Environmental Drivers of Macroinvertebrate Biomass and Waterbird Abundance in Managed Ponds of South San Francisco Bay

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Introduction

- The San Francisco Bay (SFBay) has been heavily impacted by urbanization and agriculture, which have resulted in a greater than 80% loss of historical tidal marsh habitat[1].
- In an effort to restore tidal marsh habitat in the San Francisco Bay (SFBay), the South Bay Salt Pond Restoration Project (Project) was initiated in 2003 after the acquisition of 6,100 ha of salt production ponds (Fig. 1). The goals of the Project are to:
  1) Restore 50-90% of former salt ponds to tidal marsh in 50 years;
  2) Provide recreational access for the public; and
  3) Protect the region from flooding.
- The Project must balance marsh restoration to support threatened tidal marsh species with pond management to support migratory waterbirds that depend on shallow and subtidal habitats.
- SFBay provides critical habitat for migratory waterbirds. It is part of the western hemisphere shorebird reserve network, and it is a key wintering area for waterfowl along the pacific flyway.
- A recent study by De La Cruz et al.[2] examined waterbird abundance during the first 10 years of the Project, in which 10% of ponds were breached for restoration to tidal marsh, and the remainder were managed for salinity and depth. Results indicated that pond features, including water depth, topography, salinity, and islands, affect waterbird abundance and can be manipulated to maximize waterbird abundance on managed ponds.
- To further examine the response of waterbirds and their prey to fine-scale habitat features, we examined macroinvertebrate and waterbird abundance in managed ponds divided into cells containing a gradient of salinities and gently sloping sediment mounds.

Research Questions

- How do abundances of waterbird guilds differ among ponds with different salinities?
- How do water and sediment conditions influence macroinvertebrate biomass?
- How do water conditions, habitat features, and prey resources influence shorebird abundance?
- Which macroinvertebrate taxa are consumed by shorebirds in ponds with different salinities?

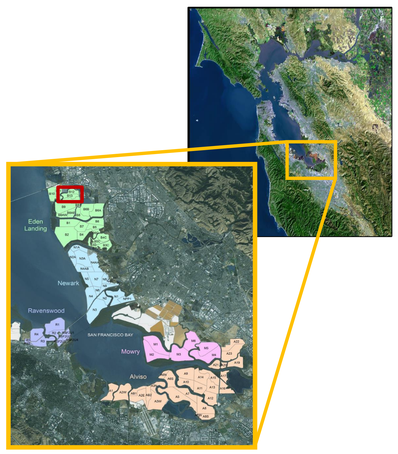

Fig. 1. Former salt production ponds acquired for habitat restoration as part of the South Bay Salt Pond Restoration Project in San Francisco Bay, CA. The experimental ponds where our study was conducted are highlighted in red.

Study Area & Methods

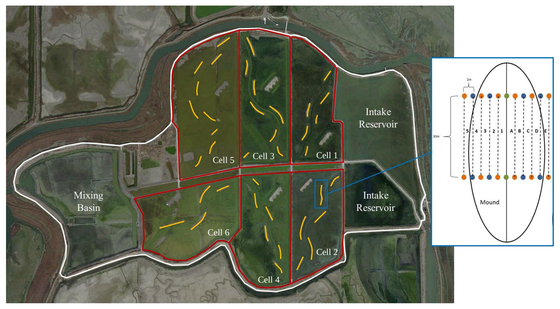

Fig. 2. Experimental pond cells (red) with intake reservoirs and mixing basin (white), mounds (yellow), and elevation zones (blue) at Eden Landing Ecological Reserve in Hayward, CA. Pond cells 1 and 2 are low salinity, cells 3 and 4 are moderate salinity, and cells 5 and 6 are high salinity. The offset (blue) shows a schematic of the 20 m x 30 m mound survey plots, with labeled 2-m elevation zones.

- Our study was conducted at Eden Landing Ecological Reserve in six experimental pond cells configured to manipulate water depth and salinity (Fig. 1). Cells 1 and 2 had low salinities (< 40 ppt), cells 3 and 4 had moderate salinities (40-80 ppt), and cells 5 and 6 had high salinities (80-120 ppt; Fig. 2 in red).
- Each pond contained several gently sloping sediment mounds that were constructed to provide roosting and foraging habitat for waterbirds (Fig. 2 in yellow).
- A survey plot composed of 10, 2-m zones was set up on each mound. In each zone, waterbirds were counted weekly and macroinvertebrate sampling was conducted monthly (Fig. 2 in blue) from October 2015 to May 2016.
- We used binomial-lognormal hurdle generalized linear mixed models (GLMMs) to examine the effects of sediment chemistry, grain size, water quality, and depth on macroinvertebrate presence and biomass.
- We used binomial-negative binomial hurdle GLMMs to assess the effects of salinity, elevation, exposure, distance to the nearest levee, and mean macroinvertebrate biomass on small shorebird presence and abundance. Small shorebirds were selected for analysis because they were the most abundant guild using the ponds. Data were analyzed at two spatial scales: among sediment mounds (mound-scale), and among elevation zones on the mounds (zone-scale).
- We selected important variables in GLMMs by summing the AIC weights of models containing each variable in the model set.
- The contents of the upper gastrointestinal (GI) tracts of 21 small shorebirds observed foraging in different salinity treatments were compared to the contents of sediment cores collected where birds were foraging. Samples were collected in January 2016 and October to December 2016.

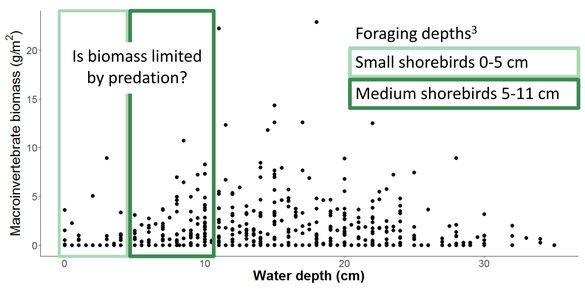

Fig. 3. Macroinvertebrate biomass (grams per square-meter to 10 cm sediment depth) per core (n = 574), collected on mounds (n = 24) at different water depths, in pond cells at Eden Landing Ecological Reserve.

Results

Table 1. GLMMs were used to assess the effects of environmental variables on the abundance of foraging and roosting small shorebirds. Predictor variables with effects on the response variable were selected using variable importance values (indicated in parentheses). Larger variable importance values indicate stronger effects of the predictor variable on the response variable (in bold). The relationship (+ or -) between predictor and response variables is also indicated in parentheses.

GLMM		Response variable	Variables used in the analysis	Variables selected (Effect on response variable/ Variable importance)
Mound-scale	Foraging	Abundance	Salinity, Proportion Exposed, Distance to Levee, Invert Biomass/Core	Proportion Exposed (+/21.79)
	Roosting	Abundance	Salinity, Proportion Exposed, Distance to Levee, Invert Biomass/Core	Proportion Exposed (+/1.99), Salinity (-/1.15)
Zone-scale	Foraging	Presence	Elevation, Exposed or Not, Invert Biomass/Core	Elevation (+/10.13), Exposed or Not (+/8.78)
		Abundance	Elevation, Exposed or Not, Invert Biomass/Core	None
	Roosting	Presence	Elevation, Exposed or Not, Invert Biomass/Core	Exposed or Not (+/14.73), Elevation (+/4.17)
		Abundance	Elevation, Exposed or Not, Invert Biomass/Core	None

- We observed 39 species of waterbirds from 11 guilds.
- The abundance of guilds differed among salinity treatments; small shorebirds were most abundant at high salinities, medium shorebirds were most abundant at moderate salinities, and dabbling ducks were most abundant at low salinities.
- Water depth had the most notable effect on macroinvertebrates, with the greatest biomass observed at water depths between 10 and 20 cm (Fig. 3). This depth is inaccessible to most small and medium shorebirds[3], suggesting that predation may play a role in limiting macroinvertebrate biomass at shallower depths.
- Small shorebirds were the most abundant guild we observed, and they were strongly influenced by the elevation and exposure of sediment mounds in the ponds (Table 1).
- We did not detect a relationship between macroinvertebrate biomass and the presence or abundance of foraging small shorebirds on ponds (Table 1).
- Nematodes and dipterans were the most common prey consumed by small shorebirds in all three salinity treatments (Fig. 4).
- Percent similarity indices < 60 indicated that the proportions of prey consumed by small shorebirds differed from availability in sediment cores from all three salinity treatments (Fig. 4).

Contact Information

To learn more about this project please contact Laurie Hall at lahall@usgs.gov or 831-233-2795

Results cont.

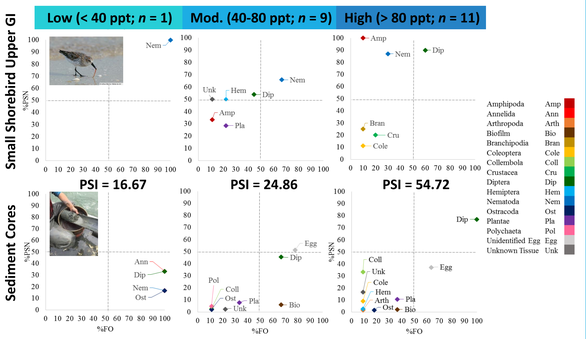

Fig. 4. Prey-specific number (%PSN) and frequency of occurrence (%FO) of diet items from the GI tract of foraging small shorebirds (top row), and available prey items from sediment cores (bottom row) collocated with the bird's foraging location in low, moderate, and high salinity cells. Percent similarity indices (PSI) comparing the taxonomic compositions of GI contents and sediment cores are shown between plots.

Management Implications

- Our study indicates that a broad suite of waterbird taxa can be supported by managing ponds at different salinities.
- It also provides evidence that constructing sediment mounds and managing water depths to increase mound exposure increases abundance of foraging and roosting small shorebirds on the pond.
- Although other studies have detected a relationship between macroinvertebrate biomass and shorebird abundance[4,5], we did not. The values of macroinvertebrate biomass we observed were 8x less than biomass observed at an adjacent mudflat in San Francisco Bay[6]. Thus, the current biomass in the ponds may be too low to elicit a response from foraging birds. This relationship may change as biomass in the ponds increases over time. Further, macroinvertebrate communities in the ponds are still developing, and some important prey taxa, such as bivalves, have not yet colonized the ponds.
- As sea level rises, shorebirds are expected to become more dependent on prey resources in managed ponds to sustain their energetic demands.
- The experimental ponds where we conducted our study provide a unique opportunity for future research aimed at refining our understanding of physical drivers of shorebird and macroinvertebrate prey abundance that will be critical for managing remaining pond acreage in the Project area.

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6. USGS unpbl. data.

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