

Building a Habitat Conversion Model for San Francisco Bay Wetlands: A Multi-Species Approach for Integrating GIS and Field Data¹

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Abstract

More than 80 percent of San Francisco Bay's original tidal wetlands have been altered or displaced, reducing available habitat for a range of tidal marsh-dependent species, including the Federally listed California Clapper Rail (*Rallus longirostris obsoletus*) and three endemic Song Sparrow (*Melospiza melodia*) subspecies. In the South Bay, many tidal marshes were converted to commercial salt ponds, which have since become among the most important Pacific coast sites for shorebirds, waterfowl and other waterbirds. Recently, however, over 6,000 ha of commercial salt ponds were sold to wildlife management agencies for creation and restoration of tidal marsh systems, which will result in a significant change in the Bay's wetland landscape. This situation creates a need to evaluate the interrelated and potentially conflicting habitat needs of a wide range of species, in order to inform priorities for wetland restoration and management. Using a combination of standardized bird survey protocols, GIS habitat mapping, statistical modeling and simulation, PRBO is developing the first iteration of a "habitat conversion model." The goal of this project is to identify the key relationships between habitat features and bird distributions, develop models to predict bird community changes that accompany habitat conversion and disseminate results to other scientists and land managers.

Key words: habitat restoration, salt ponds, San Francisco Bay, tidal marsh, waterbirds.

Introduction

Since the mid-19th century, > 80 percent of original tidal marsh as well as large amounts of mudflats, seasonal wetlands, and upland habitats in the San Francisco Bay have been lost due to human development (Goals Project 1999). In the southern San Francisco Bay (South Bay), almost 15,000 ha of historic tidal marsh were converted to commercial salt evaporation ponds, primarily from the 1930s through

the 1950s (Goals Project 1999, Josselyn 1983; *fig. 1*).

Historically, natural salt pannes were an integral component of the tidal marshes in San Francisco Bay (Goals Project 1999), and along with seasonal wetlands, presumably provided important wintering and breeding habitat for waterbirds. Thus, for many species, commercial salt evaporation ponds have filled a habitat void left by displaced natural salt pannes and loss of tidal mudflats. Today the San Francisco Bay salt pond complex is one of the most important Pacific coast sites for waterbirds, hosting millions of wintering and breeding birds annually (Accurso 1992, Page et al. 1999, Takekawa et al. 1988 and 2001, Warnock et al. 2002). However, the dramatic displacement of natural wetlands has reduced available habitat for a range of tidal marsh-dependent bird species, including three endemic Song Sparrow subspecies (*Melospiza melodia pusillula*, *M. m. samuelis*, *M. m. maxillaris*) (Marshall and Dedrick 1994), the Salt Marsh Common Yellowthroat (*Geothlypis trichas sinuosa*), and the Federally listed California Clapper Rail (*Rallus longirostris obsoletus*) (Albertson and Evens 2001), as well as plants and other animals.

The San Francisco Bay Habitat Goals Report (Goals Project 1999) and Save the Bay (2002) have recommended a threefold increase in South Bay tidal marsh habitat (from 3,500 to 10-11,000 ha) to improve the quality, extent and connectivity of natural wetland systems and protect populations of threatened marsh-dependent species. Thus, as commercial salt production becomes less economical and regulatory pressures lead to more tidal marsh restoration and mitigation, salt evaporation ponds are being sold to wildlife management agencies and non-governmental organizations (NGOs) for tidal marsh restoration and creation projects. In March of 2003, Cargill Salt, which operates the South Bay salt ponds, sold nearly 6,500 ha of salt ponds in the South Bay to the State of California and the federal government. The cost of restoring and managing these salt pond areas has been estimated to range from \$314 million to more than \$1 billion, with initial annual costs of \$6.5 million to \$14 million (Siegel and Bachand 2002).

The addition of extensive areas of new tidal marsh will benefit a host of tidal marsh-dependent species. For some, it may make the difference between population extirpation and survival or recovery. However, there is a danger that the hundreds of thousands of birds and

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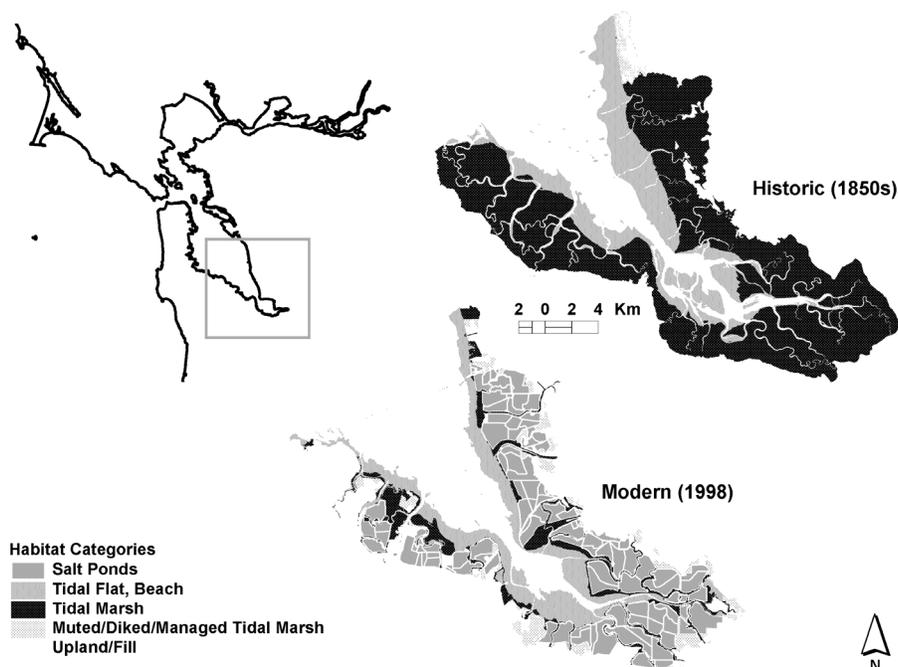


Figure 1— Change in south San Francisco bayland habitats, 1850 to present. Map source: San Francisco Estuary Institute EcoAtlas, v.1.50b4.

other wildlife that are now dependent on salt ponds will be negatively affected by this habitat conversion. Tidal marsh restoration and preservation of some existing commercial salt ponds are necessary to maintain or enhance current bird populations in the San Francisco Bay (Goals Project 1999). In addition, the creation of ponded areas within tidal marshes may improve habitat diversity and help maintain existing populations of waterbirds (Siegel and Bachand 2002). However, the size, location and physical attributes of salt ponds preferred by waterbirds, and the value to birds of natural salt ponds, channels and other features within variable tidal marsh habitat, are not well known. We have identified the need to quantify this variation and relate it to the differential use of tidal marsh by birds.

The goal of this project is to identify the key relationships between habitat features and bird distributions in tidal marshes and salt ponds, and develop models to predict bird community changes that accompany habitat conversion. Results of these models will then be made available to management agencies, the scientific community, conservation NGOs and partnerships such as the San Francisco Bay Joint Venture and California Partners in Flight.

Objectives

Using a combination of standardized bird survey protocols, GIS habitat mapping, statistical modeling and

simulation techniques, PRBO Conservation Science is working toward the development of a first generation *habitat conversion model* (HCM). Our goal is to develop a model that can be used to estimate the quantitative and qualitative effects of bayland habitat conversion on bird populations, initially with respect to tidal marsh and salt pond habitat, but eventually expanding to include tidal flats, bayland-adjacent uplands and non-tidal wetlands. Although bird numbers and distributions are driven by a variety of complex and difficult-to-quantify factors (Wiens 1992), we hope to characterize the sensitivity of avian communities to anticipated habitat changes within the South Bay. Even order-of-magnitude estimates and predictions of presence/absence throughout the South Bay may be helpful in planning and implementing large-scale habitat restoration projects.

Our objectives are:

1. To identify costs and benefits to birds of habitat conversion, as a result of salt pond loss and tidal marsh gain;
2. To develop a quantitative basis for guiding:
 - Design of restoration projects to maximize habitat potential (site level) and
 - Optimal ratio and configuration of tidal marshes and salt ponds (landscape level); and
3. To monitor and evaluate the cumulative effects of restoration on birds.

Model development will be an iterative process, allowing us to quickly disseminate preliminary results and predictions to managers. Following model evaluation and solicitation of peer review, we hope to be better able to incorporate the spatial and temporal dynamics of restoration, as well as demography and energetics of avian populations. We envision three phases, each building on and improving upon the previous phase:

- Phase 1 – static model predicting bird responses to restoration at pond/marsh level
- Phase 2 – spatially-explicit dynamic model incorporating change in restoration sites over time
- Phase 3 – mechanistic model incorporating demography and energetics of selected species

Phase 1 Methods

General steps for constructing a Phase 1 Habitat Conversion Model (HCM) can be summarized as follows: (1) conduct field surveys; (2) develop site- and landscape-level GIS maps; (3) identify model currency; (4) compare marsh and pond bird densities and diversity; (5) identify bird responses to habitat and landscape variation among ponds and among and within marshes; (6) develop integrated model; (7) predict bird loss/gain for specific

tidal marsh restoration scenarios; and (8) suggest optimal restoration configurations.

Field Surveys

From fall 1999 to spring 2001, we conducted monthly high- and low-tide surveys of selected accessible salt evaporation ponds and tidal marshes in the South Bay (fig. 2). Several marshes were highly modified and in some cases consisted of a linear strip surrounding a tidal channel (e.g., Ravenswood Slough). Although the historic extent of natural salt ponds is not well known, most study marshes lacked a natural configuration of ponds and salt pannes, with many ponded areas forming along roads and levees.

Salt pond and tidal marsh survey methods were standardized with respect to South Bay tidal conditions and survey period. Salt pond surveys were accompanied by water salinity samples (see Warnock et al. 2002 for complete description). Each bird observation was coded by behavior (e.g., foraging, roosting, flushing) and microhabitat category (e.g., salt pan, channel, man-made structure or vegetation within marshes; and island, mud, man-made structure or open water within salt ponds). Because visibility within the marsh was variable, we noted the distance of each bird to the observer and mapped the estimated visibility for each site.

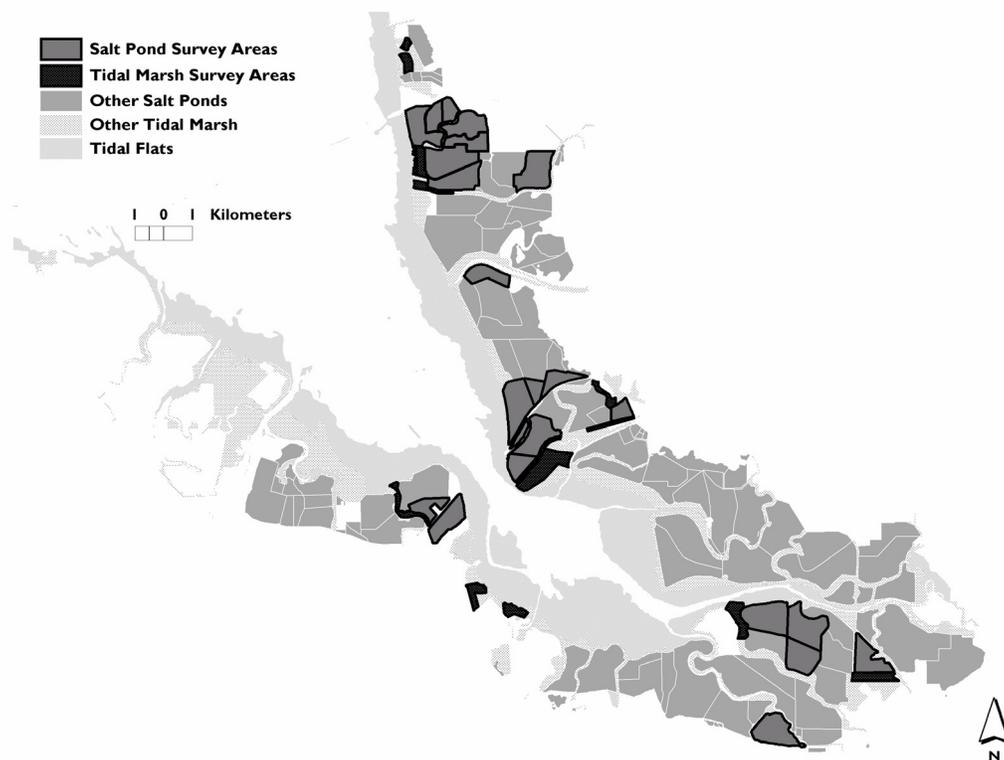


Figure 2— South San Francisco Bay tidal marsh and salt pond study sites (1999-2001). Map source: San Francisco Estuary Institute EcoAtlas, v.1.50b4.

We also conducted point-count surveys (Ralph et al. 1993) at 102 point-count stations in 14 tidal marshes. Point-count surveys are better suited for estimation of passerine densities, and may be used to quantify within-marsh variation in some species. Because they were conducted year 'round, they should allow us to estimate breeding, as well as winter density and diversity of tidal marsh birds. In addition to the data we collected, we sought ancillary breeding season data for the Federally-listed Clapper Rail and Western Snowy Plover (*Charadrius alexandrinus nivosus*), which are important target species for restoration and management.

GIS Mapping

Our initial comparison of tidal marsh and salt pond bird use has included a GIS-based analysis of site-level habitat characteristics, pond/marsh habitat configuration, and surrounding landscape characteristics.

For site-level comparisons of marsh study sites, we used large-scale (1:4800), high-resolution (0.5' pixels) color-infrared photos (flown at high tide in August 2001) to map channels and natural salt ponds within our tidal marsh study sites. We used ArcView's Image Analysis extension (ESRI 2000) to classify each photo into three basic landcover types: marsh vegetation, open water (ponds and channels) and upland (including levees). We then used ArcInfo 8.1 (ESRI 2001) to manually digitize ponds and channels, classify the channels by width category and classify the ponds as either tidal (connected to bay via channels) or ephemeral (not connected, only flooded at extreme tides).

For landscape metrics, we used a composite landuse GIS layer, comprised of data from the San Francisco Estuary Institute's EcoAtlas (1998), the U.S. Geological Survey's Midcontinent Ecological Science Center (USGS MESC 1985), and the National Oceanographic and Atmospheric Administration's Coastal Change and Analysis Program (NOAA C-CAP 1993). Within a 1-km radius of each site (pond and marsh), we used ArcView's Spatial Analyst extension (ESRI 1999) to calculate the percent marsh, salt pond, tidal flat, urban development and other upland land uses (fig. 3). We also calculated marsh/pond size, shape and isolation (distance to nearest pond/marsh), as well as distance to the open bay.

Model Currency

Given the wide range of potential management objectives, we did not attempt to prioritize or assign value to particular species or groups, but instead provide value-neutral predictions for a variety of species and guilds. Our approach is to combine the examination of densities of wetland-associated focal species (Lambeck

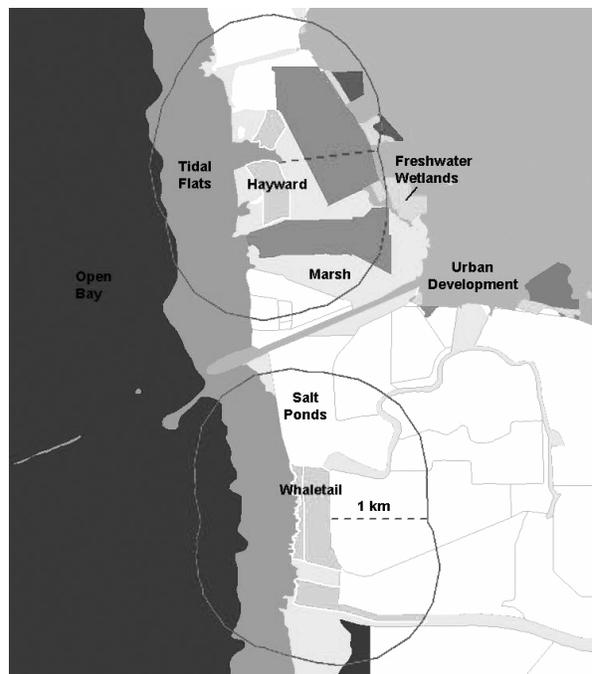


Figure 3— Sample calculation of landscape metrics for Whaletail Marsh and Hayward Regional Shoreline. Map source: San Francisco Estuary Institute EcoAtlas, v.1.50b4.

1997) and species groups, as well as overall species richness and diversity. Preliminary focal species and groups include:

Wintering Species Groups:

- Large shorebirds (Black-bellied Plover [*Pluvialis squatarola*] and larger)
- Small shorebirds
- Diving ducks
- Dabbling ducks and coots
- Eared Grebe (*Podiceps nigricollis*)
- Other grebes, pelicans and cormorants (fish-eaters)
- Gulls and terns
- Herons and egrets
- Landbirds
- Rails

Breeding Species:

- Song Sparrow
- Common Yellowthroat
- Clapper Rail

- American Avocet (*Recurvirostra americana*)
- Black-necked Stilt (*Himantopus mexicanus*)
- Snowy Plover.

Preliminary Marsh-Pond Waterbird Comparisons

During 2 years of surveys, we recorded 75 species of waterbirds at salt pond sites, with shorebirds being the most dominant group, followed by dabbling ducks and diving ducks (Warnock et al. 2002). Seventy-three non-passerine species were recorded at tidal marsh sites. Averaging across all winter surveys (Nov. to Feb.), we examined the differences between salt pond and tidal marsh densities of selected shorebird, waterfowl and seabird species, finding significant between-habitat differences (two-tailed T-tests, $P < 0.05$) for most species (figs. 4-6). While most waterbird species were more abundant in salt ponds than in tidal marsh, it is important to note that these comparisons do not include data from peak fall and spring migration periods (to be included in future analyses). Nor do they include tidal-marsh-dependent songbirds and rails, which are essentially absent from salt ponds.

Given the high variation in densities among salt pond and tidal marsh sites, however, we recognize that it is important to quantify the effects of this variation on bird communities in order to construct meaningful predictive models.

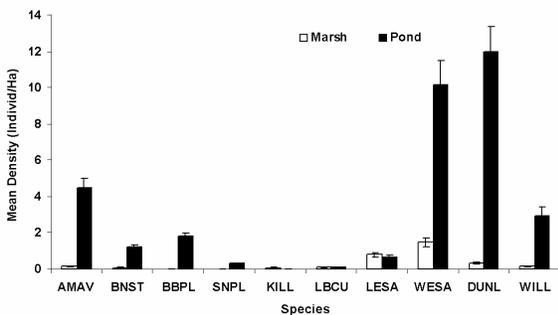


Figure 4— Mean (+/- SE) winter (Nov-Feb) densities for shorebird species, tidal marshes (N = 104 surveys) vs. salt ponds (N = 210 surveys). Mean pond densities significantly higher than mean marsh densities for all species examined except KILL, LBCU and LESA (two-tailed T-tests, $P < 0.05$). AMAV = American Avocet; BNST = Black-necked Stilt; BBPL = Black-bellied Plover (*Pluvialis squatarola*); SNPL = Snowy Plover; KILL = Killdeer (*Charadrius vociferous*); LBCU = Long-billed Curlew (*Numenius americanus*); LESA = Least Sandpiper (*C. minutilla*); WESA = Western Sandpiper (*C. mauri*); DUNL = Dunlin (*C. alpina*); WILL = Willet (*Catoptrophorus semipalmatus*).

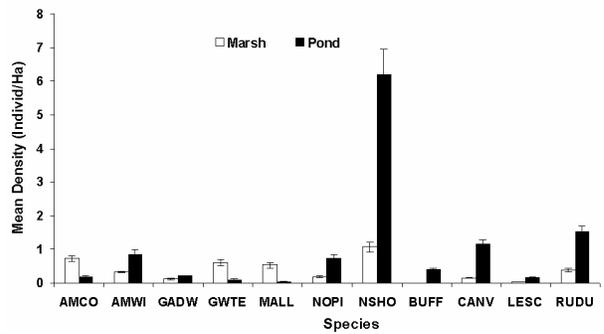


Figure 5— Mean (+/- SE) winter (Nov-Feb) densities for waterfowl species, tidal marshes (N = 104 surveys) vs. salt ponds (N = 210 surveys). Mean pond densities significantly higher than mean marsh densities for AMWI, NOPI, NSHO, BUFF, CANV, LESC and RUDU; mean marsh densities significantly higher for AMCO, GWTE and MALL (two-tailed T-tests, $P < 0.05$). AMCO = American Coot (*Fulica americana*); AMWI = American Wigeon (*Anas americana*); GWTE = Green-winged Teal (*A. crecca*); MALL = Mallard (*A. platyhynchos*); NOPI = Northern Pintail (*A. acuta*); NSHO = Northern Shoveler (*A. clypeata*); BUFF = Bufflehead (*Bucehalia clangula*); CANV = Canvasback (*Aythya valisineria*); LESC = Lesser Scaup (*A. affinis*); RUDU = Ruddy Duck (*Oxyura jamaicensis*).

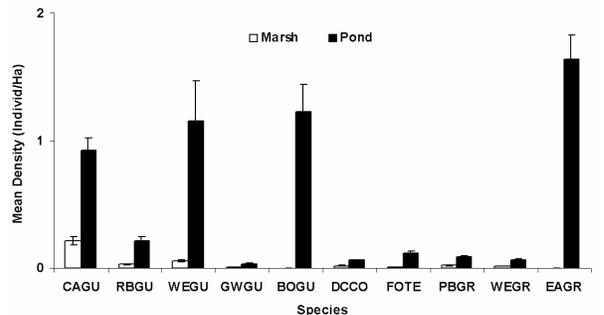


Figure 6— Mean (+/- SE) winter (Nov-Feb) densities for selected seabird species, tidal marshes (N = 104 surveys) vs. salt ponds (N = 210 surveys). Mean pond densities significantly higher than mean marsh densities for all species examined (two-tailed T-tests, $P < 0.05$). CAGU = California Gull (*Larus californicus*); RBGU = Ring-billed Gull (*L. delawarensis*); WEGU = Western Gull (*L. occidentalis*); GWGU = Glaucous-winged Gull (*L. glaucescens*); BOGU = Bonaparte's Gull (*L. philadelphia*); DCCO = Double-crested Cormorant (*Phalacrocorax auritus*); FOTE = Forster's Tern (*Sterna forsteri*); WEGR = Western Grebe (*Aechmophorus occidentalis*); PBGR = Pied-billed Grebe (*Podilymbus podiceps*); EAGR = Eared Grebe.

Bird Responses to Variation Among Ponds and Marshes

Our first objective in developing a habitat conversion model was to characterize variation in abundance and diversity of birds in the two habitat types in relation to site- and landscape-level features. Standardized bird densities and species diversity metrics were compared across ponds and marshes, accounting for differences

in pond depth and salinity, as well as marsh vegetation, channelization and pond characteristics. We also analyzed microhabitat use within tidal marshes, attempting to quantify the relative importance of channel vs. pond vs. marsh plain. These analyses are presently ongoing; preliminary results are presented here.

Salt ponds – preliminary results

Shorebirds and dabbling ducks were the most abundant groups of birds using the salt ponds. Shorebirds, in particular, responded to the tide cycle, with higher numbers using the ponds at high tide and lower numbers at low tide, and pond salinity was important for almost all groups examined (Warnock et al. 2002). Waterbird abundance and species richness were significantly affected by the salinity of ponds in a non-linear fashion with lower numbers of species predicted on the highest salinity ponds (*fig. 7*). For most groups examined, tide height at the Bay significantly affected bird numbers in the salt ponds with ponds at high tides having higher numbers of birds than the same ponds on low tides. Considerable numbers of birds fed in the salt ponds on high and low tides, although this varied greatly by species. Exposed moist soil around the perimeter of ponds was observed to be important for foraging, while islands in the ponds were important for roosting birds.

Tidal marsh – preliminary results

For tidal marsh species, we found significant associations between various landscape parameters and species richness summed over all surveys. For example, shorebird species richness was positively associated with the proportion of tidal mudflat habitat contained within 1 km of tidal marsh survey areas (*fig. 8*), but negatively associated with tidal marsh size (*fig. 9*), perhaps because the smaller marshes tended to be linear segments along major sloughs, whose mudflat edges attract large numbers of shorebirds (Spautz, pers. obs.). For site-level habitat characteristics, however, we found that individual species' responses differed among species and in some cases were inconsistent with the overall patterns demonstrated by species richness. We found that responses to channel and pond characteristics, as well as tide conditions, varied greatly among species (*table 1*).

Integrated Model Development

We plan to use existing field and GIS data sets to conduct a series of statistical analyses identifying important site- and landscape-level habitat parameters for wetland-associated bird species and guilds. Analyses will be conducted by species/guild, season (winter and breeding season) and general habitat type (salt pond and marsh). Statistical methods will primarily

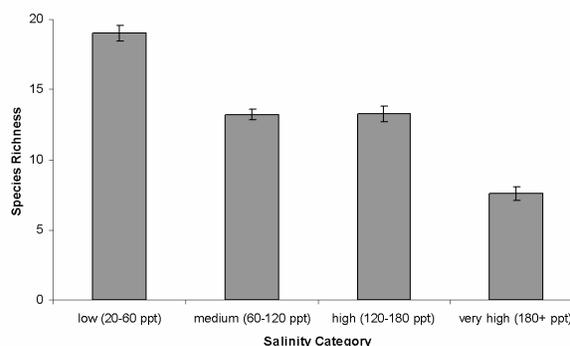


Figure 7— Species richness by salt pond salinity category (ppt) in south San Francisco Bay salt ponds, 1999 and 2000. Error bars represent standard errors of the mean for each salinity category.

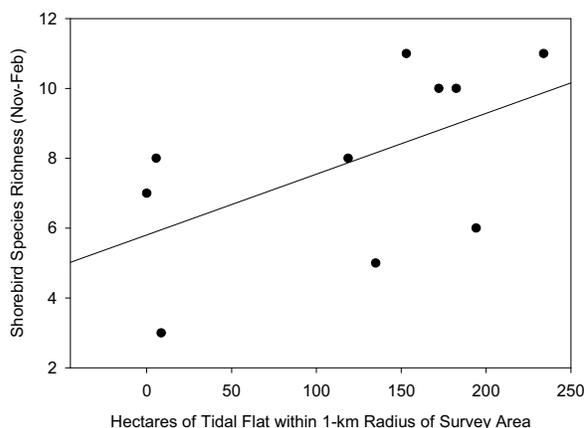


Figure 8— Winter (Nov. to Feb.) shorebird species richness vs. tidal flat area within 1 kilometer of tidal marsh study sites in South San Francisco Bay, 1999-2001.

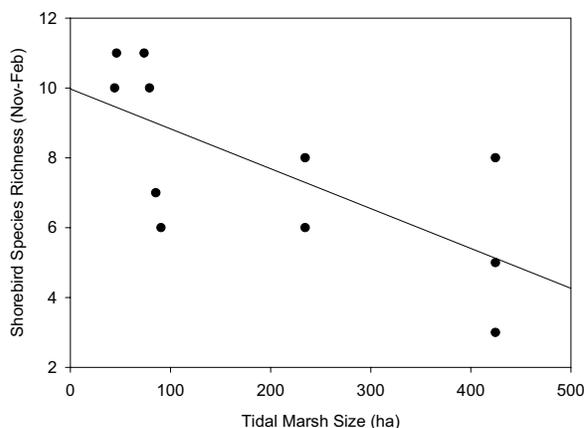


Figure 9— Winter (Nov. to Feb.) shorebird species richness vs. size of tidal marsh study sites in South San Francisco Bay, 1999-2001.

Table 1— Significant month, tide, and habitat associations for winter (Nov. to Feb.) densities of selected species surveyed in South San Francisco Bay tidal marshes. Significant terms in ANOVA models denoted by * ($P < 0.05$) or *** ($P < 0.001$). Direction of effect denoted by + or -.

	Northern Shoveler	Northern Pintail	American Avocet	Willet	Snowy Egret
Month			(*)		
Tide					(*)
Channel Density		- (*)			+ (*)
Pond Density	+ (***)				- (*)

consist of regression analysis with generalized linear models (GLM), and may also include multivariate techniques such as canonical correspondence analysis (CCA), classification and regression tree (CART) models, and spatial autocorrelation analysis. Results of statistical analyses will be combined with ancillary data sources, prior knowledge and information from relevant wetland ecology literature to develop an integrated (static) model predicting salt pond loss and tidal marsh gain (in terms of birds) for a range of restoration scenarios. The next objective is to use our integrated model to compare and quantify differences in the predicted distribution and abundance (including species richness) of bird populations under various management and restoration scenarios. Our model prediction efforts will be conducted at two scales of analysis: the site (pond/marsh) level and the regional landscape (South Bay) level. In the next phase of model development, we will seek out independent datasets to validate our integrated model, preferably from existing restoration projects.

Predicting Restoration Outcomes

Site level predictions

First we will select representative characteristics of several actual ponds proposed for restoration and, for each pond, develop a range of feasible tidal marsh outcomes. Assuming current land use conditions, we will present three or more alternative predicted outcomes, depending on ultimate tidal marsh conditions. We will make the simplifying assumption that tidal marsh habitat parameters can be designed and controlled, and that such a restoration marsh will function in the same way as an existing tidal marsh with the same parameters.

Model results for a range of restoration scenarios will be presented in tabular and graphical form (*fig. 10*), with model parameters specified. Restoration scenarios will be assumed to proceed from salt pond to marsh. Thus results will be expressed in terms of salt pond losses and tidal marsh gains for each hypothetical pond-to-marsh restoration. We will present results for multiple species and groups and refrain from assigning priorities to the species and groups modeled. The results for each species, however, will be evaluated in

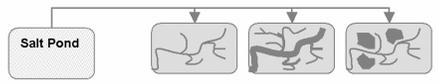
the context of its conservation status, population trends and the relative geographic importance of San Francisco Bay. To the extent possible, we will use the attributes of existing marshes as hypothetical restoration endpoints.

Landscape level predictions

The next step will be to look at restoration outcomes at the landscape or regional level, setting the stage for prioritization of prospective tidal marsh restoration sites. The product of this analysis will be spatially explicit, and presented in map format. We will develop a series of maps of South Bay ponds and marshes, representing the following conditions:

- Value of study salt ponds and marshes for selected species/groups
- Predicted salt pond loss and tidal marsh gain (current salt ponds only) for a range of restoration scenarios, varying by:
 - number and configuration of ponds restored to tidal marsh
 - type of tidal marsh restoration (based on site level predictions)
- At this stage, we will make the simplifying assumption that any pond can be restored to any tidal marsh condition, with respect to channel and pond configuration. We will not consider admittedly important issues such as elevation and level of subsidence, available sediment and seed source, and hydrologic constraints such as tidal exchange volume, effects of levees and freshwater inputs (see Siegel and Bachand 2002).

The next step will be to develop an algorithm for selecting optimal configurations of tidal marshes and salt ponds that satisfy a given conservation objective. A key part of this exercise is to identify the appropriate currency for a cost-benefit analysis. In addition, there is a need to derive spatially explicit optimal solutions. Potential methods include linear programming



		Alt. 1	Alt. 2	Alt. 3
	Salt Pond Loss		Tidal Marsh Gain	
Waterfowl				
Winter	W	X	Y	Z
Spring	.	.	.	.
Breeding	.	.	.	.
Shorebirds				
Winter	.	.	.	.
Spring	.	.	.	.
Breeding	.	.	.	.
Seabirds				
Winter	.	.	.	.
Spring	.	.	.	.
Breeding	.	.	.	.
Landbirds				
Winter	.	.	.	.
Spring	.	.	.	.
Breeding	.	.	.	.

Figure 10— Sample format for site-level tabular results of habitat conversion model predictions for three different restoration scenarios.

techniques (Hof and Bevers 2002, Nevo and Garcia 1996) as well as numerical simulation models, such as the Spatially-Explicit Species Index (DeAngelis et al. 1998) and Spatially-Explicit Simulated Annealing (Ball 2000). A simplified representation of a hypothetical optimization result is shown in *figure 11*.

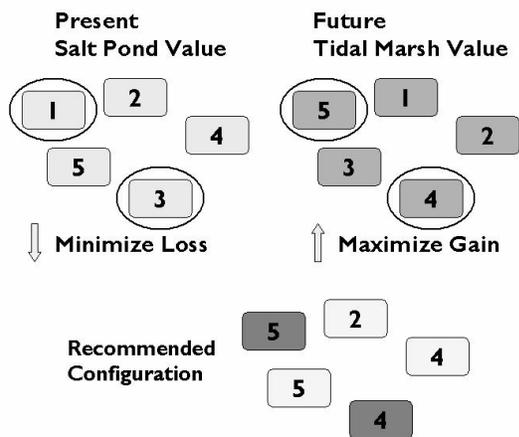


Figure 11— Simplified optimization scenario for salt pond to tidal marsh conversion. Squares represent hypothetical existing salt ponds and potential future tidal marshes with given predicted values for birds (1-5). The circled ponds and marshes represent those that would be identified as the best candidates for restoration. The recommended configuration below would provide the best overall value for birds, minimizing salt pond loss while simultaneously maximizing tidal marsh gain.

Future directions

For the first iteration, our modeling units will be discrete ponds and marshes, with habitat parameters such as sloughs and ponds aggregated at the marsh or pond level. However, future versions may include predic-

tions of intra-site variations in bird use, to the extent that our data capture specific habitat preferences of individual species. For example, it may be useful for modeling purposes to develop a layer of grid cells or hexagonal units for which important habitat, landscape and spatial proximity parameters could be determined using GIS data and aerial photos. Although additional field data may be needed, we hope to develop a spatially-explicit model and extrapolate bird distributions to a broader area.

Using GIS data to simulate real or hypothetical marsh/pond landscapes, we will eventually evaluate the relative value of various management scenarios for wetland birds, based on existing relationships detected from our field data to date. Using comprehensive habitat data for the South Bay (interpreted from satellite imagery), we plan to simulate landscape changes over time and model waterbird responses to those changes. A combination of aerial photo interpretations and field-collected data may be used to assign habitat classifications to 30-m satellite imagery (e.g., LANDSAT TM) pixels using geostatistical scaling (Sanderson et al. 1997) or other relevant techniques. Alternately, high-resolution (1-m) satellite imagery (e.g., IKONOS) may be used to derive a finer-scale representation of South Bay habitats.

The final phase will be to develop a dynamic model of San Francisco Bay bird populations that incorporates key demographic, energetic and spatial parameters, as well as the underlying physical processes of restoration (see Nur and Sydeman 1999).

Conclusions

San Francisco Bay habitats are changing quickly. Thus we realize the immediate need to evaluate the impacts of these changes on birds and other species. Our approach is intended to quickly provide useful information to land managers and other interested parties. The proposed Habitat Conversion Model may provide a valuable opportunity to integrate GIS, field data and spatial analysis to guide and optimize the restoration process and monitor the cumulative impacts of restoration on birds. The success of this effort will depend on the formation of effective partnerships with land managers and researchers from other disciplines.

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