from ground	+ 0.157	< 0.001
Number of nest support branches	- 0.044	0.037
Plant substrate height	+ 0.081	< 0.001
Nest clump height	+ 0.080	< 0.001
Distance to clump edge	+ 0.166	< 0.001
Clump length	+ 0.105	< 0.001
Clump width	+ 0.080	< 0.001
Clutch completion date	+ 0.106	< 0.001

TABLE 16. IMPACT OF *LEPIDIUM* ON SONG SPARROW NEST SUCCESS. SAN PABLO AND SUISUN BAY. SAN FRANCISCO ESTUARY. 1996-2003.

Results are from logistic regression analyses, looking first at the effects of *Lepidium* alone and then controlling for year and marsh site. β values are for logistic regression coefficients. Likelihood ratio P -values shown.

Reproductive success metric	<i>Lepidium</i> alone	<i>Lepidium</i> , year, and site
Overall nest success	$\beta = -0.135, P > 0.48$ Model Pseudo $-R^2 < 0.001$	<i>Lepidium</i> : $\beta = 0.075, P > 0.7$; partial $R^2 < 0.001$ Year: $P < 0.001$; partial $R^2 = 0.141$ Site: $P = 0.001$; partial $R^2 = 0.006$ Overall Pseudo $-R^2 = 0.019$
Nest failure due to depredation	$\beta = 0.381, P = 0.037$ Model Pseudo $-R^2 = 0.001$	<i>Lepidium</i> : $\beta = -0.095, P > 0.6$; partial $R^2 < 0.001$; Year: $P < 0.001$; partial $R^2 = 0.141$ Site: $P < 0.001$; partial $R^2 = 0.016$ Overall Pseudo $-R^2 = 0.039$
Nest failure due to flooding	$\beta = -2.29, P = 0.023$ Model Pseudo $-R^2 = 0.012$	<i>Lepidium</i> : $\beta = -0.926, P > 0.3$; partial $R^2 < 0.001$ Year: $P < 0.001$; partial $R^2 = 0.088$ Site: $P = 0.001$; partial $R^2 = 0.049$ Overall Pseudo $-R^2 = 0.168$

TABLE 17. IMPACT OF *LEPIDIUM* ON SONG SPARROW NEST SUCCESS WHILE CONTROLLING FOR LOCAL HABITAT VARIABLES. SAN PABLO AND SUISUN BAY. SAN FRANCISCO ESTUARY. 1996-2003.

Results are from logistic regression analyses including *Lepidium* and other local habitat variables. β and likelihood ratio test P values in first column for each model are for logistic regression coefficients.

	Overall nest success		Nest failed due to depredation		Nest failed due to flooding	
Full model Pseudo R ²	0.057		0.066		0.282	
	β Coefficient P	Partial R ²	β Coefficient P	Partial R ²	β Coefficient P	Partial R ²
Lepidium substrate or cover	$\beta = -0.085$ $P = 0.744$	Partial R ² < 0.001	$\beta = -0.047$ $P = 0.852$	Partial R ² < 0.001	$\beta = -0.929$ $P = 0.337$	$P = 0.337$ Partial R ² = 0.001
Mean nest concealment	NS		NS		NS	
Distance to closest channel	$\beta = +0.023$ $P < 0.001$	Partial R ² = 0.051	$\beta = -0.014$ $P = 0.016$	Partial R ² = 0.003	NS	
Width of closest channel	NS		NS		NS	
Height of nest from ground	NS		$\beta = +0.012$ $P = 0.008$	Partial R ² = 0.002	$\beta = -0.071$ $P < 0.001$	Partial R ² = 0.033
Plant substrate height	NS		$\beta = +0.005$ $P = 0.013$	Partial R ² = 0.003	$\beta = -0.017$ $P < 0.001$	Partial R ² = 0.013
Nest clump height	NS		NS		NS	

	Overall nest success		Nest failed due to depredation		Nest failed due to flooding	
Full model Pseudo R ²	0.057		0.066		0.282	
	β Coefficient <i>P</i>	Partial R ²	β Coefficient <i>P</i>	Partial R ²	β Coefficient <i>P</i>	Partial R ²
Clutch completion date	$\beta = -0.015$ $P < 0.001$	Partial R ² = 0.028	$\beta = +0.010$ $P < 0.001$	Partial R ² = 0.013	$\beta = +0.017$ $P < 0.001$	Partial R ² = 0.022
Year	$P < 0.001$	Partial R ² = 0.023	$P < 0.001$	Partial R ² = 0.019		Partial R ² = 0.095
Site	$P = 0.174$	Partial R ² = 0.003	$P = 0.031$	Partial R ² = 0.005	$P < 0.001$	Partial R ² = 0.033

TABLE 18. EFFECTS OF *LEPIDIUM* AND DISTANCE TO NEAREST CHANNEL ON SONG SPARROW TERRITORY DENSITY, RUSH RANCH, SUISUN BAY. 2002.

Model	Regression coefficient	<i>P</i> -value	Partial R ²	Model R ²
Percent <i>Lepidium</i> cover	- 8.87	0.019	-	0.070
Distance to channel	+ 0.13	0.4	-	0.008
<i>Lepidium</i> and distance to channel	<i>Lepidium</i> : - 8.61	0.027	0.063	0.071
	Distance: 0.05	0.8	0.001	