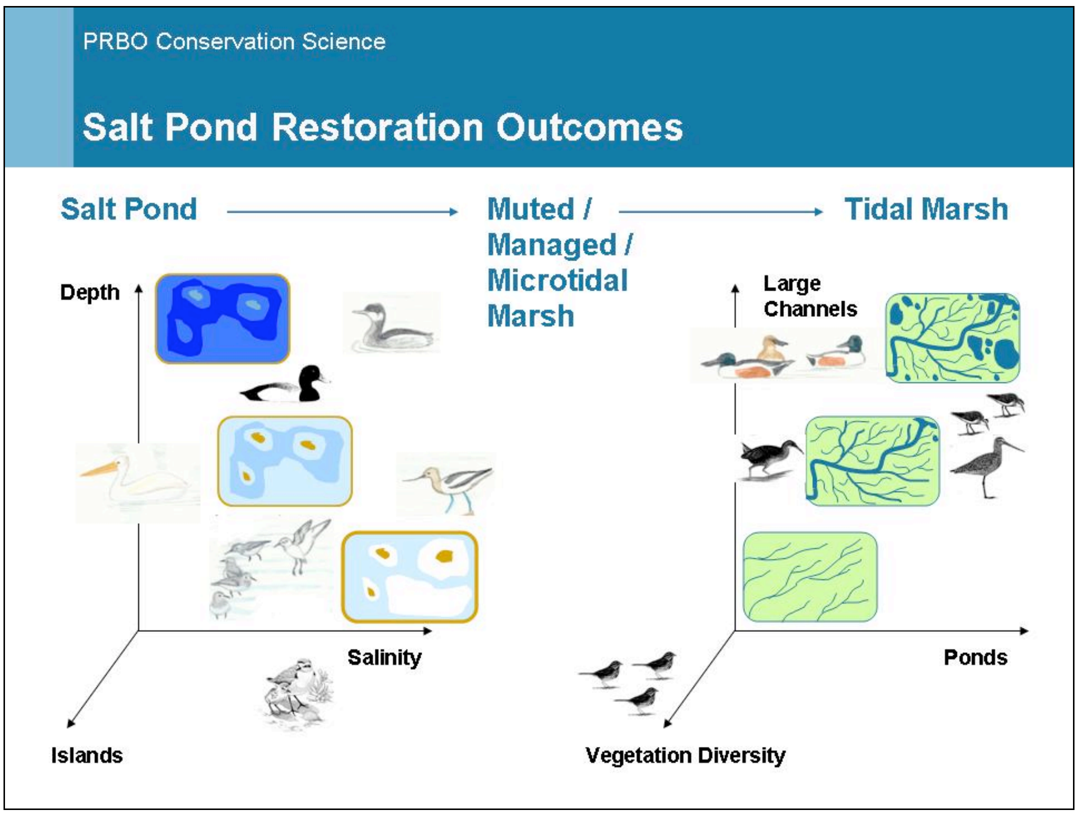
SYNTHESIS OF SCIENTIFIC KNOWLEDGE FOR MANAGING SALT PONDS TO PROTECT BIRD POPULATIONS

South Bay Salt Pond Restoration Project



Draft Final Report

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Acknowledgements

This synthesis was improved by conversations with staff at PRBO Conservation Science, the San Francisco Bay Field Station of the U.S. Geological Survey, and by the San Francisco Bay Bird Observatory. Additional input from staff with Phil Williams and Associates and HT Harvey and Associates are appreciated. Graphs and figures for parts of this report were provided by Diana Stralberg at PRBO Conservation Science. Funding for this synthesis was provided by the California Coastal Conservancy with special thanks to Amy Hutzel. Help with oversight of this synthesis was provided by Lynne Trulio and Steve Richie. Comments and review by Doug Barnum, Chris Elphick, José A. Masero, and Cheryl Strong greatly improved the content of this synthesis. This is contribution 1167 of PRBO Conservation Science.

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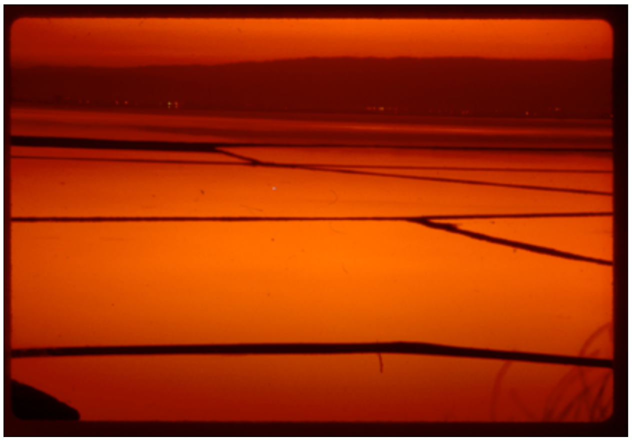


IMPORTANCE OF SAN FRANCISCO BAY SALT PONDS TO WATERBIRDS

San Francisco Bay contains the most important salt pond complexes for waterbirds in the United States, supporting more than a million waterbirds through the year (Stenzel and Page 1988, Accurso 1992, Page *et al.* 1999, Takekawa *et al.* 2001). Birds counts on San Francisco Bay from 1964-1966, showed highest densities of birds in salt ponds, followed by tidal flats, open water, and tidal marshes (Bollman and Thelin 1970). Single day counts of waterbirds in the salt ponds during winter months can exceed 200,000 individuals (Harvey *et al.* 1992), and single day counts during peak spring migration have exceeded 200,000 shorebirds in a single salt evaporation pond (Stenzel and Page 1988). Takekawa et al. (2000) reported that the South Bay salt ponds supported up to 76,000 waterfowl (up to 27% of the Bay's total waterfowl population) including 90% of the Bay's Northern Shovelers, 67% of the Ruddy Ducks, and 17% of the Canvasbacks. Depending on the year, 5-13% of the federally threatened U.S. Snowy Plover (*Charadrius alexandrinus*) Pacific Coast population breeds at San Francisco Bay, mainly in the South Bay salt ponds (Page *et al.* 1991, Strong et al. 2004a). In some years, >20% (1,500 – 2,500 pairs) of the Pacific Coast Forster's Terns may nest in the salt ponds of the South Bay (Strong et al. 2004b).

At issue here, is the potential effect of the restoration of the 15,000 acres of South Bay salt ponds recently acquired by state and federal agencies to other habitat types, particularly tidal marsh habitat. Various modeling efforts and expert opinion have suggested that there is the potential for significant declines in waterbird populations if salt ponds are converted to tidal marshes. For instance, Takekawa et al. (2000) estimated that if 50% of the South Bay's salt ponds were converted to tidal marsh, that 15% of the 76,000 waterfowl that use those salt ponds could be lost. Despite the documented importance of San Francisco Bay salt ponds to populations of Pacific Flyway waterbirds, few guidelines exist for state and federal wildlife agencies on how to actively manage a significantly smaller amount of salt pond habitat in the South Bay than currently exists to achieve the maximum abundance and diversity of birds using the habitat while keeping maintenance costs and efforts to a minimum. Questions remain about which salt ponds to keep and which ones to convert. Answers to these questions rely in part on understanding bird use patterns in and around the salt ponds. For instance, the most important salt ponds for foraging may not be the most important ones for roosting (D. Barnum pers. comm.). Additionally, little is known on how bird populations will be affected as the salt pond restoration progresses.

WHAT DO WE KNOW ABOUT BIRD USE IN SALT PONDS?

Commercial salt ponds in San Francisco Bay have existed for over a century (Ver Planck 1958). Prior to European settlement, perhaps 800 ha of natural salt crystallizing ponds were found primarily in southern reaches of the Bay. A series of these ponds of about 400 ha were farmed for salt by the native Yrgin tribe (Goals Project 1999). Beginning with European colonization around the mid 1800s, extensive diking of tidal wetlands occurred to create salt ponds (Josselyn 1983), with accelerated conversion of tidal marsh to salt ponds from the 1930s through the 1950s (Goals Project 1999). Presently, there are over 12,000 ha of salt ponds in San Francisco Bay (Goals Project 1999), most in the south region of the Bay.

Coastal salt ponds (solar ponds, or salinas), areas where salt is extracted from salt water through solar evaporation, provide important nesting, foraging, and roosting habitat to waterbirds world-wide (Rufino *et al.* 1984; Sampath and Krishnamurthy 1989; Velasquez 1993; Sadoul et al. 1998, Masero and Pérez-Hurtado 2001). For instance, in Australia, three of the ten most important areas for shorebirds encompass commercial salt ponds (Lane 1987), while in Puerto Rico, the Cabo Rojo salt complex holds more shorebirds than any other site on the island and is one of the most important shorebird areas in the Caribbean (Collazo *et al.* 1995). In the Mediterranean, over half of the approximately 500,000 migratory and wintering shorebirds that occur in the region use salinas (Sadoul et al. 1998). Along the Pacific coast of North America, salt pond habitat supports large numbers and diverse populations of waterbirds at critical Pacific Coast sites such as Laguna Ojo de Liebre, Baja California del Sur, Mexico (Page *et al.* 1997); San Diego Bay, California (Terp 1998); and San Francisco Bay, California (Page *et al.* 1999). While salt ponds can act as functional wetlands, worldwide their value is threatened by changing economics driven by the world salt trade and competing land uses (J. Masero pers. comm., Sadoul et al. 1998, ALAS 2002).

Roosting Habitat

Species and numbers of birds roosting – The role of roosting sites for waterbirds in salt ponds, and how the loss of these roosting sites affect migratory waterbird populations has received little attention by researchers (J. Masero pers. comm.). Globally, many different species of waterbirds have been observed roosting in salt ponds, with shorebirds, ducks, waders, gulls and terns generally making up the majority of the species (Rufino et al. 1984, Sampath and Krishnamurthy 1989, Velasquez 1993). A high diversity of waterbirds has been documented roosting and feeding on San Francisco Bay salt ponds. Warnock et al. (2002, see also Stralberg 2003) listed 75 species of waterbirds using the saltponds in the South Bay. Use by roosting birds is highest on the high tides when tidal flats are covered. Of the 10 or so most common species observed in the salt ponds during high tide, the majority are shorebirds (8 species, Dunlin and Western Sandpipers most common), dabbling ducks (Northern Shoveler and Ruddy Duck), California and Herring gulls, and Eared Grebes (see Warnock et al. 2002). On high tides, 43%-46% of birds observed on the salt ponds were roosting while on low tides, 37%-39% of birds observed were roosting (Warnock et al. 2002). However, considerable variation exists in the frequency of roosting and feeding behavior in salt ponds between tides within different groups of waterbirds (Warnock et al. 2002, Fig. 1). For instance, within shorebirds, Marbled Godwit (*Limosa fedoa*), Black-bellied Plover, and Long-billed Curlew (*Numenius americanus*) were almost always seen roosting in the salt ponds on high tides, while other species such as Least Sandpiper (*Calidris minutilla*), Black-necked Stilt (*Himantopus mexicanus*), and American Avocet commonly fed in salt ponds on high tides. At low tide, the majority of shorebirds found in the salt ponds fed (Fig. 1). In San Diego salt ponds at high tide, roughly 70% of Western Sandpipers and Willets observed were roosting (Terp 1998).

Fidelity to roost sites – In general, shorebirds show a great deal of fidelity to roost sites, although there can be significant variation within and among species depending on location and other variables (Symonds et al. 1984, Rehfisch et al. 2003). Little is known about interannual fidelity to roost sites by waterbirds in San Francisco Bay; however, individual species have shown high fidelity to roost sites within seasons. Swarth et al. (1982) noted that waterbirds roosted on the same sections of salt pond levees throughout a winter period. Using radiomarked birds, Warnock and Takekawa (1995, 1996) showed that Western Sandpipers in the South Bay consistently moved back and forth to the same roosting sites in salt ponds and foraging sites on tidal flats within the winter and spring periods. Kelly and Cogswell (1979) found that Willet and Marbled Godwits habitually used certain roost and foraging sites in the South Bay. These data indicate that for at least shorebirds, there is a great deal of fidelity to individual roost sites within seasons.

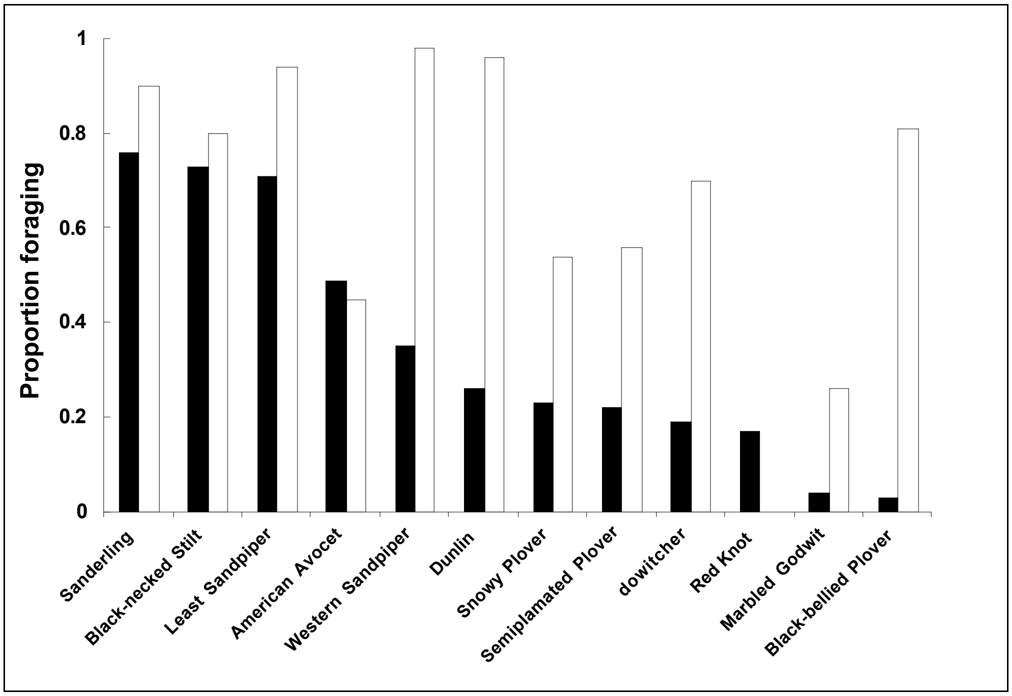


Figure 1. Proportion of most abundant shorebirds seen foraging on high and low tides in salt ponds of south San Francisco Bay. Numbers combined for 1999 and 2000. Dark column = high tide, white column = low tide. (from Warnock et al. 2002).

Physical and landscape characteristics of roost sites – Quantitative studies of preferred roost habitat of waterbirds in San Francisco Bay are generally lacking (but see Fig. 2). Larger shorebirds such as stilts and avocets are often seen roosting in shallow water of salt ponds. Many different species of waterbirds use islands, isolated levees, and dikes for day time roosts. Many of these shorebirds, such as Willets and Marbled Godwits, will also use tidal marshes for roosting, especially if there is open water areas where visibility is good (N. Warnock unpubl. data). At nearby Bolinas Lagoon, various shorebirds including Dunlin and dowitchers roost in tidal marshes at night but not in the day, perhaps in response to different suites of predators (Warnock 1996). During windy conditions, the leeward side of levees get heavily used by roosting shorebirds (Swarth et al. 1982). Other substrates used for roosting include boardwalks running through salt ponds and across tidal marshes. Waterfowl and gulls are often observed roosting on the water of salt ponds.

Not much has been published on the design of roost sites. In England, Burton et al. (1996) studied roost behavior of shorebirds on a man-made rock island. They advised minimizing human disturbance around the roost site, and noted that the design of their island, a steep-sided, kidney shaped island, favored rocky shoreline birds like turnstones and Purple Sandpipers. For birds that favor estuaries such as oystercatchers and knots, they advised constructing open, flat-topped islands with gently sloping sides.

Alternative roost sites – Especially during storm events with heavy rain and wind, waterbirds have been observed moving to alternative roost sites away from the Bay. Around Palo Alto Baylands, Willets and Marbled Godwits have been seen feeding on nearby golf courses and flooded upland fields (Kelly and Cogswell 1979). Flocks of dowitchers and other small shorebirds have been observed feeding and roosting in flooded fields in Union City 5-10 miles from the Bay during storm events (N. Warnock pers. obs.). Research on the characteristics of these alternative roost sites including the role of water quality, water depth, structural orientation (parallel or at right angles to prevailing winds), and other physical and landscape factors should be the focus of further research (D. Barnum pers. comm.).

Movements among roost sites – Little has been published about movements of waterbirds among roost sites. Kelly and Cogswell (1979) show that while Willets and Marbled Godwits are faithful to certain roosts within seasons, there is limited exchange among sites. Rehfisch et al. (2003) found that shorebirds moved short distances among roost sites in the Moray Basin (Scotland) but with significant interspecies differences. Red Knots moved the most, averaging over 15 km among sites, while Ruddy Turnstones, Ringed Plover, and Eurasian Curlew moved the least, averaging 0.7 to 1.3 km among roosts. They suggest that a combination of food distribution, predation risk, and disturbance explain much of the observed movements among the roosts.

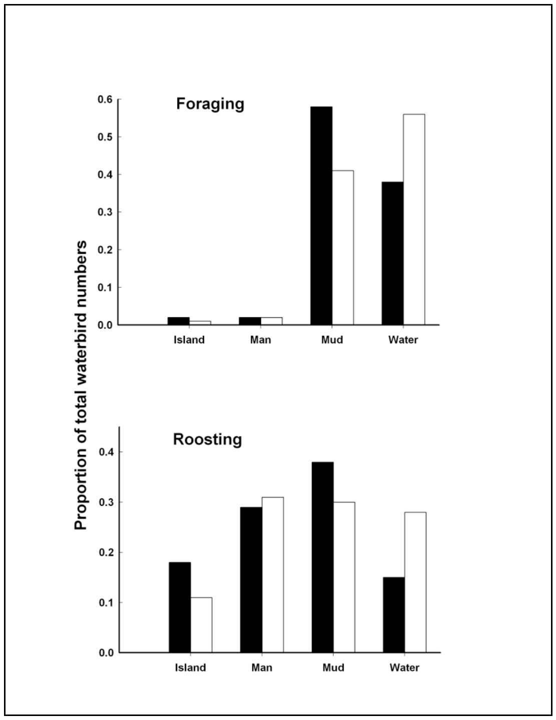


Figure 2. Proportion of waterbird use of different habitats within south San Francisco Bay salt ponds for foraging and roosting during high and low tides. Numbers combined for 1999 and 2000. Island = island of dry substrate which could not be covered by water in a strong wind; Man = man-made structure such as dikes, roads, pilings, boardwalks etc.; Mud = mudflat (dry or wet) or shallow water less than 10 cm deep; Water = open water greater than 10 cm. Dark column = high tide, white column = low tide. (from Warnock et al. 2002)

Foraging Habitat

Species and numbers of birds foraging – Globally, many species of waterbirds have been observed feeding in salt ponds, with shorebirds, ducks, waders, gulls, and terns generally making up the majority of the species (Rufino et al. 1984, Sampath and Krishnamurthy 1989, Velasquez 1993). In San Francisco Bay, over 70 different species of waterbirds have been seen feeding in salt ponds (Swarth et al. 1982, Warnock et al. 2002).

Fidelity to foraging sites and alternative foraging sites – As with roosting sites, various studies of foraging birds have shown that waterbirds can exhibit strong fidelity to foraging areas within the South Bay within seasons (also see discussion in roosting section above). The majority of the bird species that use the salt ponds move to the tidal flats to feed when tides and weather permits. Warnock and Takekawa (1996) found that radiomarked Western Sandpipers moved an average of 2.2 ± 0.1 km between roosting sites in the South Bay salt ponds to tidal flat foraging sites. As with many of the shorebirds, Western Sandpipers fed on the tidal flats mainly at the edge of the tide line. Tidal flats were also used nocturnally (Warnock and Takekawa 1996). In Spain, Masero (2003) found that salt ponds (salinas) contributed 25% of the daily prey consumption of waterbirds in the winter and 79% during the pre-migration period compared with intertidal mudflats.

Movements among foraging sites – Bird studies of waterbirds (mostly shorebirds) have shown that these birds generally have strong fidelity to specific areas of the Bay, limiting their foraging and roosting sites to relatively small and predictable areas (see studies by Kelly and Cogswell 1979; Warnock and Takekawa 1995, 1996; Takekawa et al. 2002, Hickey 2002; Warnock and Takekawa unpubl. data). However, if conditions change at a site (e.g. because of predators, food availability, or weather) shorebirds often will switch sites. In North San Francisco Bay and at nearby Bolinas Lagoon, it has been shown that Dunlin and dowitchers will move 100's of km to the Central Valley of California in response to changing weather conditions (often associated with rain; Warnock et al. 1995, Takekawa et al. 2002). In the Bay area, Dunlin will make daily 10-15 km movements among wetlands, perhaps increasing feeding opportunities at estuaries due to tidal lags among the sites (Warnock et al. 1995, Warnock 1996). However, there are trade-offs, and for shorebirds feeding at the Dutch Wadden Sea, it has been calculated that for every extra kilometer that a bird has to commute between its roost and foraging sites energy expenditure increases 1.3 % (van de Kam et al. 2004)

Within the San Francisco Bay estuary, data for only a few shorebird species' home range are available for comparison. The average home range size for breeding

Black-Necked Stilts in the North and South bays was 283.5 ha (95% CI = 196-667 ha, range = 9.2-5490 ha; Hickey 2002). Warnock and Takekawa (1995) found an average home range size of 2,200 ha for wintering and migrating Western Sandpipers (*Calidris mauri*) in the South Bay, while for wintering Long-billed Dowitchers (*Limnodromus scolopaceus*) in the North Bay average home range size was 1,700 ha (Takekawa et al. 2002). For breeding Snowy Plovers, based on observations of marked birds, Feeney (1991) estimated that the average home range of Snowy Plovers in the Baumberg and Oliver Brothers salt ponds was about 1.6 ha.

Although due in part to different methods used for area estimation and different seasons in which data were collected, the large differences between home range size for stilts and the sandpiper species reflect varying wetlands use patterns within the estuary by the species. The sandpipers and dowitchers travel on a daily basis from high tide foraging and roosting areas to the edge of the tidal flat when it is exposed at lower tides (although less so in Long-billed Dowitchers than Western Sandpipers). Stilts are more highly dependent on diked wetlands throughout the tidal cycle, sometimes spending weeks in one small area. In this regard, stilts are more like Long-billed Dowitchers that have relatively small core use areas compared to Western Sandpipers (Hickey 2002, Takekawa et al. 2002).

Physical Characteristics of foraging sites – Waterbirds in South Bay salt ponds are most often observed feeding on moist soils or shallow waters (Fig. 2). Foraging is dictated by depth that birds are able to access prey. For most shorebirds (phalaropes excepted), birds are generally not found feeding in water deeper than 15 cm or so; and most prefer water depths under about 4 cm (Isola *et al.* 2000). Dabbling ducks are often observed foraging in the same areas as shorebirds (Warnock et al. 2002), while grebes and other diving birds typically use ponds < 2m in depth (Accurso 1992; J. Takekawa unpubl. data). In the depth controlled rice fields of the Central Valley of California, maximum species richness of waterbirds was found in ponds maintained 10-15 cm deep (Elphick and Oring 1998, 2003). Traditional waterbird management often manages water too deep for many waterbird (water too deep to access prey) and invertebrate species (water to deep for maximum productivity – perhaps a function of water temperature), thus, in developing a management plan, the basis must be on the biology of the birds and their prey items (D. Barnum pers. comm.).

In South Africa, Velasquez (1993) found that highest foraging densities of waterbirds were in salt ponds of 25-70 ppt salinity and 170-220 ppt salinity. Warnock et al. (2002) found highest numbers of birds in salinities around 140 ppt and highest species diversity in salinities around 126 ppt, but as Fig. 3 shows (see also Table 1), different groups of waterbirds respond to salinity in various ways. For instance, in San Francisco Bay salt ponds, densities of diving ducks generally decreased with increasing salinities while densities of small shorebirds increased (Stralberg et al. 2003).

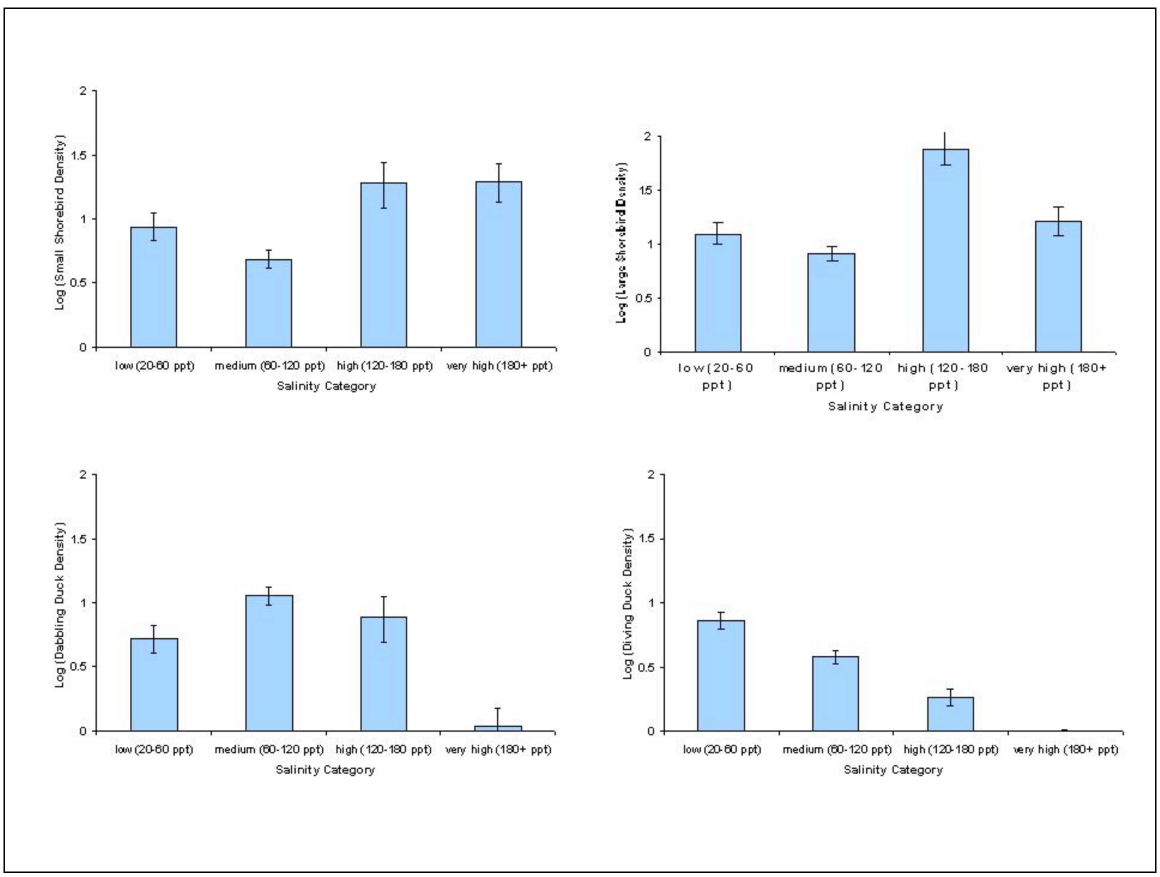


Figure 3. Mean log-transformed small shorebird, large shorebird, dabbling duck, and diving duck densities (graphs from top right across to lower left) by salt pond salinity category for South San Francisco Bay salt ponds surveyed in 1999/00 and 2000/01. Error bars represent standard errors of the mean for each salinity category. Information from Stralberg et al. (2003).

Pond salinity has been shown to be an important non-linear predictor of waterbird abundance and diversity in South Bay salt ponds (Swarth et al. 1982, Warnock et al. 2002), and this is undoubtedly related at least in part to prey abundance. Other factors may be the sensitivity of certain waterbird species to salinities because of thermoregulatory stress induced at extreme hypersalinity and the flocking nature of many of the waterbird species observed may also contribute to this response pattern (D. Barnum, C. Elphick, and J. Masero pers. comm.). For invertebrates, species richness declines with increasing salinity (Britton and Johnson 1987; Williams *et al.* 1990), but for invertebrate biomass, this is not a linear effect.

Highest densities of important waterbird prey species in San Francisco Bay, the Franciscan brine shrimp (*Artemia franciscana*, often called *A. salina*; Larsson 2000), the Reticulated Water Boatman (*Trichocorixa reticulata*) and brine flies (*Ephydra* spp. and *Lipochaeta slossonae*), occur in salinities of 60 - 200 ppt (Carpelan 1957; Larsson 2000; Maffei 2000a, b). These invertebrate species are targeted by many waterbird species, especially shorebirds and waterfowl (Anderson 1970). Swarth *et al.* (1982) found a strong positive correlation between numbers of Eared Grebe and invertebrate biomass in eleven South Bay salt ponds. This positive relationship of bird numbers (or density) to prey density has been found for other species of waterbirds in other habitats (Yates *et al.* 1993) and in salt pans around the world, although the predictive ability of this relationship tends to be poor (Velasquez 1993; Terp 1998; Grear and Collazo 1999). This lack of predictability may relate to the biology of the invertebrates and relationships to both water and air temperatures. Furthermore, the development of statistically valid sampling protocols for organisms such as the brine flies, water boatmen, and brine shrimp, which by nature occur in very patchy locations, is difficult, and this may obscure relationships (D. Barnum pers. comm.).

Diet of birds – The diet of birds that feed in salt ponds of the South Bay is poorly understood. Anderson (1970) found that for most shorebirds that feed in the salt ponds, the most common prey consumed was the brine fly, while waterfowl were mostly eating plants. While brine shrimp are abundant in certain ponds, only a few waterbirds appear

Table 1. Classification of core salinity ranges for 50* most abundant waterbird species detected in South Bay salt ponds between October and April, 1999/2000 and 2000/2001 (feeding detections only). Core salinity ranges represent the values between 25th and 75th percentiles; i.e., at least 50% of detections were within the given salinity range (from Stralberg et al. 2003). * Lesser and Greater Scaup were combined in this analysis. Thayer's Gull was not included due to lack of feeding detections.

0-60 ppt	60-120 ppt	120-180 ppt	180+ ppt
American Coot			
Green-winged Teal			
Gadwall			
Northern Pintail			
American Wigeon			
Red-breasted Merganser			
American White Pelican			
Pied-billed Grebe			
Canvasback			
Double-crested Cormorant			
Forster's Tern			
Marbled Godwit			
Red Knot			
Black-crowned Night Heron			
Great Egret			
Snowy Egret			
Western Grebe			
Glaucous-winged Gull			
Canada Goose	Canada Goose		
Northern Shoveler	Northern Shoveler		
Clark's Grebe	Clark's Grebe		
Common Goldeneye	Common Goldeneye		
Ruddy Duck	Ruddy Duck		
Mallard	Mallard		
Black-bellied Plover	Black-bellied Plover		
Long-billed Curlew	Long-billed Curlew		
Dowitcher	Dowitcher		
Semipalmated Plover	Semipalmated Plover		
Western Gull	Western Gull		
Bufflehead	Bufflehead		
Greater Yellowlegs	Greater Yellowlegs		
Ring-billed Gull	Ring-billed Gull	Ring-billed Gull	
Killdeer	Killdeer	Killdeer	
Snowy Plover	Snowy Plover	Snowy Plover	
	Bonaparte's Gull		
	Mew Gull		
	Lesser / Greater Scaup	Lesser / Greater Scaup	
	Red-necked Phalarope	Red-necked Phalarope	
	Eared Grebe	Eared Grebe	
	American Avocet	American Avocet	
	Sanderling	Sanderling	
	Black-necked Stilt	Black-necked Stilt	
	Ruddy Turnstone	Ruddy Turnstone	
	Willet	Willet	
	Dunlin	Dunlin	
	Least Sandpiper	Least Sandpiper	
	Western Sandpiper	Western Sandpiper	Western Sandpiper
	California Gull	California Gull	California Gull

to preferentially select brine shrimp, probably because of their low nutritional value (both in terms of caloric value and lipid content) compared to brine flies (Herbst et al. 1984, Herbst 1986). In a study of Red-necked Phalaropes at Mono Lake in eastern California, Rubega and Inouye (1994) showed that Red-necked Phalaropes fed only *Artemia monica* lost significant amounts of body mass while those eating brine flies *Ephydra hians* maintained body mass. Additionally, in preference experiments, phalaropes chose brine flies over brine shrimp (Rubega and Inouye 1994). In Europe however, the mean energy density of brine shrimps from Spanish salt ponds, is 22.8 KJ/g AFDM (J. Masero pers. comm.), a value similar to chironomid larvae or estuarine polychaetes (22-24 kJ/g AFDM; Brey et al. 1988). It has been noted that Mono Lake is dominated by the algae *Dunaliella* and this alga species is limited in its nutritional profile. Salt ponds, through their pond diversity in terms of salinity and primary productivity probably offer up a much wider nutritional variety than a near monoculture lake like Mono Lake, and the brine shrimp in the South Bay salt ponds may consequently have a higher nutritional value (J. Masero pers. comm.).

In the South Bay, the only species found eating *Artemia* were Eared Grebes (9% of the volume of food found in stomachs), American Avocets (48% of volume in one day of collection, 0% in another day of collection), and Wilson's Phalaropes (9% of volume; Anderson 1970). Corixids dominated the diet of Wilson's and Red-necked (Northern) phalaropes, Least Sandpipers, and Ruddy Ducks. Takekawa and Marn (2000) report that Canvasback feeding in salt ponds less than about 60ppt generally eat mollusk, especially clams. In Central Valley evaporation ponds, prey selection by American avocets and black-necked stilts was opportunistic with the most abundant prey being the one eaten (D. Barnum pers. comm.).

Based on numerous hours of observation around the Baumberg salt ponds, Feeney (1991) suggested that Snowy Plovers were mainly eating brine flies. Plovers were also seen eating moths (*Perizoma custodiata*), some type of beetle (perhaps *Cicindela hiricollis* – Tiger Beetle), and unidentified green caterpillars. Prey items in the stomach of a Snowy Plover chick from Alameda salt ponds included 11 beetles of which 9 were *Tanarthrus occidentalis* (flower beetles) and 2 *Bembidion* spp. (Feeney 1991). Feeney (1991) also suggested that adult midges and their larvae and Digger Wasps

(*Ammophila* spp.) may be important prey items to Snowy Plovers in salt ponds. Adult Snowy Plovers (Kentish Plovers) watched in salt ponds in Spain are also known to feed on brine flies while their chicks were seen feeding on small pelagic beetles (Castro and Pérez-Hurtado 1996, Castro 2001).

The diets of breeding California Gulls have been looked at in various studies (eg. Jones 1986, Dierks 1990), and the most common food items fed to chicks in the South Bay include garbage, brine shrimp, midges, fish, and brine flies. Jones (1986) looked at chick regurgitation pellets of California Gulls nesting at the Alviso salt ponds and found that 40% of the pellets were usually some form of garbage and the other 60% came from natural sources. Of the natural items, brine flies were found in 68% of the pellets in one year and only once in the next. Fish were important in one year. Brine shrimp were not reported as a prey item. In a more extensive study of the diets of breeding California Gulls, also at the Alviso salt ponds, Dierks (1990) found that chicks were fed (based on regurgitated samples) 40% garbage, 15 % midges, 15% brine shrimp, 13% fish, and 10% brine flies. She also found that young California Gull chicks were fed more brine flies than older chicks.

Looking at diet studies done at other saline systems around the west and the rest of the world, a pattern emerges that of the two dominant invertebrates found in the higher salinity areas, brine shrimp and brine flies, brine flies are usually the preferred prey item, with some exceptions (e.g. Masero 2002). At Mono Lake, an alkali lake in eastern California, various studies have looked at bird diets. From 2000-2002, Hite et al. (2004) looked at food fed to California Gull chicks and found that in two years, brine shrimp (*Artemia monica*) were the most common food item brought to chicks followed by brine flies (*Ephydra hians*). In one year, brine flies were the most common prey items with cicadas (*Okanagana cruentifer*) replacing brine shrimp as the next most common prey item. Also at Mono Lake, Jehl (1988) has shown that staging Eared Grebes mainly feed on brine flies in the early summer and then switch to brine shrimp in the last fall months. Staging adult Wilson's Phalaropes fed on 60-80% brine shrimp while the juveniles mainly fed on brine flies (Jehl 1988). At the saline Abert Lake in south-central Oregon, in an extensive prey selection study of Wilson's and Red-necked (Northern) phalaropes, American Avocets, Eared Grebe, Ring-billed Gull, California

Gull, and Northern Shoveler, Boula (1986) found that the majority of birds were eating various stages of the brine fly. Brine shrimp were occasionally eaten by all birds but significantly (>10% of occurrence in prey samples) only by Wilson's Phalarope, Eared Grebe, and Northern Shoveler. At Mono Lake, Eared Grebes lengthen their guts when feeding on brine shrimp (C. Elphick pers. comm.), and it may be that many waterbird species have limited phenotypic flexibility when it comes to being able to change their guts to effectively feed on brine shrimp (see discussion by Piersma and Lindström 1997).

Breeding Habitat

Species and numbers of birds breeding – In the 1970s, Gill (1972, 1977) noted 41 species of birds breeding within the San Francisco Bay Estuary. Numbers of species actually breeding in South Bay salt ponds are fewer and include: Snowy Plover, Killdeer, American Avocet, Black-necked Stilt, Least Tern, Forster's Tern, Caspian Tern, California Gull, and the occasional Black Skimmer (Gill 1977, Layne et al. 1996, Strong et al. 2004b).

Rintoul et al. (2003) assessed the status of breeding populations of Black-necked Stilts (*Himantopus mexicanus*) and American Avocets (*Recurvirostra americana*) in South San Francisco Bay, California, in May 2001. They counted 1,184 stilts and 2,765 avocets. Considering only birds observed exhibiting breeding behaviors, their low estimates of breeding birds in the South Bay were 270 stilts and 880 avocets. Their breeding size estimates fall within the range of similar estimates from the South Bay from 20-30 years ago. No other sites on the Pacific coast of the United States have breeding populations of stilts and avocets that approach those of the South Bay in size. The greatest numbers of stilts and avocets bred on salt ponds in the South Bay with lesser numbers breeding in a combination of fresh and salt marshes.

During a Snowy Plover survey of the South Bay during the 2004 breeding season, Strong et al. (2004a) counted 113 adult plovers in the South Bay, or 5.9% of the total Snowy Plovers (n = 1904 plovers) counted along the California coast in 2004 [compared to 5.0% (72/1444) in 2003, and 12.8% (176/1371) in 1991 (G. Page, unpubl.

data)]. No current estimates for breeding numbers of Killdeer exist for the South Bay, although in 1971, Gill (1977) estimated 300-400 pairs bred there.

Counts of Caspian Terns, Forster's Terns, and California Gulls done in 2003 in San Francisco Bay yielded 2,300, 2,450, and 21,200 breeding birds respectively (Strong et al. 2004b). Based on previous studies done between 1982-2003, Strong et al. (2004b) noted that Forster's Tern populations had declined, Caspian Tern populations had stayed even, and California Gull populations had increased (note that Gill's 1970s surveys did not document breeding California Gulls). During the 1960s and 1970s breeding colonies of Least Terns have been documented in the South Bay including 30 breeding pairs on Bay Farm Island in Alameda County in 1969 and 15 pairs on Bair Island in San Mateo County in the 1970s (Gill 1977). Currently, Least Tern breeding in Sa Francisco Bay is mainly confined to Alameda County (Alameda Naval Air Station) and a few pairs at the Pittsburg Power Station (Feeney 2000). Beginning in the mid-1990s, a few Black Skimmers have been noted breeding in salt ponds of the South Bay (Layne et al. 1996).

Fidelity to and movements among breeding sites – Very little published data exist on breeding site fidelity of waterbirds to San Francisco Bay salt ponds. However, while avocets, stilts, plovers, terns, and gulls can exhibit strong breeding site fidelity, these species readily move breeding sites in response to changing conditions (Kotliar and Burger 1984, Page et al. 1995, Roby et al. 2002).

Hickey (2002) examined breeding site fidelity and winter site use by the Black-necked Stilt in at North and South Bay sites. Re-sighting data indicate that at least 25% of the breeding stilts tracked in the study resided in the estuary through the following winter and at least 22% bred in the estuary during the consecutive breeding season. Breeding site fidelity was higher for stilts captured in the South Bay (38%) than for stilts captured in the North Bay (0%).

Strong et al. (2004b) summarized trends of Forster's Tern and Caspian Tern colonies in San Francisco Bay and found strong interannual use of breeding sites by these birds. Site fidelity to breeding areas by these terns was found to be negatively influenced by drying out and flooding of ponds where colonies were located, predation by the introduced Red Fox (*Vulpes vulpes*), disturbance due to levee maintenance and construction, and encroachment on tern colonies by predatory California Gulls.

An understanding of site selection and fidelity by waterbirds in the estuary will help predict the effect of pending changes to wetland habitats within the estuary on breeding waterbirds. From data that exist, it appears as if waterbirds that breed in the salt ponds have high breeding site fidelity on the pond complex level, but probably not on a site specific level due to the continuously changing environment of the salt ponds.

Physical Characteristics of breeding sites – In general, birds breeding in the South Bay salt ponds are found on exposed, salt encrusted flats; on dikes; and on islands. Rintoul et al. (2003) found that the observed use by stilts and avocets of available breeding habitat in the South Bay differed significantly from expected use. Stilts used tidal marsh and salt pond habitat approximately in order of availability, whereas avocets made greater use of salt ponds. Within marshes, stilts most often used vegetated areas followed by mudflat/open water habitat, whereas for avocets the pattern was reversed. Within salt ponds, both species were most often observed on islands, but their order of use of other microhabitats in salt ponds differed. We observed little use of tidal flats by breeding stilts and avocets.

Strong et al. (2004b) found that most Forster's and Caspian Tern colonies in the South Bay were located on low-lying, bare to sparsely vegetated dredge spoil islands within the salt ponds, although a few Forster's Tern colonies have been located on vegetated islands within tidal marshes. Dakin (2000) in a study of nest site selection by Forster's Terns in the South Bay observed that terns showed a nesting preference for sparsely vegetated areas, especially areas with Alkali Heath vs. pickleweed. This vegetation is thought to provide protection again predators (e.g. offer a place for chicks to hide) as well as some shelter from weather. They preferred to nest in colonies with strongest preference being for nests with 5-12 neighbors and nests within 400 cm of each other (Dakin 2000). Dakin (2000) recommended that for Forster's Terns vegetated dredge spoil island be constructed with protective topographic features to help hide terns from the wind and predators.

Colonies of California Gulls, some over 4,000 pairs, typically nest on isolated levees and islands (Ryan 2000).

In the Baumberg and Oliver salt ponds (now the Eden Landing area), Feeney documented significant numbers of Snowy Plovers breeding on abandoned salt ponds with salt encrusted surfaces. While this study and others have found that Snowy Plovers generally nest in areas with no or little vegetation, Feeney (1991) did observe plovers occasionally using vegetation to nest near, hide chicks, and to feed in. Feeney also found that Snowy Plovers in the Bay generally nest on substrates that match the coloration of the backs of these birds. Using nest distance from levees as a proxy for the plover's preference for openness and good visibility, Feeney (1991) found that about four times as many plover nests were greater than 20 m from the closest levee. Nesting densities ranged from 0.17 to 0.58 nests/ha (from Table 9, Feeney 1991).

Engilis and Reid (1997) discuss key characteristics of breeding islands for waterfowl and shorebirds in the Great Basin and made recommendations. First, islands should be large enough for breeding birds to do predator distraction displays on. They recommend islands that are sinuous in shape thereby maximizing shoreline length, not too far from the shoreline or other islands, 30-60 cm above maximum water levels, and have a slope with a minimum 5:1 ratio.

Demography of breeding birds - Overall, little has been published on the demography of waterbirds that breed in the South Bay. Various studies have looked at the breeding success of the Snowy Plover in San Francisco Bay. In a 1989 study of Snowy Plovers at the Baumberg/Oliver Brothers salt ponds around Hayward, Feeney (1991) found that of 80 nests monitored, the percent of eggs that were laid (n = 152) and also hatched was 49-51%, the percent of chicks that hatched (n = 74-77) and also fledged (n = 21) was 27-28%, and the percent of eggs that were laid, hatched and also fledged was 14%. From 13 years of data on nesting Snowy Plovers at Monteray Bay, fledging rates averaged 24%, while from 1992 to 1997 along the coast in Oregon, Snowy Plovers fledging rates of chicks averaged 38% (USFWS 2001).

In 2004, Snowy Plover nests were monitored in salt ponds and other managed wetlands at the Don Edwards National Wildlife Refuge (Ravenswood and Warm

Springs), at sites owned by Hayward Area parks and Recreation Department (Franks Dump West and Oliver Brothers North Ponds), at all Eden Landing (Baumberg) ponds (Strong et al. 2004a). Of 59 nests monitored 48 hatched (81% hatch rate), 3 were depredated, 1 was abandoned, and 7 had unknown fates.

Jones (1986) calculated reproductive success for California Gulls breeding at the Alviso salt ponds and found that of 232 nests monitored between 1983 and 1984, California Gull nests had a hatch rate of 66%, with a 63% fledging rate.

There do not appear to be published nest success rates for Caspian and Forster's terns from the South Bay. In San Diego Bay, Kirven (1969) found that Caspian Tern's hatched 81% of their eggs and fledged 66% of chicks, rates a bit higher than other published studies (Cuthbert and Wires 1999). Forster's Tern breeding success is also unreported for the South Bay (although see Dakin 2000). Breeding success rates of Forster's Terns from around the country vary from year to year and often depend on abiotic factors such as weather and water levels (McNicholl et al. 2001).

WHAT IS THE LEVEL OF CERTAINTY OF OUR KNOWLEDGE?

Currently, the importance of salt pond habitat to a diverse and large community of wintering and migrating waterbirds has been well established through various studies. Additionally, it has been well established that the salt ponds are important breeding habitat for a number of waterbirds, notably Snowy Plovers, American Avocets, Black-necked Stilts, California Gulls, and Caspian, Least and Forster's terns. Some of the big uncertainties to be dealt with include how should new salt pond habitat be designed and which ponds should be retained to optimize waterbird diversity, abundance, and fitness; how can the conflicting needs of federally listed species including the Snowy Plover and Clapper Rail be met (as well as the often conflicting human-wildlife needs), and what will happen to bird populations through the South Bay restoration process. These issues and others are discussed below (Key Salt Pond Issues).

PREDICTIVE TOOLS FOR GAINING AN UNDERSTANDING OF THE EFFECT OF SALT POND RESTORATION ON BIRDS

Various predictive tools have been used to look at interactions of biotic and abiotic variables in the South Bay. PRBO habitat conversion models (Stralberg et al. 2003) distilled a diverse wetland landscape into two basic habitat types, salt ponds and tidal marsh, in an effort to understand the effects of converting these two types of habitats on bird populations using the South Bay. In reality, the South Bay contains many other valuable habitats, both natural and man-made. For birds, some other important habitat types include tidal mudflats (critical for certain waterbirds), seasonal wetlands, freshwater marshes, levees, and natural or constructed salt pannes. Future iterations of this model will attempt to include these habitats and the species that depend on them. An important next step for this effort 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, in terms of bird numbers and diversity. There is still a need to derive spatially-explicit optimal solutions. Potential methods include mathematical optimization techniques (Nevo and Garcia 1996, Hof and Bevers 2002, Cabeza 2003) as well as numerical simulation models, such as the Spatially-Explicit Species Index (DeAngelis et al. 1998) and Spatially-Explicit Simulated Annealing (Ball 2000).

Other modeling efforts will be informative to the South Bay process. PRBO has done preliminary modeling to look at the potential effect of the spread of *Spartina alterniflora* on shorebird populations in the South Bay (Stralberg at al. 2004). The models are currently restricted to the spread of *Spartina* on tidal flats. Phil Williams and Associates have developed sediment models and models to predict habitat change in the South Bay, although they have not been carried over to address things such as effects on birds. USGS has also completed extensive sediment models and have data that will be useful for future bird modeling.

In Europe, The Centre for Ecology and Hydrology (England) and the University of Cadiz (Spain) are developing a behavior-based model to predict the effects of salt ponds loss as well as the restoration of abandoned salt ponds on shorebird populations.

They are modeling salt ponds and intertidal mudflats of the Bay of Cadiz (SW Spain). The first version will be available in early February 2005 (J. Masero pers. comm.). The use of behavioral-based models have recently been used to evaluate the effect of mudflat loss on shorebird populations due to an extension of a port in Le Havre, France (Durrell et al. 2005), as well as to predict effects of shellfisheries on shorebird populations (Stillman et al. 2001, 2003).

Population viability analyses (PVA) are one way to identify the limiting demographic parameters (e.g., reproductive success, recruitment, and survival) for a population, and assess the population's probability of long-term survival under various habitat change scenarios (Boyce 1992, Nur and Sydeman 1999). For example, based on a PVA developed for the Pacific Coast population of the Western Snowy Plover (Nur et al. 2001), the population was shown to be sensitive to small changes in adult survival. The model also showed that a productivity of 1.2 or more chicks fledged per breeding male should increase population size at a moderate pace. In general, adult survival has been shown to be the most important limiting factor across shorebird taxa (Sandercock 2003). While demographic models often identify adult survival as limiting, management often focuses on reproductive success. Reproductive success fluctuates widely, compared to the relatively stable adult survival, and may be easier to influence through management (Nur et al. 2001). However, for some species (like the endangered Caribbean Brown Pelican and the Hawaiian Stilt), it may be impossible to recover the species without improving adult survival (C. Elphick pers. comm.).

POTENTIAL RESTORATION TARGETS AND PERFORMANCE MEASURES

Performance measures for the restoration project and potential restoration targets with regards to maintaining bird populations that rely on salt ponds will likely be complex since they will require compromises due to the complexity of interests in the restoration project. However, certain performance measures already exist. For instance, U.S. Fish and Wildlife Service (2001) has a recovery goal of 500 Snowy Plovers for San Francisco Bay. PRBO is currently trying to refine how much area of salt ponds will be required to meet this Snowy Plover goal.

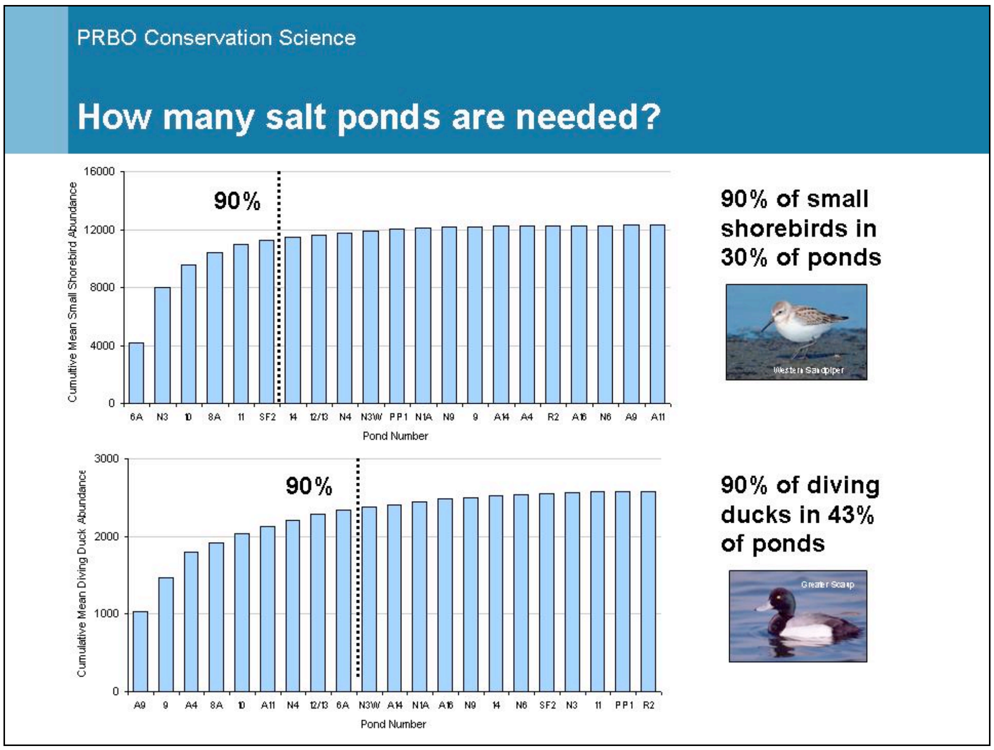
PRBO's habitat conversion models have already calculated several measures of bird abundance and diversity from existing salt ponds that can be used to measure the performance of new habitat as it is created. These measures can be calculated for individual species and well as groups of species and can be created for different seasons. In general, it is probably advisable to create a list of bird densities in different habitats of the South Bay at different seasons to help monitor the success of habitat restoration. Elphick and Oring (2003) recommend another measure for evaluating management methods on different habitats that takes into account a specie's conservation value. This is a composite measure where each species is weighted according to its mean density in a particular habitat, its mean relative abundance across its North American range during a particular season, and its population trend (Elphick and Oring 2003).

One thing that has not been done in the South Bay is to establish reproductive success criteria of birds for different restored habitats. This should be done as it will help establish whether restored habitats are sources or sinks for different breeding species of concern. Establishment of reproductive success criteria for restored habitat will require summarization of existing data as well as the collection of new data. This should also be combined with demographic modeling to determine minimum rates of reproduction needed to maintain populations. For instance, the Snowy Plover recovery plan (USFWS 2001), based on a population viability analysis, recommends trying to produce 1.2 or more chicks fledged per breeding male to meet the goal of increasing the population.

On top of long scale habitat management goals for the restoration area (such as percent salt ponds maintained, amount of tidal marsh restored, number of unvegetated or vegetated islands created, etc.) there are a number of short-term (monthly, weekly, daily) management actions that will have to be created. One will be to determine different percentages of different depth water to maintain at any given time for different bird species. Another will be to determine how many ponds of specific salinities need to be maintained to produce enough invertebrate biomass to sustain bird populations that rely on salt ponds for food. Thus having invertebrate biomass standards will be helpful. In one modeling exercise of the food requirements of European Oystercatchers, simulations predicted that the minimum required amount of food per bird would be between 2-5 times the amount actually consumed (West *in press*).

KEY SALT POND ISSUES ESSENTIAL TO THE SUCCESS OF THE RESTORATION

Habitat Features



There are a number of vital unanswered questions left with regards to the salt pond habitat that remains. Perhaps the most important is that given there will be fewer salt ponds in the South Bay after restoration, how can we manage the existing ones to optimize bird abundance and diversity? Warnock et al. (2002) made a number of suggestions in their paper on the management of salt ponds for waterbirds in the South Bay. For attracting maximum numbers and diversity of migrating and wintering waterbirds, ponds with exposed moist soil and shallow water up to about 10 cm deep were recommended. Deeper water ponds are needed for many of the ducks and divers. They recommended that salinities of ponds need to be maintained in several ranges, especially the range where fish can live (20-60 ppt), and in the range that promotes a high biomass of invertebrate prey important to a wide range of migrating and wintering shorebirds, waterfowl, gulls, and terns. Their results suggest this latter salinity range centers around 140 ppt. Roosting waterbirds used islands in the middle of salt ponds, and maintenance and creation of island habitat was suggested as important to management plans for salt ponds. While building islands and shallow water ponds is not technically challenging, managing for specific water salinities and depths, especially the higher salinities and specific depths that promote the supra abundance of brine flies and shrimp, will be a challenge. There are many unanswered questions remaining with regard to this challenge. For instance, can you build a high salinity pond without having all the other lower salinity ponds? How do you maintain large populations of brine shrimp and flies? Additionally, determining how many acres of what kinds of salt ponds will be needed to maintain waterbird populations has still not been answered. A reviewer of this document advocates first understanding the biological requirements of the aquatic invertebrates and then managing for them (D. Barnum pers. comm.). One next step is to overlay the biological requirements of the birds and manipulate water depth and land forms to provide birds access to the prey, or in some cases, to provide small refugia for the prey to escape their predators (D. Barnum pers. comm.).

Restoration Dynamics, Hydrology and Geomorphology

At the level of individual restoration sites, it would help to know more about what future restored marshes will look like, in terms of their hydrology and the resulting mix of vegetated marsh plain and open water habitat; whether they will resemble existing marshes; and how long they will take to establish. Issues like sediment availability (Haltiner et al. 1997, Williams 2001), contaminants (Hostettler et al. 1996), and invasive species (e.g., *Spartina alterniflora*) further complicate these questions (Ayres et al. 1999). The rate of marsh development and change in landscape mosaic over time will also be important in order to assess how bird populations will respond. Furthermore, the effects of new restoration on existing tidal mudflats—whether it will contribute to additional mudflat accretion or further reduce available sediments, causing a reduction in habitat—will be important for calculating the net impact on waterbirds.

Habitat Carrying Capacity

We also need to gain a better understanding of salt pond prey availability and carrying capacities for various species as has been advocated by others (Goss-Custard et al. 1996). PRBO's habitat conversion models assumed that all ponds were being used to their maximum potential. However, it may be that more waterbirds can be accommodated by fewer, high-quality ponds. Data and experience from the Central Valley indicated that a ratio of about 60% land to 40% water and water depth no greater than 6 inches was required for maximum bird use and invertebrate production (D. Barnum pers. obs.). In the case that habitats are already being used at carrying capacity, behavioral responses of birds and their prey to habitat reduction could cause a decline in bird numbers even greater than in direct proportion to the area of habitat lost (Goss-Custard 2003).

Existing data on bird energetics and prey availability can be used to estimate a range of carrying capacities for each salt pond and other habitats. In Spain, using an energetic approach combined with an understanding of prey selection, Masero (2003) found that salt ponds (salinas) contributed 25% of the daily prey consumption of waterbirds in the winter and 79% during the pre-migration period compared with intertidal mudflats. Observational data can be used to help validate these estimates. Behavior-based models relating habitat loss to fitness of individual birds may also be useful (see West et al. *in press*).

Diet studies will be important to really understand what resources waterbirds are getting from salt ponds vs. tidal flats and tidal marshes. Some of this might be done through direct sampling (collecting birds – Anderson 1970; food pellets – Dierks 1990) while other questions might be addressed using methods like stable isotope analyses (Hobson 1995).

It will also be important to look at seasonal variations in salt pond bird numbers, since the highest shorebird numbers appear to occur during spring migration (Davidson and Evans 1986, Warnock and Takekawa 1996, Takekawa et al. 2001), and salinity and depth conditions vary throughout the year based on rainfall and other weather elements.

Local and Regional Habitat Availability

One key unanswered question is where salt pond dependent birds will go if displaced by tidal marsh restoration, both on local and regional scales. Will birds move over to existing Cargill salt ponds? Will they leave the bay system? Will some die? Perhaps most pressing of these questions is to begin addressing what the potential role of existing Cargill salt ponds will play in maintaining waterbird populations of the South Bay. To answer this, we will need to know how Cargill plans to manage existing salt ponds, including at what depths and what salinities.

We need to learn more about regional habitat availability for the species that have been modeled, some of which rely predominantly on San Francisco Bay during the winter or as stopover habitat during migration. Species whose populations depend heavily upon San Francisco Bay, such as Western Sandpipers (Butler et al. 1996, Iverson et al. 1996, Warnock and Bishop 1998), Dunlin (Warnock et al. 2004), and Canvasback (Accurso 1992) may be more strongly affected by changes in habitat availability if they are unable to adapt by using other coastal wetland areas instead. Models of west coast stopover and wintering habitat availability for several key species would help managers prioritize habitats for conservation and restoration, based on their regional importance (Warnock and Bishop 1996, Takekawa et al. 2002, Warnock et al. 2002). Spatial models can be combined with energetics information to characterize the suitability and relative value of migration stopover sites (Simons et al. 2000). Similar efforts with Pectoral Sandpipers in the Great Plains region indicated that more connected wetland landscapes may provide higher stopover value for migrating birds (Farmer and Parent 1997, Farmer and Wiens 1999).

Contaminants

The biggest contaminant concern in the South Bay with respect to birds appears to be related to mercury and the thought that habitat restoration in the South Bay in particular will remobilize mercury, with potential harmful effects on wildlife. In the Bay-Delta ecosystem the highest mean concentrations of Hg in avian eggs are found in Caspian terns and Forster's terns (0.9 and 0.8 ppm [fww], respectively). An individual Forster's tern egg collected in the South Bay had the highest Hg concentration in a single egg of any bird species yet sampled among 321 eggs from 15 species at a fresh wet weight concentration of 3.3 ppm (Schwarzbach and Adelsbach 2002). Other birds sampled in San Francisco Bay, California Clapper Rails, Snowy Plovers, Black-necked Stilts, American Avocets, Surf Scoter and Greater Scaup have also exhibit high Hg concentrations in their eggs and livers (Ohlendorf *et al*. 1986, 1991, Schwarzbach and Adelsbach 2002). Diving benthivores, such as Surf Scoters that winter in the estuary, have some of the highest Hg concentrations reported for adult birds in the ecosystem (Ohlendorf et al. 1986, Hothem et al. 1998). Currently, USGS, USFWS, and a host of other groups, funded by CalFed, have initiated a 5 year study: "Mercury in birds of the San Francisco Bay-Delta: trophic pathways, bioaccumulation and ecotoxicological risk to avian reproduction".

Invasive Species Control

San Francisco Bay has seen the appearance of many invasive plant and animal species, and these introductions have the potential to impact wildlife. As salt ponds are converted to a mixture of tidal marsh habitats, one management challenge will be to control plant invasives. Perhaps the biggest concern currently with regards to invasive species and the South Bay restoration project revolves around *Spartina alterniflora*. This East Coast native is rapidly colonizing the South Bay. At Willapa National Wildlife Refuge in Washington, the introduction of *Spartina alterniflora* has led to the loss of significant amounts of tidal flats in the Bay. Jaques (2002) estimated that the spread of *Spartina* in parts of the Bay reduced available daytime feeding in the winter to shorebirds by as much as 50%.

Stralberg at al. (2004) modeled the spread of *Spartina altiniflora* in the South Bay and developed 12 potential scenarios of habitat value loss for shorebirds based on assumptions about invertebrate density, inundation tolerance of *S. alterniflora*, and temporal availability of mudflat resources. Predictions of habitat value loss ranged from

9% to 80%. They identified the upper mudflats, due to their greater exposure time, and the east and south shore mudflats, due to the high numbers of birds detected there, as the areas of highest value to shorebirds in the South Bay. These areas also coincided with the areas of greatest *Spartina* invasion potential. In Britain, the spread of *Spartina anglica* has been correlated with the decline of various shorebirds, including Dunlin (Goss-Custard and Moser 1998). Treatment of *Spartina* with herbicides has benefited waterbirds (Evans 1986).

Other invasives have the potential to be a problem during the salt pond restoration. The non-native plant, *Lepidium latifolium*, is displacing native tidal marsh plant species and altering habitat for wildlife (for review of impact on tidal marsh bird communities see Spautz et al. 2004). Additionally, new non-native invertebrate species are constantly being introduced to San Francisco Bay.

Vegetation Control

An important yet untested component of maintaining salt pond habitat for wintering and migrating waterbirds will be to prevent ponds, especially the lower salinity ponds, from becoming vegetated since many species of waterbirds, especially shorebirds, use vegetated areas, such as tidal marshes, less than unvegetated habitat (Bollman and Thelin 1970, Warnock and Takekawa 1995; PRBO unpubl. data). Strong et al. (2004b) note that a Caspian tern colony nesting at the Alameda Naval Air Station went from a high of >2,000 birds to no birds after becoming covered in vegetation. Additionally, Strong et al. (2004a) have noted that certain ponds at Eden Landing (eg. B17B) have become too vegetated with *Salicornia* for plover nesting. For Forster's Terns however, Dakin (2000) found that terns preferred nesting at sites with at least some Alkali Heath cover.

Predator Control

Throughout the South Bay, the control of predators has been and will continue to be an issue for the management of specific breeding species. These predators include feral cats, Red Fox, skunks, opossums, rats, Common Ravens, California Gulls, and a number of other avian predators including as falcons and owls. The management of the restoration area should include constant predator control for certain types of predators such as the Red Fox and feral cats. Red Fox control has significantly increased Clapper Rail populations in the South Bay tidal marshes. Strong et al. (2004a) observed a Northern Harrier take an adult Snowy Plover, an American Kestrel take a plover chick, and a Common Raven eating eggs of a plover nest. Ravens were also seen taking American Avocet eggs. Strong et al. (2004a) recommend that all restoration plans in the South Bay should include the removal of as many avian predator perches as possible with the addition of no new perches.

Listed Species

A big question that remains to be resolved for South Bay restoration planning is how much salt pond habitat will need to be maintained for Snowy Plovers. The Western Snowy Plover Pacific Coast population draft recovery plan (USFWS 2001) recommends that San Francisco Bay be managed for 500 breeding Snowy Plovers, an area they estimate to be 809 ha of managed salt ponds. They recommend that most of this habitat be located in the South Bay with a limited (amount unspecified) amount in the North Bay where low numbers of plovers currently breed. The plan suggests that management should include maintenance of desired water levels, removal of excessive vegetation, and predator control.

More recently, Strong et al. (2004a) recommend that special consideration should be given to Snowy Plover habitat requirements during the South Bay Salt Pond Restoration Plan, including: 1) ensuring the availability of drying salt ponds with adjacent high salinity forage areas; 2) spreading plover habitat out; and, 3) allowing plover habitat to vary in location from year to year in order to minimize predation levels.

Future Monitoring Efforts

In order to adaptively manage salt ponds and other habitats in the South Bay restoration area, there must be ongoing monitoring of plants, invertebrates, fish, mammals, and birds. Without this, the program will lose its ability to measure the effectiveness of different management actions and its ability to effectively manage things adaptively. One immediate question is whether monitoring needs to be done over the entire restoration area or whether a monitoring program that samples the area can be used. The benefits of a sampling design would be a reduction in the cost of monitoring. However, the potential cost is the loss of information about the effects of the restoration process. Concurrently, experimentation should be taking place to establish optimal design and management of the restored area and periodic scientific review should occur to ensure top rate science is being conducted.

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