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Habitat selection and foraging of herons and egrets in South San Francisco Bay

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HABITAT SELECTION AND FORAGING OF HERONS AND EGRETS IN
SOUTH SAN FRANCISCO BAY

A Thesis Presented to
The Faculty of the Department of Biological Sciences
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Sciences

by
Sheri Lynn Lubin
December 2005

UMI Number: 1432445

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ABSTRACT

HABITAT SELECTION AND FORAGING OF HERONS AND EGRETS IN SOUTH SAN FRANCISCO BAY

by Sheri Lynn Lubin

The habitat selection and foraging behavior of the Great Blue Heron (*Ardea herodias*), the Great Egret (*Ardea alba*), and the Snowy Egret (*Egretta thula*), were studied in salt ponds (A1 and A2W), restored marshes (CS, MVTM, and SCTM) and one managed marsh (PA) in South San Francisco Bay. The distribution of each species among the sites differed significantly, as did prey capture success rates. The number of Snowy Egrets was highest in A1 while the number of Great Blue Herons and Great Egrets were highest in PA. The number of each species among sites differed significantly in the breeding season vs. non-breeding season. The Snowy Egret used an average of nine foraging behaviors, while the Great Blue Heron used three, and the Great egret used four. Disturbance to foraging birds was frequent, especially in A2W and SCTM. Management suggestions are presented based on these data.

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TABLE OF CONTENTS

LIST OF TABLES.....	viii
LIST OF FIGURES.....	x
INTRODUCTION.....	1
Background.....	1
METHODS AND STUDY AREA.....	28
Study Area.....	28
Methods.....	32
Statistical Analyses.....	35
Bird Counts.....	36
Foraging Behavior.....	39
RESULTS.....	42
Bird Counts.....	42
Foraging Behavior.....	54
DISCUSSION.....	69
RECOMMENDATIONS.....	82
LITERATURE CITED.....	84
APPENDICES.....	88
1. Density of birds per hectare in each study site.....	88
2. Water depths while foraging for all three species alone.....	89
in each site based on bird counts	

3. Salinity ranges of each site from June 2004 - July 2005.....	90
4. Number of birds in each site by month.....	91
5. Foraging behaviors and postures used by herons and egrets.....	92
6. Study sites.....	95
7. Heron and egret life histories.....	103

LIST OF TABLES

TABLE

1. Description of study sites.....	29
2. Habitat types (or substrate) within each site used by all three species....	30
3. Specific research questions and types of statistical tests used.....	41
4. Frequency for and all three species pooled and each species..... separately within each site	46
5. Results of 24 Chi-Square tests of water depth class (low, medium and... high) and frequency for each species alone, and all three species pooled, within each site	48
6. Results of 24 Chi-Square tests of foraging depth (land, tibia, tarsus,..... and belly) for each species alone, and all species pooled, within each site	49
7. Results of 18 Chi-Square tests of habitat use for each species alone..... within each site	52
8. Results of 6 Chi-Square tests of foraging vs. non-foraging.....	52
9. Percentage of habitat types used by each species in each site during..... foraging surveys	60
10. Percentages surveys disturbed and not disturbed in each site.....	61
11. Disturbances in each site and the location of the disturbance.....	62
12. Average success rate, mean strikes and successes per minute and total... minutes observed for each species in each site	63
13. Summary of prey lengths and total prey caught by each species.....	64

14. Summary of prey type captured by each species in each site.....	65
15. Chi-square test for total prey caught in each site (all species pooled)....	65
16. Chi-square tests for total prey caught in each site for each species.....	66

LIST OF FIGURES

FIGURE

1. Map of the San Francisco estuary.....	3
2. EcoAtlas historical view map of San Francisco Bay Estuary habitat..... distributions	11
3. EcoAtlas modern view map of San Francisco Bay Estuary habitat..... distributions	12
4. South Bay Salt Pond Restoration Project Map	14
5. Aerial map of study sites in Mountain View, California.....	26
6. Research sites and trail map in Shoreline at Mountain View.....	31
7. Distribution of birds from June 2004 through July 2005.....	45
8. Frequency of foraging depths by the Great Blue Heron, Great Egret,..... and the Snowy in Egret in each site	50
9. Habitat use in each site by each species.....	51
10. Number of birds in each site foraging and not-foraging.....	53
11. Average salinity (ppt) in each site	53
12. Average number of foraging behaviors of each species in all sites	59
13. Number of behaviors used by each species in each site.....	59
14. Percentages of disturbances to herons and egrets (species pooled)..... while foraging	61
15. Number of prey and type captured by each species in each site.....	67
16. Prey length classes caught by each species in each site.....	68

INTRODUCTION

The San Francisco Bay is one of the largest estuaries in the United States. It is home to at least 500 species of fish and wildlife and to more than a million waterbirds (Goals Project 1999, Warnock *et al.* 2002). However, the majority (80%) of San Francisco Bay's historic tidal marshes have been developed for agriculture, housing, business, and salt pond production over the last two centuries (Goals Project 1999). Historically, salt marshes were used by herons and egrets for both nesting and foraging but the development and loss of marshes have affected their overall populations and distributions (Kelly *et al.* 1993, Ryan and Parkin 1998). Recently, several thousand acres of salt ponds, in the South San Francisco Bay, have been acquired for tidal marsh restoration. It is hoped that the salt pond restoration will provide more tidal marsh habitat for species of concern. Scientists are concerned about how the restoration will affect local and migratory waterbird populations (Goals Project 1999, Warnock *et al.* 2002). This study addresses how herons and egrets use tidal marshes, both restored and natural, in comparison to their use of low salinity (< 40 ppt) salt ponds, with the overall goal of inferring how restoration will affect them.

Background

The San Francisco Bay estuary, which is a drowned river valley, includes San Pablo Bay in the north, the Suisun Bay east of the Carquinez Strait, the Sacramento-San Joaquin River Delta, Central Bay and South Bay (Josselyn 1983) (Fig. 1). Suisun Marsh is the largest expanse of wetlands in the San Francisco Bay. South San Francisco Bay is fed by small streams and creeks including the San Francisquito Creek and

Guadalupe River, and smaller tributaries such as Steven's, Permanente and Adobe creeks. The South Bay water tends to be more saline than the North Bay (Goals Project 1999, Hart and Sanger 2003). The Bay estuary contains two thirds of the entire Pacific coast's salt marsh and tidal mud flats (Taniguchi 1996).

San Francisco historic tidal marshes formed around 10,000 years ago during the Holocene submergence. Prior to that time, during the Pleistocene epoch, the estuary was a broad stream valley. The South Bay salt marshes formed later than the North Bay marshes as the Santa Clara Valley was deeper and received less eroded material than in the North Bay. Archaeological findings indicate that humans may have inhabited the Bay area 10,000 years ago, and evidence found in the East San Francisco Bay from Ohlone Indians dates back to around 4,000 years ago (Conradson 1996, Blueford 1996). Native Americans hunted fish, clams, oysters, mussels, crabs and waterbirds near or in the estuary (Goals Project 1999). The local Tuibeen and Yrgin Indians collected salt that naturally occurred around the inland borders of the baylands, and used this salt for themselves and for trade (Warnock *et al.* 2002). Native Americans also used wetland and upland plants such as oaks (*Quercus* spp.), willows (*Salix* spp.), tules (*Scirpus* spp.), and cattails (*Typha* spp.) for food, medicine, toys, clothing, basketry, and shelter.

The estuary was used for cattle and sheep grazing, especially in the North Bay by the Spaniards in the early 1800's. The Gold Rush began in the mid-1800's; this changed the estuary drastically as tidal marshes and mudflats were diked, filled and/or drained. Marshes were bought and sold by speculators (Josselyn 1983) and much of the estuary

Figure 1. Map of the San Francisco estuary. Map courtesy of 1999 Baylands Ecosystem Habitat Goals Report (copied with permission).

was filled as the San Francisco Bay area became a major hub as ports, rail lines and roads were built. Water was diverted from the freshwater flows and the marshes for both agriculture and domestic city water. During the 1850's more farming, diking and draining occurred as agriculture increased (Josselyn 1983). South Bay freshwater discharges have converted many salt marsh areas into brackish tule marshes (Kelly *et al.* 1993). The South Bay was used for salt production more extensively than the North Bay although, in 1952 The Leslie Salt Company (now owned by Cargill Salt Division) expanded salt production into the North Bay.

In 1854, John Johnson, a seaman, started the first commercial salt harvesting company in Hayward; this salt was used in silver refining. By 1868, 17 salt operations had been activated on the eastern side of the South Bay (Hart and Sanger 2003). In 1901, Leslie Salt Refining Company was established in San Mateo, owning 47 square miles of ponds and producing one million tons of salt every year. Salt ponds had taken over one fifth of the historical tidal marshes by the 1950's (Goals Project 1999). In 1979, Cargill, an agricultural company, purchased the Leslie Salt Company. In modern day salt ponds, salt making takes about five years through solar evaporation starting with water salinities of 25 ppt (part per thousand) that eventually reach 250 ppt before reaching the crystallizer beds. It takes six gallons of bay water to yield one pound of salt (Hart and Sanger 2003).

Between 1850 and 1910 rapid and extensive diking of the marshland for agriculture and grazing occurred. Hydraulic mining in the Sierra Nevada for gold caused sediment flow into streams, rivers and into the Bay creating new wetlands that were eventually diked (Josselyn 1983). In the South Bay, most of the tidal marshland was

diked and drained for pasture and then converted to salt ponds (Kelly *et al.* 1993). By the 1950's, salt ponds had taken over one fifth of the historical tidal marshes (Goals Project 1999). In total, 137,000 acres of the bay have been diked and 50,000 acres have been filled. There are presently only 40,000 acres left of 190,000 historic acres of tidal marsh in the Bay (Goals Project 1999).

Salt marshes provide habitat and food for fish and wildlife, help improve water quality by controlling pollution, oxygen production, and sediment filtration and serve as flood control. However, over the years water quality has suffered and the estuary has shrunk causing flooding and a need for dredging. As a result of these activities, much of the biodiversity including many species of fish and wildlife has declined, and twenty local species are now listed as threatened or endangered (Goals Project 1999).

San Francisco Bay Habitat Types

Bay habitats can be loosely divided into major categories as follows; tidal baylands, diked baylands and adjacent habitats. Tidal baylands include tidal flats, tidal marshes and lagoons. Diked baylands include diked wetlands, managed marshes, diked marshes, agricultural baylands, salt ponds, and storage/treatment ponds. Adjacent habitats include riparian forests, willow groves, grasslands, oak woodlands, and mixed evergreen forests (Goals Project 1999).

Salt marshes are considered one of the most valuable habitats in the Bay area (Taniguchi 1996, Goals Project 1999). Plant zones within the marsh can range widely depending on the salinity and tidal influence of the water. Most salt marshes have four zones of tidal influence: mud flats with algae at Mean Low Water (MLW), a midtide

zone with stands of dominant Pacific cordgrass (*Spartina foliosa*) found between Mean Tide Level and Mean High Water (MTL-MHW), a high tide zone with pickleweed (*Salicornia virginica*) which can intermingle with *S. foliosa*, and an upland marsh zone that is furthest from the bay and dominated by gumplant (*Grindelia stricta* var. *angustifolia*) and salt grass (*Distichlis spicata*) (Josselyn 1983, Conradson 1996).

Pacific Cordgrass is often a focal species of salt marsh restoration and is an important habitat because it provides protection from predators and nesting habitat for many species such as the California clapper rail (*Rallus longirostris obsoletus*) (Josselyn 1983). Plants in salt marshes are referred to as halophytes as they are adapted to being submerged by salty tidal waters. Many of these plants, especially pickleweed and salt grass, provide habitat for mammals such as the salt marsh harvest mouse (*Reithrodontomys raviventris*) and many invertebrates. Both tules (*Scirpus* spp.) and cattails (*Typha* spp.) grow in brackish water and provide nesting and foraging habitat to many species of wildlife such as the Red-winged Blackbird (*Agelaius phoeniceus*), American Bittern (*Botaurus lentiginosus*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Green Heron (*Butorides virescens*), Snowy Egret (*Egretta thula*), Marsh Wren (*Cistothorus palustris*), and many other species of birds, amphibians and fish (Goals Project 1999). Several non-native plants in these zones have become invasive. These include perennial peppergrass (*Lepidium latifolium*), Saltwort (*Salsola soda*), iceplant (*Carpobrotus edulis*), and ripgut brome (*Bromus diandrus*). Green macroalgae such as *Enteromorpha* spp. is an important part of the estuary flora serving as food and

shelter for predators and prey. Macroalgae is often found in shallow, low-salinity water and in salt ponds (Lonzarich 1989).

Wildlife Distribution in San Francisco Estuary

The San Francisco Bay is the primary destination and stop-over for many migratory birds (Josselyn 1983). More than half of the diving ducks on the Pacific Flyway spend their winter in and around the estuary (Josselyn 1983). The majority of birds found in tidal marshes are migratory, while some spend the winter in or around San Francisco Bay and some only stop briefly to rest and forage before heading south. Many species of birds such as the California Least Tern (*Sterna antillarum brownii*) and the American Avocet (*Recurvirostra americana*) breed in the Bay Area (Josselyn 1983).

Tide plays a large part in the abundance and diversity of shorebird species found in the estuary. Most species feed on aquatic vegetation, invertebrates and fish in and on tidal flats, salt ponds, and managed wetlands (Goals Project 1999, Conradson 1996). Prey diversity and foraging behavior vary among shorebirds such as avocets, dowitchers, willets, plovers and sandpipers. Their common prey includes small bivalves, polychaetes, and ostracods. Fish-eating birds such as herons and egrets take advantage of various tide heights in tidal marshes using a wide range of foraging behaviors to catch prey depending on the type of microhabitat (Josselyn 1983). Seventy-five species of waterbirds were found using salt ponds from September 1999 to February 2001 (Warnock, *et al.* 2002). Two hundred thousand individual waterbirds have been counted in a single day during peak spring migration in a single salt evaporation pond (Warnock *et al.* 2002).

Among the invertebrates found in the Bay are Franciscan brine shrimp (*Artemia franciscana*), which feed on the phytoplankton and blue green algae in salt ponds (Goals Project 1999). Reticular water boatman (*Trichorixa reticulata*), mud crabs, hermit crabs, clams such as the jackknife clam (*Tagelus californianus*), the San Francisco Bay clam (*Macoma balthica*), the non native Atlantic gem clam (*Gemma gemma*), the Atlantic soft shelled clam (*Mya arenaria*) (Pittman 1996), mud snails, and numerous species of brine flies are also important prey items for shorebirds in the Bay (Conradson 1996). Common polychaetes or marine worms found in salt marshes and mudflats are the neriid worm (*Nereis procera*), the blood worm (*Glycera robusta*), and lugworms (*Abarenicola* spp. and *Arenicola* spp). There are several introduced deposit-feeding annelids including *Polydora ligni*, *Streblospio benedicti*, and *Neanthes succinea*, which arrived in the 1800's (Pittman 1996).

Common fish found in the Bay include the bat ray (*Miliobatus californicus*), Pacific herring (*Clupea harengus pallasi*), shiner surfperch (*Cymatogaster aggregata*), staghorn sculpin (*Leptocottus armatus*), topsmelt (*Atherinopsis affinis*), and the introduced Mosquito fish (*Gambusia affinis*). Many of these fish are important prey items for the larger waterbirds such as cormorants, herons, and egrets. The raccoon (*Procyon lotor*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), harbor seal (*Phoca vitulina*), brush rabbit (*Sylvilagus bachmani*), Norway rat (*Rattus norvegicus*), and black rat (*Rattus rattus*) can be found in the bayland habitats. Among these, the red fox and the Norway and black rats were introduced to California and have

become invasive species. The red fox is a threat to the eggs of ground nesting shorebirds and ardeids (Conradson 1996, Ryan and Parkin 1998).

In addition to the introduction of non-native species (many introduced through the process of large ships draining their ballast water into the bay), the San Francisco Bay has suffered many stresses including loss of wetlands and water pollution. Several attempts at wetland and water protection have been initiated over the years. In 1968, Don Edwards, a local congressman, introduced a bill to establish a wildlife refuge in the East and South Bay. The bill passed in 1972 when the Clean Water Act was initiated. The Don Edwards San Francisco Bay Wildlife Refuge currently protects 67 square miles of wetlands (Hart and Sanger 2003).

Tidal Marsh Restoration

The loss and development of the Bay's tidal marshes during the last 200 years have taken a disastrous toll on the fish and wildlife. Tidal flat habitat has decreased from 50,000 acres to 29,000 acres (Goals Project 1999), while tidal marsh habitat has decreased from 190,000 acres to 40,000 acres (Fig. 2 and 3). Currently, there are 51 species of plants and animals that live near or in the Bay that are listed as either threatened or endangered under state and federal law (Goals Project 1999). Not only is there deep concern about threatened and endangered species, there is also great economic value in wetlands. Wetlands contribute to commercial harvesting of fish and shellfish, provide recreational value, and have immense aesthetic and heritage value. Wetlands help stabilize the global levels of available nitrogen, methane, carbon dioxide and atmospheric sulfur (Goals Project 1999). In the San Francisco Bay estuary, several tidal

marsh restoration projects have been conducted (e.g., Hayward Marsh, Cogswell Marsh, and New Chicago Marsh), are in process, or are planned for the future. This is especially true in the South San Francisco Bay.

Many state and federal agencies, concerned scientists and citizens have worked to improve the estuary's ecosystem over the years. In 2004, an immense salt pond restoration undertaking began in the South San Francisco Bay. In October 2000, the Cargill Company, who operates several salt ponds in the South San Francisco Bay, proposed to consolidate their operations. By March of 2003, state and federal agencies acquired more than 15,000 acres of Cargill salt ponds (Trulio and Clark 2005). This has become one of the largest restoration projects on the West Coast. The project is managed collaboratively by the California State Coastal Conservancy, the U.S. Fish and Wildlife Service (FWS), and the California Department of Fish and Game (DFG) and is called the South Bay Salt Pond Restoration Project (SBSRP, also known as South Bay Salt Ponds or SBSP). The goals of the SBSRP are to restore and enhance a mix of wetland habitats, provide flood management, and allow public access and recreation opportunities (Trulio and Clark 2005). The methods of restoration vary in this project; several ponds are being restored by breaching levees thereby encouraging natural restoration through tidal flow and inundation. Some of the ponds will be manually restored by constructing low berms across a shallow basin floor, others will be maintained or managed seasonally at higher salinities for specific wildlife needs (Goals Project 1999). This restoration project has attracted the involvement of many educational institutes and the public.

Figure 2. EcoAtlas historical view map of San Francisco Bay Estuary habitat distributions. Map courtesy of 1999 Baylands Ecosystem Habitat Goals Report (copied with permission).

Figure 3. EcoAtlas modern view map of San Francisco Bay Estuary habitat distributions. Map courtesy of 1999 Baylands Ecosystem Habitat Goals Report (copied with permission).

Questions have been raised as to how this restoration process will affect the wildlife. Specifically, there is a need to know what the current habitat use and prey base is for many shorebirds. A high degree of uncertainty exists as to how birds are using salt ponds, salt marshes and restored marshes according to the South Bay Salt Pond Restoration Draft Adaptive Management Plan (2005). Other questions pertaining to how birds use tidal marsh, tidal mudflat and Bay habitats concurrently with use of salt pond, managed pond, and open Bay habitat have also been raised (e.g., Goals Project and SBSP report 2005).

The South Bay salt pond restoration consists of 54 ponds ranging from 30 to 680 acres in size. These ponds are organized into three distinct regions bordering South San Francisco Bay: the Alviso Complex (25 ponds), Eden Landing Complex (22 ponds) and the Ravenswood Complex (7 ponds) (Trulio and Clark 2005) (Fig. 4). Most of this area consists of former wetlands that were diked off from the Bay as early as the 1860s; the levees built for the salt ponds and diked areas have contributed significantly to the loss of 80% of the historical wetlands, as well as to changes in both sediment dynamics and species composition and distribution (Goals Project 1999). Many species affected by this type of land conversion are now threatened with extinction. Wildlife, such as the endangered salt marsh harvest mouse, the California clapper rail, the California least tern, the Western snowy plover (*Charadrius alexandrinus*), Steelhead (*Oncorhynchus mykiss irideus*), Chinook Salmon (*Oncorhynchus tshawytscha*), and many other native fish and plants such as the salt marsh owl's clover (*Castilleja ambigua* ssp. *ambigua*), invertebrates, and marine mammals will benefit from the salt pond restoration process.

Figure 4. South Bay Salt Pond Restoration Project Map (7/21/2004). Research sites for the present study are within the black rectangle. Map source: South Bay Salt Pond Restoration Project website, retrieved August 1, 2005: <http://www.southbayrestoration.org/Maps.html>. (Copied with permission).

Such rare taxa are high on the priority list for monitoring and research (Goals Project 1999).

The Western Sandpiper (*Calidris mauri*), Wilson's Phalarope (*Phalaropus tricolor*), and Northern Pintail (*Anas acuta*), are among many that are considered "Key Species" by scientists involved in the Goals Project. The San Francisco Bay Area Wetlands Ecosystem Goals Project involves both state and federal agencies and scientists that have come together to make recommendations and provide guidance on restoring and improving the baylands of the San Francisco Estuary. These "Key Species" are the basis for defining regional wetland habitat goals. Some of these shorebird species are tidal flat specialists such as the sandpipers and plovers and some are salt pond specialists such as the American avocet (Goals Project 1999). The Goals Project also makes recommendations for other baylands birds considered to be "Evaluation Species". These birds require large, well-developed tidal marsh and salt pond or shallow saline pond habitats. Evaluation species need a variety of habitats for nesting and foraging and the restoration process must take individual habitat requirements into consideration. Among these species is the Snowy Egret, which is considered to be representative of other associated species (Goals Project 1999). Even though wading birds, especially herons and egrets, use the salt ponds and salt marshes for foraging throughout the year, they are not currently considered 'species of concern'.

Regional Status of Herons and Egrets

Herons and egrets (family Ardeidae), specifically; the Great Blue Heron (*Ardea herodias*), the Great Egret (*Ardea alba*), the Snowy Egret, and the Black-crowned Night-

Heron (*Nycticorax nycticorax*) have been adversely affected by hunting, pesticides such as DDT, industrial pollution (Pratt 1993), loss of foraging and breeding habitat, and human disturbance over the last century. The plumage trade and dichloro-diphenyl-trichloroethane (DDT) both nearly caused the extinction of the Great Blue Heron and the Great Egret. In the 1800's, ardeids were hunted for sport and their eggs were collected for museums and hobbyists. Heron plumes were favored especially from the Great Egret and its long slender plumes called aigrettes that grow from the shoulder after the fall molt (Ehrlich, *et. al.* 1988, Pratt 1993); these plumes were used for women's hats and accessories. Eventually, charges of cruelty to the egrets diminished the demand as the Audubon Society was formed and offered public lectures on the affects of hunting on egret populations.

DDT, and its metabolite DDE, are known to accumulate in the tissues of herons and egret prey and then are eventually transferred to the eggs causing shell weakness and crushing of eggs during incubation, which led to a decline in populations. The Great Egret population diminished significantly in the San Francisco Bay region because of the egg thinning. DDT was found in Great Egret egg yolks and pesticide residue was found in dead adults (Pratt 1972). In 1970, Pratt and others witnessed two adult Great Egrets dying in convulsions on the ground while three others were found dead underneath their nest in a colony at the Bolinas Lagoon Preserve of Audubon Canyon Ranch in Northern California. In 1972, the chlorinated hydrocarbons were totally banned by the Environmental Protection Agency and researchers found no other dead egrets at Audubon Canyon Ranch due to pesticide contamination. However, many members of the heron

family winter in Latin American where pesticides are poorly regulated so the threat of pesticides on heron populations is still a concern (Pratt 1993).

After the decline of the plumage trade and the ban of DDT, heron and egret populations increased (Ryan and Parkin 1998). However, these birds now face threats of habitat conversion (e.g., landfills, housing development, and recreation), increase of native predators (e.g. American Crow, *Corvus brachyrhynchos*, and raccoons) and the introduction of non-native predators (e.g. red fox, domestic and feral cat, *Felis domestica*). These disturbances have resulted in the loss of several nesting colonies and foraging sites. Nesting sites are generally established near available foraging habitat, and the decline, movement, and disappearance of colony sites is correlated with habitat change (Kushlan 1978).

In 1993, Kelly *et al.*, established an annual program to monitor regional populations, breeding habitat and reproductive success of the Great Blue Heron, Great Egret, Snowy Egret and Black Crowned Night-Heron in San Francisco Bay. They found a total of 55 active breeding colony sites which included 45 Great Blue Heron, 17 Great Egret, seven Snowy Egret and 11 Black-crowned Night-Heron colonies. All of the Great Egrets (except one pair) and Snowy Egrets nested in mixed species colonies. They found that the most important subregions were in the Central Bay and the South Bay for the Snowy Egrets and the Black-Crowned Night-Herons. Disturbances to the ardeid nests and/or colonies included raccoon predation, presence of dogs, an immature Golden Eagle (*Aquila chrysaetos*) who flushed the ardeids from their nests, and nest predation or attempted nest predation by Red-tailed Hawks (*Buteo jamaicensis*), Black-crowned

Night-Herons, Western Gulls (*Larus occidentalis*), Great Horned Owls (*Bubo virginianus*) and Common Ravens (*Corvus corax*) (Kelly *et al.* 1993).

Kelly *et al.* (1993) suggested that the availability of nesting islands, which are safe from terrestrial predators, rather than the availability of nearby feeding areas accounts in part for the breeding distributions of the Snowy Egret, and Black-crowned Night-Heron. They also found that Great Blue Herons, Snowy Egrets and Black-crowned Night-Herons abandoned their nesting site on Bair Island in the South Bay due to red fox nest predation. However, many of those birds re-nested in nearby transmission towers and in small Eucalypt groves north of the island. Isolated islands in the Central and South Bay regions provide nesting habitat for most of the Snowy Egrets and Black-crowned Night-Herons and may represent critical habitat for their populations.

South San Francisco Bay heron colony data from 1982-1997 were summarized by the San Francisco Bay Bird Observatory's Colonial Waterbird Monitoring program in 1998. Ryan and Parkin reported that a total of 18 Great Blue Heron breeding sites were found, mostly at Bair Island and Baumberg (East Bay), in addition to several single species colonies. Their numbers in the study area appeared to be increasing. In 1980, San Francisco Bay Bird Observatory (SFBBO) placed artificial nesting platforms at the Bair Island sites due to a decline in breeding pairs that apparently resulted from the degeneration of nesting substrate, mainly Coyote Bush (*Baccharis pilularis*). A total of six Great Egret breeding sites were found in the South Bay; the Mallard Slough rookery was the largest. Their overall population appeared to be increasing. Seven Snowy Egret breeding sites were found in the South Bay and overall their populations have been in

decline in the South Bay and the Bay Area as a whole. Black-crowned Night-Herons bred at seven sites and at six of the sites they were nesting in mixed colonies with Snowy Egrets and Great Egrets. However, Ryan and Parkin noted that Snowy Egret and Black-crowned Night-Herons nests are difficult to monitor therefore the numbers may be under-represented.

In the past, there were large Great Blue Heron and Great Egret nesting colonies in nearby sites such as Moffett Field, however the only known nearby large active colonies are on Bair Island on the Peninsula, Eden Landing in the East Bay, Mallard Slough near the end tip of the South Bay, and the Duck Pond in Palo Alto Baylands (which only supports Black-crowned Night Herons and Snowy Egrets; Ryan and Parkin 1998, pers. obs. 2005). In June of 2005, there were approximately 25 Black-crowned Night-Heron nests and 25 Snowy Egret nests in a colony in the palms and other trees near the Duck Pond in the Palo Alto Baylands Preserve situated about 1.25 miles away from Shoreline at Mountain View (pers. obs.). Most of the nesting sites mentioned above are located over 10 miles from the Shoreline at Mountain View salt ponds and marshes.

The decline, movement, or disappearance of colony sites near foraging habitat are correlated with habitat changes (Kushlan 1978). There have been several attempts to assist the herons and egrets in the Bay area by creating new nesting platforms in less disturbed areas. However, predation pressure from feral cats, fox and humans has prevailed in some cases (Ryan and Parkin 1998). There is great need for the creation of new habitat or restoration of historical foraging and nesting habitat.

Several studies have been done on heron breeding biology in the San Francisco

Bay (Pratt 1970, 1972, 1974, 1993, Kelly *et al.* 1993, Ryan and Parkin 1998). Foraging behavior and foraging energetics by herons and egrets have also been well documented (Kushlan 1978, Hancock and Kushlan 1984, Buchanan 1990, Custer and Galli 2002, Gawlick 2002, Brzozad *et al.* 2004) but only a few studies have been done on their foraging behavior and habitat selection and use in the South San Francisco Bay.

Hom (1980, 1983) found that resource partitioning among the Great Blue Heron, Great Egret and Snowy Egret in Charleston Slough (located in Shoreline at Mountain View, California) resulted from their selection of different lengths of prey. Each species had different foraging methods and prey selection was associated with a difference in body size. He also found that the Great Egret had an ecological role that was intermediate to the other two species as suggested by niche breadth and niche overlap. Foraging and abundance of ardeids varied daily but increased from January to July with the greatest numbers observed in late June to July. Eleven foraging behaviors were observed among the ardeids.

Another study done by Buchanan in 1990, determined habitat utilization of Great Blue Herons in Elkhorn Slough, California. Buchanan tested parameters such as strike rate and success, total prey and mean prey length by various weather conditions, tide height and habitat types (i.e., *Salicornia* flats, islands, inland shallow, restored marsh, main channels, and mudflats). He found that *Salicornia* flats and the island habitat are both used primarily for non-foraging activities such as loafing, preening and social interactions with other ardeids, while the restored marsh was used most for foraging. The total number of prey caught by the herons was greatest in the restored marsh and lowest

in the *Salicornia* flats, although the mean prey length was highest in the island habitat. However, submerged *Salicornia* played an important role in the restored marsh habitat as cover for fish. Buchanan also found that cloud cover significantly reduced foraging success, and that wind and tidal conditions did not affect foraging success.

Heron and egrets forage both in groups, where there is a high prey density, and alone (Kushlan 1978). Even when feeding in groups, herons may defend feeding territories which can be defined by the distance it can reach with its head and neck (Hancock and Kushlan 1984). Aggregated feeding may occur when the prey is clumped and territories are reduced. This type of social feeding may help the birds achieve a sufficient net energy gain or capture rate to remain in a particular place which may also attract other birds to the same area. Commensal feeding may occur when a wading bird, such as the Snowy Egret, serves as the "beater" by foot stirring or raking and can increase prey for other bird species (Kushlan 1978).

Over 30 types of behaviors have been identified among herons and egrets (Kushlan 1978, Hom 1983, Hancock and Kushlan 1984, Gawlick and Kieckbusch 2003, Kelly *et al.* 2003). Behaviors can be classified as either a "posture" and/or a "body movement." The Great Blue Heron has been observed using at least 16 foraging behaviors, while the Great Egret uses at least 26 and the Snowy Egret uses at least 30 behaviors to hunt and capture prey.

When birds are foraging they can either strike their prey by piercing it or grasp their prey with the bill. A strike is made with the bill open whereas smaller prey such as worms are grasped. The way in which birds handle prey can vary as well. Ardeids can

catch prey, which may move up the bill during the event, which is then released and re-caught at the tip of the bill. Many prey are captured by flipping the bill upwards and catching the prey. After prey is caught and swallowed the bird often does a "headshake". Drinking or bill dipping is often seen after prey has been eaten.

Size and foraging activity have been correlated in herons and egrets; the Great Blue Heron and the Great Egret are known to be less active and use fewer foraging behaviors than medium sized egrets such as the Snowy Egret who may use several behaviors when foraging (Kushlan 1978). However, herons and egrets will often switch common behaviors due to changes in the pattern of prey density, habitat type or niche, or perhaps even in changing weather conditions. Gawlik (2002) suggests that prey availability does not always equal prey density, and that prey availability is a composite variable consisting of prey density and the vulnerability of a prey item. Many studies have suggested that weather, time of day, water level, and habitat type may effect foraging behaviors, strike rate and strike success (Buchanan 1990, Bancroft *et. al* 2002, and Gawlik 2002). Therefore, it was important to document the different foraging behaviors in each species in each site during this study, as these birds may use different behaviors and have different strike rates and success rates in different habitats, water levels, and weather conditions.

Quality habitat for wading birds is defined by water depth, vegetation characteristics, food abundance, distance from breeding sites, and distance from human disturbance (Custer and Galli 2002). Disturbance to foraging and nesting shorebirds by humans and dogs has been documented in several studies. It has been suggested that

chronic disturbance could reduce shorebird reproduction, survivorship, foraging efficiency and resting time. Lafferty (2001a, 2001b) found that thirty-nine percent of dogs observed disturbed 22 birds (in which 75% of birds flew off). When people were within 20 meters of birds this caused the birds to move or fly away. Birds were less reactive to human disturbance than to dogs. In Lafferty's study area, dogs were required to be on leash, however the law was not enforced and many dogs were unleashed; unleashed dog disturbance was a disproportionate source of disturbance. Thomas, *et.al.* (2003) found that number and activity of people significantly reduced the amount of time sanderlings (*Calidris alba*) spent foraging and that the most significantly negative factor was the presence of free running dogs on the beach. They also suggest that people be kept at a minimum of 30 meters away from birds to avoid disturbance. Rodgers and Smith's (1995) study on set-back distances to protect nesting bird colonies from human disturbance in Florida recommended a set-back of at least 100 meters, specifically from wading birds. Rodgers and Schwikert's (2002) study on buffer-zone distances to protect foraging and loafing waterbirds from disturbance by water craft and outboard-powered boats in Florida recommend a set-back of 150 meters.

Erwin *et al.* (1995) found that more than 30 species of colonial waterbirds, including herons and egrets, depend heavily on both natural and man-made islands smaller than 20 ha for nesting especially as human disturbance and coastal development has increased. They also found that the birds inhabiting these small islands were vulnerable to certain other types of disturbance, including inundation and erosion with sea level rise and lack of adequate maintenance of their nesting habitat especially in the

case of the man-made islands.

Very few studies have been done on disturbance to foraging herons and egrets in the South San Francisco Bay. Herons and egrets are disturbed easily and flushed more readily than shorebirds (Josselyn 1983). Other studies have suggested that weather, time of day, water level, and habitat type may effect foraging behaviors, strike rate, and strike success (Buchanan 1990, Bancroft *et. al* 2002, and Gawlik 2002).

There is a need for research on the foraging behaviors, habitat use, and selection among salt ponds and salt marshes by ardeids. To assess the value of an area for herons and egrets, it is necessary to monitor the use of feeding habitat and the proximity to breeding colonies, especially in the Bay area, where restoration is being conducted. This information would be useful in establishing a baseline dataset for biologists who are working with the South Bay restoration process. Many research and wetland restoration projects (e.g. Goals Project and SBSRP) are hoping to answer questions regarding shorebird use of low, medium, and high salinity ponds, managed marshes, and muted tidal marshes. Studies on the effects of disturbance on shorebirds to aid in developing suitable habitat buffer zones should also be a high priority in the restoration process.

This study looks at the specific habitat selection, use, foraging behaviors and possible effects of disturbance during foraging of the Great Blue Heron (*Ardea herodias*), the Great Egret (*Ardea alba*) and the Snowy Egret (*Egretta thula*), collectively called "ardeids", across low salinity salt ponds (< 40 ppt) and restored salt marshes in South San Francisco Bay. It is important to determine habitat use so that appropriate conservation measures can be taken where they are needed. I conducted abundance and behavior

surveys in each site for approximately 12 months to determine habitat selection and use.

The study sites are located at or near Shoreline at Mountain View in South San Francisco Bay approximately 15 miles north of the City of San Jose, California

(Fig. 4). The sites include Salt Pond A1 (inactive salt pond), Salt Pond A2W (inactive salt pond), Charleston Slough (former salt pond restored in 1996), Mountain View Tidal Marsh (restored in 1991), the Palo Alto Baylands Flood Control Basin (managed tidal marsh) and Steven's Creek Tidal Marsh (restored in 1983) (Fig. 5 and 6).

Figure 5. Aerial map of study sites in Mountain View, California. Map source: U.S. Geological Survey National Map Viewer, retrieved September 6, 2005: (<http://nmviewogc.cr.usgs.gov/viewer.htm>). Image courtesy of the USGS. Data available from U.S. Geological Survey, at the National Center for EROS, Sioux Falls, SD. (Copied with permission.) White-dotted lines are approximate viewshed areas within research sites. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Project Objectives

The goal of this study is to determine patterns of habitat selection of salt ponds and salt marshes by three ardeid species, by observing their abundance, use, and foraging behavior among six sites in the South Bay. This study addresses the following questions (specific hypotheses are listed in Table 3):

1. Does heron and egret abundance differ among salt ponds, restored salt marshes and the natural salt marsh site?
2. Is heron and egret abundance in each site associated with water depth, breeding season vs. non-breeding season, or salinity levels?
3. Does foraging depth differ among species or across sites?
4. Do heron and egret foraging behaviors differ among species and sites?
5. Does disturbance during foraging events differ among sites?
6. Do heron and egret foraging success rates or strike rates differ among sites?
7. Do prey size and type differ among ardeid species and sites?

METHODS AND STUDY AREA

Study Area

To determine the use of salt ponds and salt marshes by three resident ardeid species in the Shoreline at Mountain View and Palo Alto Baylands areas, six sites were chosen to represent a gradient of estuary habitat types (Table 1): Salt Pond A1 located in the Alviso Complex (inactive salt pond referred to as A1); Salt Pond A2W located in the Alviso Complex (inactive salt pond referred to as A2W); Inner Charleston Slough (former salt pond restored in 1996 referred to as CS); Mountain View tidal marsh (restored in 1991 referred to as MVTM); Palo Alto Baylands (managed tidal marsh referred to as PA) and Steven's Creek tidal marsh (restored in 1983 referred to as SCTM) (Fig. 3 and 6). Additional information on each site is listed in Appendix 6.

Abundance and foraging behavior surveys were conducted on Great Blue Heron, Great Egret and Snowy Egret in each of the six sites for approximately 12 months to determine habitat selection and use. These three species of birds are large and thus relatively easy to observe with spotting scopes and binoculars and they are year-round residents who depend on these habitats for foraging.

Bird counts were performed from June of 2004 to July of 2005. Several months of reconnaissance work were used to determine which sites and species would be appropriate for this study. Black-crowned Night-Herons were monitored for several months but removed from the study when it was determined that counts and foraging surveys would not be sufficient for statistical analyses (though they are seen regularly in Palo Alto Baylands during the day).

Table 1. Description of study sites. Data gathered for research sites were obtained through environmental sampling from June 2004 - July 2005, ArcGIS software and data from the Goals Project 1999. Refer to Table 2 for specific habitat types and substrates. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Site Descriptions:	A1	A2W	CS	MVTM	PA	SCTM
Habitat Type	Inactive salt pond	Inactive salt pond	Muted tidal marsh	Tidal marsh	Managed tidal marsh	Muted tidal marsh
Restoration Date	In process	In process	1996	1991	Natural	1983
Total Area (ha)	110	174	41	5	60	12
Total Survey Area (ha) Estimated	55	87	41	4	60	10
Potentially Suitable Habitat (ha)	38	63	35	4	56	10
Total Shoreline (m)	5684	6074	3736	1356	4305	1505
Total Edge Near Public Trail (m)	1172	1458	1754	1245	2848	1274
Total Edge Near Roads (m)	5684	6074	3736	939	2229	537
Average Salinity (ppt)	25	26	24	20	3	15
Minimum Water Height (cm)	48	60	95	-10	10	98
Mean Water Height (cm)	88	95	120	50	70	120
Maximum Water Height (cm)	300	270	128	200	92	137

Table 2. Habitat types (or substrate) within each site used all three species. Dominant short vegetation consisted of pickleweed (*Salicornia virginica*), salt grass (*Distichlis spicata*), alkali heath (*Frankenia salina*), and jaumea (*Jaumea carnosa*). Dominant tall vegetation consisted of cordgrass (*Spartina* sp.), cattail (*Typha* sp.), and gum plant (*Grindelia stricta* var. *angustifolia*). The water category consisted of open water, water channels and sloughs, ponds and pools. Artificial substrates consisted of concrete, tires, duck blinds, wooden posts, and boat and fishing docks. Algae mats (large enough to support the weight of a bird) grew only in the salt ponds. Further detail on each site is listed in APPENDIX 6. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Habitat Type	A1	A2W	CS	MVTM	PA	SCTM
Shoreline	X	X	X	X	X	X
Short-vegetation	X	X	X	X	X	X
Tall vegetation				X	X	X
Water	X	X	X	X	X	X
Levee	X	X	X	X	X	X
Island	X		X		X	
Algae	X	X				
Artificial	X	X	X	X	X	X
Mudflat			X	X	X	X

Figure 6. Research sites and trail map in Shoreline at Mountain View. Source: Wildlife Trail Map from the City of Mountain View Shoreline website retrieved July 1, 2005: http://www.ci.mtnview.ca.us/citydepts/cs/sd/trails_wildlife_map.htm. (Copied with permission).

- ◆ = Environmental Data Collection Site
- — — = Research Trail
- = Research Sites and Approximate Viewshed

Methods

Heron and egrets were monitored on two levels: Level one consisted of abundance surveys to determine habitat choice. Level two consisted of monitoring foraging (strike rate, success rate, approximate prey size, and type) and foraging behaviors to determine habitat use. Disturbance to the herons and egrets by humans, dogs, vehicles, predators, and other bird species was also monitored to determine if the relative use of sites was associated with disturbance.

At the beginning of each level one and level two survey the following parameters were noted: 1) date; 2) site; 3) survey start time; 4) survey end time; 5) air temperature (average centigrade); 6) average wind speed (mph); 7) cloud cover (% coverage); 8) water salinity (ppt); 9) site water depth (centimeters); 10) tide high time; 11) high tide height; 12) tide low time; and 13) low tide height. Environmental conditions such as average air temperature and wind speed were recorded using a Kestrel 3000 hand-held weather monitor. A refractometer was used to test salinity (ppt) levels. Relative water depth was measured from a permanent feature on the shoreline to the water's edge each survey day in each site.

Level One: Bird Count Methods

A bicycle was used to get to each of the sites as quickly as possible to avoid major tide or water level change during the surveys. Paved or dirt trails connected all sites (Fig. 6). Sites were monitored at low, medium and high water to determine if tide level had an effect on site use and behavior. I systematically altered the sequence in which sites were monitored between days. I used 8 x 35 binoculars to scan each site from two main

observation points and along the shoreline or trail, to see each side of each pond or marsh. The distance of the observations to the birds ranged from 20-200 meters (the approximate viewshed for each site is shown in Fig. 6).

In addition to environmental data, the following variables were recorded for level one surveys: 1) survey start time; 2) survey end time; 3) species; 4) species abundance; 5) quadrant of the pond or marsh where each individual was sighted (northwest, northeast, southwest, southeast); 6) habitat types that each individual occurred in or on: short vegetation (e.g., pickleweed, salt grass), tall vegetation (e.g. cattails, cordgrass), shoreline, in water (open water, channels, sloughs, ponds, and pools), mudflat, island, levee, algae, and artificial (e.g., power towers, concrete, wooden structures such as duck blinds, docks, and posts); 7) water depth category as measured on bird's leg: "land" or zero water depth (i.e., standing on exposed mud, algae, vegetation, shoreline, dock or levee), or water at the tarsometatarsus, tibiotarsus, or belly height; and 8) bird behavior: foraging or not foraging. "Not foraging" included loafing, preening and roosting. In order for the bird to be counted as "foraging" it must have been actively foraging upon first observation. Birds observed only in flight were not counted.

Level Two: Foraging Behavior Methods

To determine how foraging behavior and success differ among the sites, birds were monitored with 8x42 binoculars and a 20-60x78mm spotting scope, from a range of 20-200 meters away. Each survey consisted of 15-minutes of observation on an individual bird. I selected a bird for the foraging survey only if it was actively foraging

upon the start of the survey. The same bird was not observed again on the same day, unless two hours passed or the bird moved at least 200 meters.

Behavioral studies were done both on the same day as level one bird counts as well as on days when bird counts were not conducted. Studies were conducted from June, 2004 to July, 2005. Survey times and days were chosen both randomly and deliberately.

In addition to the same variables taken in the level one surveys, the following variables were recorded for the level two surveys: 1) age class of the bird: juvenile, adult or breeding adult; 2) foraging behavior(s); 3) number of foraging behaviors used; 4) distance to shore; 5) strike rate; 6) strike success rate determined by watching swallowing and headshake motions or by seeing the prey in the bill; 7) prey size determined by estimating the average length of prey compared to the average bill length of species (Hom 1983) (Great Blue Heron = 13 cm; Great Egret = 11cm; Snowy Egret = 8cm); 8) prey type; 9) disturbance during foraging event; 10) number of other Great Blue Herons; 11) number of other Great Egrets; 12) number of other Snowy Egrets in the site.

Strike rate and success, prey type, and size were tallied within consecutive 5-min periods. Herons and egrets can capture and swallow prey within seconds so the identification of prey was not always possible. Therefore, prey types were categorized into the following types: fish, invertebrates, unknown (too small to identify), and amphibians. Prey size was classified into 4 categories; less than 1 cm, 1-4.9 cm, 5-10 cm, more than 10 cm. The following body movement behaviors derived from Kushlan (1978), Hancock and Kushlan (1984) and Kelly, Gawlick, and Kieckbusch (2003) and

were used by the herons and egrets in this study: Stand and Wait, Walk Slowly (1 step/second), Walk Quickly (1-2 steps/second), Running, Foot Stirring, Foot Raking, Foot Probing, Bill Vibrating, Probing, Pecking, Head Swaying, Neck Swaying, Hopping, Gleaning, Dipping, Foot Dragging, Jumping, Feet First Diving, Wing Flicking, and Hovering. The herons and egrets in this study also used the following body postures: Crouching, Crouch and Wait, Crouch and Walk, Peering. In addition, "Jumping from Perch" was used to describe a distinct behavior that Snowy Egret juveniles used in pond A2W while jumping from docks into water to capture prey (similar to Feet First diving).

Every effort was made not to disturb the birds while monitoring. However, any disturbance to the bird that caused it to stop foraging for more than 5 minutes or to fly out of sight or out of the site was noted as one of the following disturbance categories: biker, jogger, walker, dog, observer, vehicle, plane, or other bird species including herons and egrets.

Statistical Analyses

Several questions were addressed relating to which sites, habitat types, foraging heights, and distance from shoreline that the herons and egrets use (Table 3). Methods for statistical analyses are from Quinn and Keough (2002). JMP software version 5.1 (business unit of SAS) was used for the statistical analyses. Several analyses pooled all three species while other analyses used separate species. Site sizes varied and potentially suitable habitat also varied within sites (Table 1). Therefore, I estimated the percentage of "potentially suitable habitat" in each site based on water depth bathymetry data (source: USGS) in Salt Pond A1 and A2W and water depth measurements in CS and PA.

The extent of potentially suitable habitat in each site was converted to a percentage of total site size in the analyses that compare frequency of birds across sites (observed versus expected). Water depth suitable for herons and egrets to forage in while wading is based on their average leg length. Total leg lengths (tarsus and tibia) from Hom (1980) are as follows: Great Blue Heron (16.8 + 21.8 cm), Great Egret (15.3 + 19.9 cm) and Snowy Egret (10.2 + 14.3 cm). For example, in Charleston Slough, a section of the northwest corner remains flooded during all tidal cycles and is too deep (~70 cm) for herons and egrets to wade in based on water depth data from Pittman (1996). Thus, that area was not included in the suitable habitat. Portions of Palo Alto Flood basin water channels are too deep for herons and egrets to wade in and were removed from the potentially suitable habitat area. The water depth in PA is based on measurements at the location where environmental data were collected and water depth was over 70 cm at low tide. This characterization of potentially suitable habitat is based on environmental conditions that existed during this study. Therefore, if environmental conditions change drastically in the future, the potentially suitable habitat areas may change, as well.

The following analyses were done (see Table 3 for questions addressed):

Bird Counts

Analysis 1: A Chi-Square analysis (Pearson test; Quinn and Keough, 2002) was used to test for differences in the use (frequency) of the research sites. All three species were pooled and the total frequencies were compared among sites, using an expected (null) frequency based on the relative extent of potentially suitable habitat at each site. Bird densities per hectare were also calculated and tabulated.

Analysis 2: Chi-Square analyses were used to test for differences in the use (frequency) of the research sites. Each species was examined separately and frequencies were compared among sites, using an expected (null) frequency based on the relative extent of potentially suitable habitat at each site.

Analysis 3: A Chi-Square analysis was used to test for differences in the use (frequency) of the research sites, between breeding and non-breeding season. Breeding season consisted of the months from February through late July and non-breeding season consisted of the months from August through late January. All three species were pooled and the total frequencies were compared between seasons.

Analysis 4: (a) Regression analyses (Quinn and Keough, 2002) were used to test for a relationship between the use of each site by each species, and water depth in centimeters measured at a standard location for each site. Methods of measuring water depth in each site were different; therefore, sites were not compared with each other in this analysis. (b) Water depth was also classified into three relative depth categories (low, medium and high) within each site. By using these codes, the general pattern of use or preference at each relative depth class could be determined for each site and for each species, using 24 Chi-Square tests, one for each combination of species and sites (18 tests) and species pooled for each site (6 tests).

Analysis 5: Differences among the number of birds of each species foraging at each water depth class were tested in each site using Chi-Square analyses. Water depth levels at foraging locations were categorized into four categories based on the depth of water on the bird itself: exposed land, tarsus, tibia, and belly depth. If a bird was

foraging but not in the water (e.g., exposed land, mudflat, non-inundated vegetation, artificial structures) then the "exposed land" category was assigned. Only the initial water depth category was recorded for each observation. Twenty-four Chi-Square tests were done, one for each combination of species and sites (18 tests) and species pooled for each site (6 tests).

Analysis 6: Differences between the use (frequency) of each habitat type in each site were tested using Chi-Square analyses. Habitat types (Table 2) differed in each site (e.g., "levee" habitat did not occur in two of the restored marsh sites; "algae" existed only within the salt ponds during the study), therefore these analyses could not be pooled across sites. However, the difference in the use of habitat types within each site was tested for each species, using 18 Chi-Square tests, one for each combination of species and sites, with a null hypothesis that assumed equal use of habitats regardless of their relative availability.

Analysis 7: Chi-Square analyses were used to test for differences in the number of foraging birds and non-foraging birds in each site (6 tests; species pooled).

Analysis 8: (a) A One-Way Analysis of Variance (ANOVA; Quinn and Keough, 2002) was used to test for differences in mean salinity among sites. (b) Regression analyses were used to test the relationship between the use of sites and site salinity levels (ppt). Species were pooled and compared within each site (6 tests total).

Foraging Behavior

Analysis 9: (a) ANOVA was used to test for the average number of foraging behaviors used by each species. Four tests were done, one for each species comparing sites and another with sites pooled comparing species. Note that there was an uneven sample size. (b) Total number of foraging behaviors used by each species in each site was tabulated. Foraging behaviors are based on Kushlan (1978), Hancock and Kushlan (1984) and Kelly, Gawlick and Kieckbusch (2003).

Analysis 10: The average foraging distance from shoreline of each species in each site was tested using ANOVA. Foraging distance from shoreline by each species in each site was estimated using binoculars, and categorized into six classes: less than 5m, 5-10m, 10-20m, 20-30m, 30-40m, or more than 40m. Seven tests were done comparing species, one for each site and another with sites pooled. Note that there was an uneven sample size.

Analysis 11: Habitat types used while foraging were tabulated. Frequencies of habitat use were calculated for each species within each site.

Analysis 12: (a) Total number of disturbances and (b) types of disturbances were tested for all species pooled in each site using Chi-Square. Seven tests were done, one for each site and one with sites pooled. (c) Percentages of disturbances versus no disturbance in each site were also tabulated.

Analysis 13: Differences in the average foraging depth of each species among sites were tested using ANOVA. Water depth levels at foraging locations were categorized into four categories based on the depth of water on the bird itself: exposed

land, tarsus, tibia, and belly depth. Foraging depth was averaged per survey according to the depths the focal bird used during the entire survey period. Four tests were done, one for each species and one with species pooled.

Analysis 14: Differences in the prey capture rates of each species among sites was tested using ANOVA. The prey capture success rate was calculated by dividing the number of successes by the number of strikes (for each individual observation). Four tests were done, one for each species and one with species pooled.

Analysis 15: Strike rate and strike successes per minute for each species in each site were tested using ANOVA. Species were not compared against each other as studies have shown that their rates differ significantly (Hom 1983, Brzorad, *et al.* 2003). Strike success was calculated by dividing the number of successes by the number of strikes per species in each site for each 5-minute interval. Note that many surveys did not go for the entire 15 minutes, in which case only the 0-5 and 5-10 intervals were recorded. Four tests were done, one for each species and one with species pooled.

Analysis 16: (a) Prey total, type, and length were summarized in tables and graphs. (b) The total number of prey captured in each site were tested with Chi-Square using an expected (null) frequency based on the number of surveys per site (due to an uneven sample size). Prey types consisted of 1) Fish; 2) Invertebrates; 3) Unknown; and 4); Amphibians. "Invertebrates" consisted of annelids, crabs, and insects. "Unknown" prey were too small to identify. Four tests were done, one for each bird species and one with species pooled.

Table 3. Specific research questions and types of statistical tests used.

Level One: Abundance Counts:

1. Is there a difference between the use (number of birds) in each site by all three species pooled?	Chi-Square
2. Is there a difference between the use (number of birds) in each site by each species separately?	Chi-Square
3. Is there a difference between the use (number of birds) in all sites by all three species pooled in breeding season vs. non-breeding season?	Chi-Square
4. (a) For each site, is there an association between the use by each species and water height (cm)? (b) Is there a difference in use of water depth categories within and across species and sites?	Regression
Chi-Square
5. Is there a difference between water depth at foraging (land, tarsus, tibiotarsus, or belly) in each site by each species?	Chi-Square
6. Is there a difference between the use of habitats in each site by all three species pooled.	Chi-Square
Graphs
7. Is there a difference between the number of birds who are foraging vs. not-foraging in each site by all three species pooled?	Chi-Square
8. (a) Is there a difference between the salinity among all sites? (b) Is site use by all three species (pooled) related to salinity?	ANOVA
Regression

Level Two: Foraging Behavior:

9. Are there differences between the mean number of foraging behaviors across all sites used by each species? What is the total number of behaviors that each species used in each site?	ANOVA
Tables
10. What was the average foraging distance from the shoreline in each site by all the species pooled and each species separately?	ANOVA
11. Which habitat types were used by each species in each site for foraging?	Table
12. Did the total number of disturbances in each site during foraging differ? What were the disturbance types for each site?	Chi-Square
Table, Chart
13. Is there a difference in average foraging depth (land, tarsus, tibiotarsus, or belly) for each species among sites?	ANOVA
14. Did the average prey capture success rate for each species differ significantly among sites?	ANOVA
Table
15. Did the strike rates and strike success rates for each species differ significantly among sites?	ANOVA
16. What were the prey type and prey length captured by each species in each site? Did the total amount of prey captured by each species differ significantly among sites?	Tables
Chi-Square

RESULTS

Bird Counts

Analysis 1: The total number of birds observed among sites was significantly different (Table 4a). The highest number of birds was highest in A2W ($n = 411$) and lowest in SCTM ($n = 25$). Frequencies are visualized in Figure 7a. The observed frequency of birds was significantly higher in A1 than expected and significantly lower in CS than expected (Table 4a). Bird densities (birds per ha) were also calculated for each site and listed in APPENDIX 1. The highest bird density was in A1 ($n = 10.42$ per ha) while the lowest bird density was in SCTM ($n = 2.5$ per ha).

Analysis 2. When each species was tested separately, site use by the each species differed significantly (Table 4b, c, d) from expected distributions based on the extents of available habitat (Figure 7b, c, d). Great Blue Heron use was highest in PA ($n = 33$) and was never observed in SCTM. Great Egret use was highest in PA ($n = 19$) and lowest in SCTM ($n = 1$). Snowy Egret use was highest in A1 ($n = 321$) and lowest in MVTM ($n = 18$).

Analysis 3: Overall use of the study area by all species pooled was significantly less ($X^2 = 178.522$, $P < 0.0001$, $df = 1$) in the breeding season ($n = 389$ February-July) when compared with non-breeding season ($n = 919$ August-January).

Analysis 4: (a) There were no significant differences for any species between the number of birds and water depth in each site (separate regressions of use of each site by each species; $P > 0.05$). (b) The number of birds by species was also compared to water depth classes (low, medium and high) in each site separately (Table 5). When water depth

use by all species pooled was compared in A1, A2W, CS and PA were significant differences in usage (Table 5) except in MVTM and in SCTM. In A1, birds were more abundant at the lowest water depth ($n = 217$), than at the medium water depth ($n = 126$) and highest water depth ($n = 54$). In A2W, birds were more abundant at the medium water depth ($n = 91$) than at low ($n = 8$) or high ($n = 50$) water depths. In CS, birds were more abundant at the highest depth ($n = 42$) than at the low ($n = 20$) or medium ($n = 29$) depths. In PA, birds were more abundant at the highest depth ($n = 177$) than at low ($n = 96$) or medium ($n = 76$) depths. Results are visualized in APPENDIX 2.

Analysis 5: The number of birds at each foraging depth (land, tarsus, tibia, and belly) for each species within each site was significantly different in most cases (Table 6). Overall, when the species were pooled there were significant differences in foraging depths in each study site (Table 6). Overall, each species foraged at the tarsus depth more than the other foraging depths in each site except for in MVTM where the birds foraged at the tibia depth more frequently. The tibia depth was used more than the belly depth in all sites. The birds foraged on land only in the CS and PA sites. Results are visualized in Figure 8.

Analysis 6: Habitat use in each site was significantly different for most species based on a null hypothesis that assumed equal use of habitats (see Table 7). The results are visualized in Figure 9. Overall, each of the species was observed in the water category in each site more than any other habitat. Short vegetation was used by each of the species except for the Great Blue Heron in CS. Mudflats were used by the Great Egret and the Snowy Egret. The shoreline was used by all species. Tall vegetation was

used in PA by the Great Blue Heron and the Snowy Egret. Algae mats were used by the Great Egret and Snowy Egret. Islands, artificial substrates and levees were used by all three species though not in high amounts.

Analysis 7: Significantly more birds were foraging ($n = 955$) than not foraging ($n = 317$) in the study area (all sites pooled). When all species were pooled and compared among sites the number of birds foraging was significantly higher than the number of non-foraging birds in all cases (Table 8). Results are visualized in Figure 10.

Analysis 8. (a) The mean salinities among sites were significantly different ($F_{5,116} = 38.955$, $P < 0.0001$) (Figure 11). The mean salinity was highest in A2W and lowest in PA. A Tukey-Kramer HSD test ($\alpha = 0.05$) showed that PA was significantly lower in salinity than all other sites. (b) When regressions were used to test for relationships between the number of birds and salinity levels (ppt) in each site the results were not significant ($P > 0.05$); no patterns were observed between salinity levels (ppt) and bird use.

Figure 7a, b, c, d. Analyses 1 and 2. Distribution of birds from June 2004 through July 2005. (a) Chi-Square was significant ($X^2 = 215.8785$, $P < 0.0001$, $df = 5$) for the total number of birds in each site. (b) Chi-Square was significant ($X^2 = 72.8866$, $P < 0.0001$, $df = 5$) for the number of Great Blue Herons in each site. (c) Chi-Square was significant ($X^2 = 39.5508$, $P < 0.0001$, $df = 5$) for the number of Great Egrets in each site. (d) Chi-Square was significant ($X^2 = 190.5454$, $P < 0.0001$, $df = 5$) for the number of Snowy Egrets in each site. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Table 4. Analyses 1 and 2. Frequency for and all three species pooled and separately within each site. The proportion of suitable habitat in each site was used as the expected probability. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

(a) Test probabilities for the total number of birds in each site			
Sites	Observed Proportion	Expected Proportion	
A1	0.30275	0.18000	
A2W	0.31422	0.31000	
CS	0.06957	0.17000	
MVTM	0.02752	0.02000	
PA	0.26682	0.27000	
SCTM	0.01911	0.05000	
Test	ChiSquare	DF	Prob>Chisq
Pearson	215.8785	5	<.0001

(b) Test probabilities for the Great Blue Heron in each site			
Sites	Observed Proportion	Expected Proportion	
A1	0.14130	0.18000	
A2W	0.32609	0.31000	
CS	0.04348	0.17000	
MVTM	0.13043	0.02000	
PA	0.35870	0.27000	
SCTM	0.00000	0.05000	
Test	ChiSquare	DF	Prob>Chisq
Pearson	72.8866	5	<.0001

Table 4. (Continued) Analyses 1 and 2. Frequency for the Great Egret and Snowy Egret in each site. The proportion of suitable habitat in each site was used as the expected probability. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh

(c) Test probabilities for the Great Egret in each site			
Sites	Observed Proportion	Expected Proportion	
A1	0.24506	0.18000	
A2W	0.35573	0.31000	
CS	0.04743	0.17000	
MVTM	0.02372	0.02000	
PA	0.31621	0.27000	
SCTM	0.01186	0.05000	
Test	ChiSquare	DF	Prob>Chisq
Pearson	39.5508	5	<.0001

(d) Test probabilities for the Snowy Egret in each site			
Sites	Observed Proportion	Expected Proportion	
A1	0.33333	0.18000	
A2W	0.30218	0.31000	
CS	0.07788	0.17000	
MVTM	0.01869	0.02000	
PA	0.24507	0.27000	
SCTM	0.02285	0.05000	
Test	ChiSquare	DF	Prob>Chisq
Pearson	190.5454	5	<.0001

Table 5. Analysis 4b. Results of 24 Chi-Square tests of water depth class (low, medium and high) and frequency for each species alone, and all three species pooled, within each site. The df = 2 for all 24 tests. The preferred water depth class is listed below each significant result. NS= Results were not significant. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. Results for each species and species pooled in each site are visualized in APPENDIX 2.

Site	Great Blue Heron	Great Egret	Snowy Egret	All Species Pooled
A1	NS	$X^2 = 13.238$ $P = 0.0013$ Medium	$X^2 = 120.505$ $P < 0.0001$ Low	$X^2 = 100.841$ $P < 0.0001$ Low
A2W	$X^2 = 21.600$ $P < 0.0001$ Medium	$X^2 = 39.800$ $P < 0.0001$ Medium	$X^2 = 51.964$ $P < 0.0001$ Low	$X^2 = 69.356$ $P < 0.0001$ Medium
CS	NS	NS	$X^2 = 6.720$ $P = 0.0347$ High	$X^2 = 8.066$ $P = 0.0177$ High
MVTM	NS	NS	NS	NS
PA	NS	NS	$X^2 = 57.314$ $P < 0.0001$ High	$X^2 = 49.175$ $P < 0.0001$ High
SCTM	NS	NS	$X^2 = 6.909$ $P = 0.0316$ Medium	NS

Table 6. Analysis 5. Results of 24 Chi-Square tests of foraging depth (land, tibia, tarsus, and belly) for each species alone, and all three species pooled, within each site. The df = 3 for all 24 tests. NS= Results were not significant. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. Refer to Figure 8 for a visualization of each species in each site and foraging depth.

Site	Great Blue Heron	Great Egret	Snowy Egret	All Species
A1	NS	$X^2 = 13.556$ $P = 0.0036$	$X^2 = 183.694$ $P < 0.0001$	$X^2 = 183.939$ $P < 0.0001$
A2W	NS	$X^2 = 41.133$ $P < 0.0001$	$X^2 = 138.784$ $P < 0.0001$	$X^2 = 170.167$ $P < 0.0001$
CS	NS	NS	$X^2 = 72.941$ $P < 0.0001$	$X^2 = 78.688$ $P < 0.0001$
MVTM	$X^2 = 11.000$ $P = 0.0117$	NS	$X^2 = 13.533$ $P = 0.0036$	$X^2 = 23.307$ $P < 0.0001$
PA	$X^2 = 11.471$ $P = 0.0094$	$X^2 = 37.286$ $P < 0.0001$	$X^2 = 129.061$ $P < 0.0001$	$X^2 = 176.218$ $P < 0.0001$
SCTM	No test: n = 0	NS	$X^2 = 35.571$ $P < 0.0001$	$X^2 = 27.500$ $P < 0.0001$

Figure 8. Analysis 5. Frequency of foraging depths by the Great Blue Heron, Great Egret and Snowy in Egret in each site. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA =Palo Alto, SCTM = Steven's Creek Tidal Marsh. Refer to Table 6 for results.

Figure 9. Analysis 6. Habitat use in each site by each species. The Great Blue Heron was not observed in SCTM and therefore is not represented in the Steven's Creek Tidal Marsh graph. GBHE = Great Blue Heron, GREG = Great Egret, SNEG = Snowy Egret.

Table 7. Analysis 6. Results of 18 Chi-Square tests of habitat use for each species alone within each site. NS= Results were not significant. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. Refer to Figure 9 for a visualization of each species in each site and habitat use.

Site	Great Blue Heron	Great Egret	Snowy Egret
A1	NS	$X^2 = 82.065$ $P < 0.0001$ $df = 6$	$X^2 = 234.268$ $P < 0.0001$ $df = 6$
A2W	$X^2 = 19.000$ $P = 0.0042$ $df = 6$	$X^2 = 170.769$ $P < 0.0001$ $df = 6$	$X^2 = 296.310$ $P < 0.0001$ $df = 6$
CS	NS	$X^2 = 12.000$ $P = 0.0348$ $df = 5$	$X^2 = 146.360$ $P < 0.0001$ $df = 5$
MVTM	$X^2 = 31.333$ $P < 0.0001$ $df = 4$	NS	$X^2 = 45.333$ $P < 0.0001$ $df = 4$
PA	$X^2 = 38.181$ $P < 0.0001$ $df = 8$	$X^2 = 193.600$ $P < 0.0001$ $df = 8$	$X^2 = 460.910$ $P < 0.0001$ $df = 8$
SCTM	NS	NS	$X^2 = 9.364$ $P < 0.0093$ $df = 2$

Table 8. Analysis 7. Results of 6 Chi-Square tests of foraging vs. non-foraging. A1 = Salt Pond A1, A2W = Salt Pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Site	Chi-square test for foraging vs. non-foraging
A1	$X^2 = 184.209$, $P < 0.0001$, $df = 1$
A2W	$X^2 = 77.055$, $P < 0.0001$, $df = 1$
CS	$X^2 = 59.756$, $P < 0.0001$, $df = 1$
MVTM	$X^2 = 11.111$, $P = 0.0009$, $df = 1$
PA	$X^2 = 23.824$, $P < 0.0001$, $df = 1$
SCTM	$X^2 = 9.000$, $P = 0.0027$, $df = 1$

Figure 10. Analysis 7. Number of birds in each site foraging (gray bars) and not-foraging (black bars). A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Figure 11. Analysis 8. Average salinity (ppt) in each site. Results were significant ($F_{5,116} = 38.955$, $P < 0.0001$) in ANOVA. Diamonds connect mean lines to standard errors. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Foraging Behavior

Analysis 9. (a) The number of behaviors used by each species in different sites was not significantly different (Great Blue Heron, $F_{3,9} = 0.7992$, $P > 0.05$; Great Egret, $F_{5,13} = 1.9876$, $P > 0.05$; Snowy Egret, $F_{5,49} = 0.6583$, $P > 0.05$). The average number of foraging behaviors that each species used was significantly different with study sites pooled ($F_{2,84} = 6.7645$, $P < 0.0001$) (Figure 12). A Tukey-Kramer HSD test ($\alpha = 0.05$) showed that the Snowy Egret used significantly more behaviors than the other two species. (b) The total number of behaviors used during the course of this study by the Great Blue Heron was five, the Great Egret was seven, and the Snowy Egret was 24 (Figure 13). Tables of the names of each behavior and posture used are located in the Appendices (APPENDIX 5).

Analysis 10: The distance foraged from shore was significantly different ($F_{1,3} = 105.8000$, $P = 0.0020$) only in CS for the Great Egret and the Snowy Egret (note that Great Blue Herons were not present in CS). In CS, the Great Egret foraged more than 40 meters from shore and the Snowy Egret foraged less than five meters from the shoreline. When the average foraging distance from shore was tested with all sites pooled the species were not significantly different ($F_{2,84} = 1.4577$, $P > 0.05$).

Analysis 11: Habitat types used by each species separately while foraging in each site were not analyzed due to uneven distribution and low sample sizes. However, frequencies of habitat use by all species pooled were calculated. The most frequently used habitat type in each site for foraging was "water" ($n = 76$); this category included open water, pools, ponds, channels, and sloughs. The shoreline habitat was used three

times in CS and mudflats were used seven times in MVTM for foraging. Table 9 lists the percentage of time each species used each habitat type while foraging.

Analysis 12: Disturbance to birds while foraging occurred 24 times out of 87 surveys (Table 10). Types of disturbances consisted of the following; bicyclist, Black-crowned Night-Heron, Great Blue Heron, Great Egret, Snowy Egret, Forster's tern, domestic dog, observer, walker, vehicle, photographer, and unknown disturbances (Table 11). The area of the site where these disturbances occurred is shown in Table 11. Percentages of time each type of these disturbances occurred are shown in Figure 14. The total number of disturbances that occurred in each site did not differ significantly ($X^2 = 9.000$, $P > 0.05$, $df = 5$). Species type disturbed during foraging surveys was significantly different ($X^2 = 9.752$, $P = 0.0076$, $df = 2$); Snowy Egrets ($n = 15$) were disturbed more than the Great Blue Heron ($n = 6$) and Great Egret ($n = 3$) (Table 11). The disturbances affected the length of foraging times for each species. Several 15-minute surveys were cut short due to disturbances mainly in A1, A2W and SCTM. On occasion, vehicles accessing salt pond levees disturbed and interrupted foraging surveys. When accessing the levees with the Department of Fish and Wildlife on two occasions, I observed several foraging herons and egrets fly away, sometimes clear across the salt pond as the vehicle passed by. On one occasion, a dog that was on a long leash walked to the waters edge of CS and forced a Snowy Egret to fly away during a foraging survey. Several times dogs had been observed off leash on the trail between CS and PA (known as the Bay trail or the Adobe Creek trail).

Analysis 13: Differences in the average foraging depth (land, tarsus, tibia and belly) during each individual behavioral survey for each species alone in each site and with species pooled in each site was tested. When all species were pooled by site, their average foraging depth class during the survey was not significantly different ($F_{5,81} = 2.1618$, $P = 0.066$). The mean water depth class while foraging for all surveys in all sites was 1.6 for Great Blue Herons and Great Egrets (which on a height scale from 0=land, 1=tarsus, 2=tibia, 3=belly is in between the tarsus and tibia height). The mean water depth class while foraging for the Snowy Egret was 1.5, which is between tarsus and tibia depth. Analysis of each species separately showed that differences in average foraging depth among sites was significant for the Snowy Egret ($F_{5,49} = 2.6435$, $P = 0.0341$) but not for the other two species. A Tukey-Kramer HSD test ($\alpha = 0.05$) showed that only CS was significantly different from the other 5 sites; the Snowy Egret foraged more often at the "exposed land" depth in CS than in the other sites.

Analysis 14: When the success rate of prey capture of all species (pooled) was tested among sites the results were not significant ($F_{5,68} = 1.6607$, $P > 0.05$). However, the mean success rate was significantly different among sites for the Great Egret ($F_{4,11} = 6.8305$, $P = 0.0051$) but not for the other two species ($P > 0.05$); a Tukey-Kramer HSD test ($\alpha = 0.05$) showed that in CS the success rate was significantly higher than in the other 4 sites. The Great Egret success rate was highest in CS and lowest in SCTM. Success rates for each species in each site are listed Table 12.

Analysis 15: The mean strikes per minute was significantly different among sites only for the Snowy Egret ($F_{5,44} = 2.5679$, $P = 0.0401$). A Tukey-Kramer HSD test ($\alpha =$

0.05) showed that in CS the strikes per minute were significantly greater than in the other 5 sites; the mean strike per minute was highest in CS and lowest in PA.

Strike success was significantly different among sites only for the Snowy Egret ($F_{5,44} = 2.7247$, $P = 0.0314$). A Tukey-Kramer HSD test ($\alpha = 0.05$) showed that only in CS was the strike success per minute significantly greater than in the other 5 sites; the mean strike success per minute was highest in CS and lowest in PA. Strikes and success per minute for each species in each site are list in Table 12.

Analysis 16: (a) Prey types and lengths are summarized in Tables 13 and 14 and shown graphically in Figures 15 and 16. The "Invertebrates" category included annelids, insects and crustaceans. Snowy Egrets captured worms (*Annelid spp.*) from muddy shorelines in both MVTM and A2W. The worms were not identified but resembled earthworms up to approximately 8 cm in length. The "Amphibians" prey category consisted only of one small frog (~10cm) captured by a Snowy Egret. The "Unknown" category consisted of prey that were too small to identify but may have included annelids, insects and crustaceans. (b) The total number of prey caught by all species was significantly different among sites ($X^2 = 71.0455$, $P < 0.0001$, $df=5$; Table 15). The prey capture was highest in A2W and lowest in CS. The total prey captured was higher in CS and in SCTM than expected, while the total amount of prey captured in PA was lower than expected (Table 15). The total amount of prey captured by the Great Blue Heron in each site was significantly different ($X^2 = 10.6969$, $P = 0.0135$, $df = 3$; Table 16). The observed amount of prey captured was lower than expected in A2W and higher than expected in both A1 and PA. The Great Blue Heron captured the highest amount of prey

in PA ($n = 13$) and the lowest amount in A2W ($n = 2$). The total amount of prey captured by the Great Egret in each site was significantly different ($X^2 = 54.0062$, $P < 0.0001$, $df = 5$; Table 16). The observed amount of prey captured was lower in A1 and higher in A2W than expected. The Great Egret captured the highest amount of prey in A2W ($n = 86$) and the lowest in CS and SCTM ($n = 6$). The total amount of prey captured by the Snowy Egret in each site was significantly different ($X^2 = 60.6238$, $P < 0.0001$, $df = 5$; Table 16). The observed amount of prey captured was lower in PA than expected. The Snowy Egret captured the highest amount of prey in A1 ($n = 120$) and the lowest amount in PA ($n = 58$).

Figure 12. Analysis 9. Average number of foraging behaviors of each species in all sites ($F_{2,84} = 6.765$, $P < 0.0001$). Diamonds connect the mean lines to standard errors. GBHE = Great Blue Heron, GREG = Great Egret, SNEG = Snowy Egret.

Figure 13. Number of behaviors used by each species in each site. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. GBHE = Great Blue Heron, GREG = Great Egret, SNEG = Snowy Egret.

Table 9. Analysis 11. Percentage of habitat types used by each species in each site during foraging surveys. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. GBHE = Great Blue Heron, GREG = Great Egret, SNEG = Snowy Egret.

A1	Shoreline	Short Veg.	In Water	Island	Algae
GBHE			100		
GREG			100		
SNEG	6	6	63	6	19

A2W	Shoreline	Short Veg.	In Water	Artificial	Algae	Levee
GBHE	20		60			20
GREG	20		80			
SNEG	13	13	60	7	7	

CS	Shoreline	Short Veg.	In Water	Island	Mudflat
GREG			50		50
SNEG	50	33	0	17	0

MVTM	Shoreline	Short Veg.	In Water	Mudflat
GBHE	50		50	
GREG		100		
SNEG	8	8	75	8

PA	Shoreline	Tall Veg.	Branch	In Water	Mudflat
GBHE				100	
GREG				100	
SNEG	6	11	11	67	6

SCTM	Shoreline	In Water	Mudflat
GREG		50	50
SNEG	8	46	46

Figure 14. Analysis 12. Percentages of disturbances to herons and egrets (species pooled) while foraging.

Table 10. Analysis 12. Percentages of surveys disturbed and not disturbed.

Site	# Surveys	% Disturbed	% Not disturbed
Salt Pond A1	20	15	85
Salt Pond A2W	23	40	60
Charleston Slough	5	20	80
Mountain View Tidal Marsh	11	36	64
Palo Alto	20	15	85
Steven's Creek Tidal Marsh	8	50	50

Table 11. Analysis 12. Disturbances in each site and the location of the disturbance. NW=Northwest corner of the site, SW=Southwest corner of the site, NE=Northeast corner of the site, SE= Southeast corner of the site. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh. GBHE = Great Blue Heron, GREG = Great Egret, SNEG = Snowy Egret.

Date	Site	Species	Disturbance	NW	SW	NE	SE
8/25/04	A1	SNEG	Photographer		X		
9/5/04	A1	SNEG	Plane		X		
7/16/04	A1	SNEG	SNEG		X		
7/1/04	A2W	SNEG	BCNH		X		
2/5/05	A2W	GBHE	Bicyclist		X		
2/12/05	A2W	SNEG	GBHE		X		
7/16/04	A2W	GREG	GREG		X		
3/6/05	A2W	GBHE	Plane		X		
11/8/04	A2W	GBHE	Vehicle, SNEG		X		
6/27/05	A2W	SNEG	SNEG				X
5/23/05	A2W	SNEG	Unknown		X		
5/23/05	A2W	GREG	Vehicle		X		
12/22/04	CS	SNEG	SNEG	X			
1/29/05	MVTM	GBHE	GBHE	X			
2/5/05	MVTM	GREG	GREG			X	
1/13/05	MVTM	SNEG	Observer		X		
5/28/05	MVTM	SNEG	Observer		X		
7/17/05	PA	GBHE	Forster's Tern		X		
6/10/05	PA	GBHE	GREG				X
3/25/05	PA	SNEG	SNEG				X
8/19/04	SCTM	SNEG	Bicyclist			X	
8/3/04	SCTM	SNEG	Domestic Dog			X	
2/18/05	SCTM	SNEG	Unknown			X	
3/6/05	SCTM	SNEG	Walker			X	

Table 12. Analyses 14 and 15. Average success rate, mean strikes and successes per minute and total minutes observed for each species in each site. The success rate for the Great Egret was significantly different ($F_{4,11} = 6.8305$, $P = 0.0051$) among sites. Analysis 15: The mean strike per minute for the Snowy Egret was significantly different ($F_{5,44} = 2.5679$, $P = 0.0401$) among sites. The mean strike success per minute among sites for the Snowy Egret was significantly different ($F_{5,44} = 2.7247$, $P = 0.0314$). A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

	Percent Success Rate	Mean Strikes/ Minute	Mean Success/ Minute	Minutes Observed
Great Blue Heron				
A1	83%	0.53	0.30	25
A2W	100%	0.13	0.13	20
MVTM	No strike	No strike	No success	15
PA	83%	0.38	0.23	75
Great Egret				
A1	96%	0.42	0.40	45
A2W	97%	0.78	0.73	110
CS	100%	1.20	1.20	40
MVTM	No strike	No strike	No Success	5
PA	96%	0.47	0.42	45
SCTM	66%	0.40	0.27	15
Snowy Egret				
A1	81%	0.89	0.76	95
A2W	89%	0.77	0.68	100
CS	89%	2.07	1.90	15
MVTM	86%	0.87	0.73	95
PA	78%	0.63	0.42	160
SCTM	72%	1.16	0.93	90
Total Minutes Observed				940

Table 13. Analysis 16a. Summary of prey lengths and total prey caught by each species. The total prey captured with species pooled in each site was significantly different ($X^2 = 71.0455$, $P < 0.0001$, $df = 5$). The total prey captured by the Great Blue Heron in each site was significant ($X^2 = 10.6969$, $P = 0.0135$, $df = 3$). The total prey captured by the Great Egret in each site was significant ($X^2 = 54.0062$, $P < 0.0001$, $df = 5$). The total prey captured by the Snowy Egret in each site was significant ($X^2 = 60.6238$, $P < 0.0001$, $df = 5$). A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

		Prey < 1 cm	Prey 1-4.9 cm	Prey 5-10 cm	Prey > 10 cm	Total prey
Great Blue Heron						
	A1	8	0	2	0	10
	A2W	1	1	0	0	2
	PA	6	1	5	1	13
Great Egret						
	A1	10	8	0	0	18
	A2W	43	23	20	0	86
	CS	6	0	0	0	6
	PA	16	3	0	0	19
	SCTM	4	2	0	0	6
Snowy Egret						
	A1	100	4	16	0	120
	A2W	59	8	9	1	77
	CS	62	5	0	0	67
	MVTM	46	28	14	0	88
	PA	53	2	3	0	58
	SCTM	76	1	2	0	79

Table 14. Analysis 16a. Summary of prey type captured by each species in each site. "Unknown" prey were too small to identify. "Amphibians" prey consisted of one small frog. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

	Fish	Invertebrates	Unknown	Amphibians
Great Blue Heron				
A1	2	0	8	0
A2W	1	0	1	0
PA	6	1	6	0
Great Egret				
A1	8	0	10	0
A2W	43	0	43	0
CS	0	0	6	0
PA	3	0	16	0
SCTM	1	0	5	0
Snowy Egret				
A1	19	0	101	0
A2W	9	20	47	0
CS	5	3	104	0
MVTM	22	19	46	0
PA	3	1	53	1
SCTM	3	0	78	0

Table 15. Analysis 16b. Chi-square test for total prey caught in each site (all species pooled). Data are summarized in Table 13. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Site	Expected Proportion	Observed Proportion	Total Prey Caught
A1	0.22992	0.22981	148
A2W	0.26506	0.24845	160
CS	0.05723	0.11335	73
MVTM	0.12651	0.13665	88
PA	0.22992	0.13975	90
SCTM	0.09137	0.13199	85
Test	Chi-Square	DF	Prob>Chisq
Pearson	71.0455	5	<.0001

Table 16. Analysis 16b. Chi-square tests for total prey caught in each site for each species. Data are summarized in Table 13. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

Great Blue Heron			
Site	Expected Proportion	Observed Proportion	Total Prey Caught
A1	0.23000	0.40000	10
A2W	0.31000	0.08000	2
MVTM	0.08000	0.00000	0
PA	0.38000	0.52000	13
Test	Chi-Square	DF	Prob>Chisq
Pearson	10.6969	3	0.0135
Great Egret			
Site	Expected Proportion	Observed Proportion	Total Prey Caught
A1	0.21212	0.13846	18
A2W	0.47475	0.62308	86
CS	0.05051	0.04615	6
MVTM	0.16162	0.00000	0
PA	0.05051	0.14615	19
SCTM	0.05051	0.04615	6
Test	Chi-Square	DF	Prob>Chisq
Pearson	54.0062	5	<.0001
Snowy Egret			
Site	Expected Proportion	Observed Proportion	Total Prey Caught
A1	0.24000	0.24540	120
A2W	0.18000	0.15746	77
CS	0.07000	0.13701	67
MVTM	0.16000	0.17996	88
PA	0.22000	0.11861	58
SCTM	0.13000	0.16155	79
Test	Chi-Square	DF	Prob>Chisq
Pearson	60.6238	5	<.0001

(a) Great Blue Heron

(b) Great Egret

(c) Snowy Egret

Figure 15. Analysis 16. Number of prey and type captured by each species in each site. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

(a) Great Blue Heron

(b) Great Egret

(c) Snowy Egret

Figure 16. Analysis 16. Prey length classes caught by each species in each site. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM = Mountain View Tidal Marsh, PA = Palo Alto, SCTM = Steven's Creek Tidal Marsh.

DISCUSSION

The number of Great Blue Herons, Great Egrets and Snowy Egrets observed among sites were significantly different than expected based on available habitat. Both the Great Blue Heron and the Great Egret had higher frequencies than expected in PA, the natural marsh site, whereas the Snowy Egret had higher frequencies in A2W than the other sites. The observed frequency of birds was much higher in MVTM and PA than expected. In contrast, the observed number of each species was much lower in CS and SCTM than expected. In general, the larger sites (A1, A2W and PA) were used more frequently by all three species. However, the least frequently used site (SCTM) was not the smallest sized site, which was MVTM. SCTM, the second to smallest site, had the lowest use by each species. A study conducted by Custer and Galli (2002), on the feeding habitat selection by Great Blue Herons and Great Egrets in East Central Minnesota, showed that Great Blue Herons preferred large bodies of water (≥ 350 ha), while Great Egrets preferred small ponds (< 25 ha). In contrast, my results showed that the Great Egret preferred the larger sites, PA (56 ha) and A2W (63 ha), over the smallest sites (< 35 ha).

Prior to initiation of the study, I observed Snowy Egrets in the inner and outer portions of MVTM in the winter season when water levels were higher and the pickleweed was submerged. The water levels in MVTM appear to not have reached that level again during the period of this study and only on one occasion, in January of 2004, were Snowy Egrets seen in the inner marsh. The Great Blue Heron was also observed foraging in the northeast end of MVTM in a water channel dominated by pickleweed

during reconnaissance surveys, but hasn't been observed in that area since. Over the course of this study MVTM appears to becoming more densely vegetated, without inundation, which may attribute to lower use in the inner marsh. Buchanan (1990) found that submerged *Salicornia* played an important role in the restored marsh habitat as cover for fish. However, a general pattern of increased use by all species of the large slough and Permanente creek in MVTM was seen over the course of this study.

Numbers of observed birds were significantly lower during breeding season than in the non-breeding season. It was assumed that lack of large breeding colonies in the immediate area of the research sites accounted for the seasonal fluctuations. This fluctuation was possibly due to the fact that large heron and egret nesting colonies are located at a distance that prevents breeding birds from expending the energy to travel to the study area. Custer and Galli (2002) found that Great Blue Herons fed less than 1 km from its breeding site while Great Egrets fed within 4 km of the breeding site; they noted that quality feeding habitat should be in proximity to breeding colonies. During my study, breeding adults occupied nearly all of the sites though never in great proportions. Territoriality among the breeding adults of the same species was also observed. Even though breeding adults of different species could be found together in close proximity, breeding adults stopped foraging to chase off other breeding adults of the same species several times. During non-breeding season, especially in late summer when algae mats grew in the salt ponds, numbers of birds increased and territoriality appeared to decrease. Kushlan (1978) noted that some individuals might establish feeding territories based on season and that high prey availability may be correlated with small territory size. Groups

of same species foraged and preened together in the larger sites such as PA, A1, and A2W (pers. obs.). During the breeding season, Forster's Terns bred on islands both in CS and A1 and heron and egret use decreased as the terns were aggressively protective of their nests and young and mobbed the herons and egrets even when not being directly threatened (pers. obs.). Most foraging in A1, during tern breeding season, was in the southwest and northwest corners away from the tern breeding island located in the southeast corner.

Each site was used for both foraging and non-foraging activities such as preening or loafing, though all sites were used significantly more for foraging. These results are not surprising as these marshes and salt ponds serve mainly as foraging habitats rather than for roosting or nesting or other social activities. In contrast, Buchanan (1990) found that *Salicornia* flats and island habitats were both used primarily for non-foraging activities such as loafing, preening, while the restored marsh was used most for foraging.

Salinity did not have an effect on the abundance of birds among sites. However, salinity did play a part in the types of vegetation communities available in each site. Both PA and SCTM were the most brackish of the sites and contained higher vegetation diversity than the other sites. It is not surprising that salinity (at the observed range of 0-30 ppt) did not affect the bird distribution, since herons and egrets are commonly found foraging in both freshwater and saltwater habitats around the San Francisco Bay (pers. obs.).

Use of different water depths was only significant in four of the sites. The highest use by birds was associated with high water levels in CS and PA. High bird use was

associated with low and medium depths in both of the salt ponds. Unfortunately, in this study water levels were not measured in absolute depth (Shoreline would not allow meter staffs to be placed in the water), only in relative depths for each ponds, so correlations between absolute water depth and wading bird depth could not be made. Maximum water depths for the Snowy Egret (19cm) and the Great Egret (28cm) have been used in experimental treatments for the effect prey availability on numerical responses of wading birds (Gawlick 2002). Gawlick found that Snowy Egrets were more abundant in shallow and medium water depths than in deep depths. Preferred water and foraging depth for herons and egrets is important to understand as hydrologic patterns and water level fluctuation are correlated with decline in the number of breeding birds and wading birds species in some regions. Water depth has been shown as a major variable in determining where wading species can forage which is also correlated with reproductive success (Bancroft, *et al.* 2002).

A problem with measuring water depth in CS and SCTM arose during this study, which may account for the non-significant differences. The place where water measurements (from observation docks) were taken in CS and SCTM silted in with mud over the course of the study. Therefore, the differences between measurements slowly decreased during the year. Even though the water depth in CS drastically changed throughout the day (with tidal fluctuations), those changes were scarcely observed at the end of the study as the water measurement area silted in with mud. As water depths changed throughout the day in CS the bird use did, as well. During high tide in CS the dominant birds are ducks while at low tide, as mudflats are exposed, the area is mostly

used by sandpipers, dowitchers, godwits, avocets and willets (pers. obs.). Herons and egrets tended to use CS during the mid-tide cycle when water levels were at medium or high.

When water levels were manually or naturally decreased in the salt ponds, especially during the summer, heron and egret use increased. Water levels in A1 and A2W are currently controlled manually by the Department of Fish and Wildlife. During a visit to another salt pond in the Alviso complex in the summer of 2004, a large number of all three species of herons and egrets were seen foraging together. An accurate count was not made due to the sheer number of birds; however, at least 30 Great Egrets, foraging in close proximity to each other, were counted along one shoreline. The technician raised the water level during that visit due to concerns of a possible botulism outbreak in the pond. A week later, the same technician reported back that there were fewer herons and egrets and that islands, mudflats, and land masses that were used as foraging substrate were no longer exposed. This same pattern was observed in my research sites; as the water level was lowered during the summer of 2004, an increase of herons and egrets was seen. It is not known if the increase in number of birds was due to the water levels or to the non-breeding season population increase.

Foraging behaviors have been associated with both water depths and habitat types in previous studies by Buchanan (1990), Hom (1980, 1983), Kasner and Dixon (2003), Kelly *et al.* (2003), and Kushlan (1978). Many studies have shown that Snowy Egrets are more active and display more types of foraging behaviors in the pursuit of prey (Rodgers 1983, Kushlan 1978, Hom 1980). Similarly, my study showed that Snowy Egret used

many more (24) foraging behaviors than the other two species. The Great Blue Heron used a total of five foraging behaviors and the Great Egret used seven behaviors. Each species used the highest number of foraging behaviors in A2W. The lowest number of behaviors used was in CS. In late summer of 2004, juvenile Snowy Egrets were observed jumping from a wooden dock into the water in A2W attempting to capture prey with their feet (pers. obs.). Snowy Egrets were often seen Foot Dragging: flying along the water with legs extended vertically with their feet in the water. There were no observations of prey capture with this method. On several occasions, during high winds (10-15 mph) in both A1 and A2W, Snowy Egrets would stand in a Crouched posture while the waves came in towards it, the bird slowly dipped its bill into the water to catch prey (pers. obs.). Similarly, Rogers (1983) noted that Snowy Egrets became less active in increased wave height. This was confirmed in the present study, as normally Snowy Egrets were not observed in the Stand and Wait or Crouched positions. Several Great Egrets were observed flying low over water ranging from shallow to medium depths in both salt ponds (southeast corner) appearing to use their bills to capture prey (called Aerial foraging), but they were never successful during my observations. The Foot Dragging and Aerial foraging behaviors were observed only in open water habitats. Kasner and Dixon (2003) found that Great and Snowy Egrets also used the Aerial foraging method over open water ranging 3-12 m deep. They noted that Aerial foraging is rarely observed. Rodgers (1983) noted that foraging behaviors may change with different habitats. He found that the Aerial foraging method was used in deep water (>20cm) during the pursuit of prey.

My observations of usage of habitat types may further help to understand what types of habitats the birds prefer to forage in. Studies have shown that wading bird distribution is related to both vegetation type and water depth (Bancroft *et al.* 2002, Brzorad *et al.* 2003). Sparse submerged vegetation is used by wading birds in the Everglades (Gawlik 2002), while Hom (1983) found dense vegetation was preferred for foraging by the Great Blue Heron, Great Egret and Snowy Egret in CS. Hom also found that the birds avoided open water and wooden structures which is in contrast to my results. Buchanan (1990) found that both pickleweed and island habitats were used for loafing and social interactions by the Great Blue Heron. Overall, each of the species in this study was observed foraging in the water more than any other habitat in each site. Short vegetation was preferentially used for foraging and loafing by each of the species except for the Great Blue Heron in CS. Mudflats were used by the Great Egret and the Snowy Egret but usually only when covered with water. Shoreline was used mostly for loafing by all species. Tall vegetation was used in PA by the Great Blue Heron and the Snowy for foraging. When PA water levels were highest, the Snowy Egret used cattails and cordgrass to support its weight and to forage in and around (pers. obs.). The Snowy Egret captured the only "Amphibian" prey in PA, a small frog (possibly a *Hyla* spp.). On the same occasion, in the same area, a Snowy Egret was observed capturing and foraging on a dragonfly (Order Odonata). Even though the Black-crowned Night Heron was not used in any of the analyses it also was frequently found in the tall vegetation in PA. Algae mats were a significant and important foraging area and substrate for the Snowy Egret. Snowy Egrets were apparently able to forage further out into the salt ponds by

standing on the algae mats. Great Egrets also stood in and on the mats while foraging on small fish (pers.obs). Artificial substrates such as concrete and wooden structures were used in both of the salt ponds for foraging and loafing. In certain areas, the water is very deep near of the shoreline in the salt ponds and Snowy Egrets were often found using the concrete to stand on while crouching and striking at the water. Levees were used for loafing, although the Great Egret was seen attempting to forage on a levee in salt pond A2W. The islands in both A1 and CS were used for foraging during non-breeding season.

The Great Egret and Snowy Egret were both observed foraging in the middle water channels at low tide when most of CS becomes mudflats. Main and smaller channels in mudflat type habitats may provide habitat for schooling prey (Buchanan 1990). However, during high tide the Snowy Egret was found foraging on or near the shoreline in pickleweed. As mentioned before, when pickleweed, salt grass, or other vegetation is submerged prey may get trapped in or on the vegetation providing foraging habitat (Hom 1983, Buchanan 1990). This same behavior was seen in MVTM during reconnaissance surveys and in PA during high tide. In MVTM slough and Permanente creek the slopes are very steep and therefore the habitat cannot be used by Snowy Egrets during high tide unless there is some type of substrate or submerged vegetation for it to stand on. Gawlick (2002) found that gradual sloping land surface coupled with slow water recession ensured good foraging patches.

The Snowy Egret had higher mean strikes and successes per minute in Charleston Slough than in the other sites. This result may be largely the result of two individual

observation days when they were foraging on small prey (too small to identify) in submerged pickleweed and in pickleweed that was just newly uncovered from a high tide. A higher strike rate and success rate does not necessarily mean that the bird is getting more energetic or caloric gain, if the prey size is very small. Snowy Egrets captured several worms (*Annelid spp.*) from muddy shorelines in both MVTM and A2W. The worms were not identified but resembled earthworms up to approximately 8 cm in length. The worm foraging events happened often in MVTM after a rain event or just as the tide had gone out (pers. obs).

Snowy Egrets have higher prey capture per minute than the other two species. This result is associated with foraging for smaller prey including invertebrates. In contrast, low capture rates by Great Blue Heron's are offset by larger prey (Rodgers 1983). The Great Blue Herons in this study also had some of the lowest strikes and successes per minute. However they had an average success rate of 100% in A2W. They had equal success rates (83%) in A1 and PA. Their lowest success rates were in SCTM. Overall, the highest success rates among the Great Egret and Snowy Egret were in the A2W and CS and the lowest success rate was in SCTM for both Species. Buchanan (1990) studied foraging success of Great Blue Herons in *Salicornia* flats, restored marshes, mudflats, and islands. He found that the percent of success strikes were more frequent in restored marshes and lowest in mudflats.

Disturbances during foraging surveys occurred 24 times out of the 87 surveys. These occurrences are related to how close the trail or levee is to the bird that is foraging. Several of the sites in this study have trails and roads that are close to edges of the ponds

and/or marshes where disturbance to birds can be a problem. In PA, there is more shoreline area between the trail and the water's edge providing a buffer from humans and dogs (dogs are allowed in PA). PA also has a mosaic of short, medium and tall vegetation to create a visual buffer between the trail and the marsh. In contrast, the levees along the salt ponds have almost no buffer between the levees to the water edge. In some places along A1 and A2W there is either tall vegetation consisting of peppergrass weed, or short vegetation consisting of pickleweed, *Jaumea*, and *Frankenia*, which provide a sufficient buffer from human disturbance of the foraging birds. There are also levees in both A1 and A2W that are off limit to recreational use because of locked levee gates.

The surveys that were disturbed by the observer occurred in areas where there was no buffer zone between the bird and the shoreline, trail, or levee. In SCTM, there are two observation areas where one can stand within a meter of the foraging habitat and on several occasions birds were disturbed by other observers during foraging events. Other disturbances consisted of a dog that was off leash (even though dogs are not allowed in SCTM), walkers, and bicyclists. In CS, there is also an observation deck that is right on the waters edge though herons and egrets were not commonly seen in the immediate area. The trail along CS has shoreline area with short vegetation that creates a buffer though not as wide as the buffer on the other side where PA is located.

Each of the study sites in Shoreline at Mountain View provide important habitat for herons and egrets though they all differ in quality, size, and perhaps prey density and vulnerability. The bird densities per ha were highest in A1 and surprisingly in MVTM

(one of the smallest sites). A2W and PA were almost equal in bird density while CS and SCTM had the lowest bird densities. The only site that did not appear to be used by the Great Blue Heron was SCTM. SCTM also had the lowest success rate of prey capture for both the Great Egret and the Snowy Egret. Further studies on prey types and density may help to resolve why the success rates were so low in SCTM.

The PA site was very important in providing both foraging and non-foraging habitat for all three species. This site is also one of the most important for the birds as there is a high amount of vegetation and land buffer from human-related disturbances. On the other hand, the salt ponds provided the most shoreline area (in meters) for foraging. A large portion of the shorelines along the levees was protected from human disturbance due to locked gates. However, occasional vehicle use on the levees did disturb a few of the foraging surveys. If the salt pond levees continue to be off-limits for recreational activities they will also offer important areas for the herons and egrets to foraging without disturbance (other than occasional service vehicles). Buffer zones from human disturbance in several sites increased foraging times and perhaps foraging success. Further studies should be conducted on the size of buffer zones and foraging success and foraging time (length) in each of these sites.

Two similar sized sites, CS and PA had significantly different use. It appears that water height and perhaps the lack of vegetation diversity in CS played a large part in its low use by ardeids. The pickleweed and salt grass habitats in CS are important foraging habitat for the Snowy Egret. Reasons for the lack of Great Blue Heron and Great Egret foraging use in CS were not resolved. Hom (1980) observed several hours of foraging

time for all three species. However, his surveys were conducted from dawn till dusk in both the inner and outer slough. During tern breeding season, both in CS and A1, herons and egrets were mobbed and chased off by terns and tended to stay out of those sites especially near the breeding islands. Furthermore, the habitat in CS appears to have changed greatly since Hom's 1980 study, as it fills in with sediment.

MVTM appeared to become denser with vegetation while the water channels and smaller sloughs in the inner marsh were less inundated with water, over the course of this study. The production of prey may be increased by long periods of inundation (Gawlik 2002). The slopes of the water channels were also steep sided through MVTM, which may affect wading bird use negatively. Birds were never observed standing on steep slopes. The use of the main slough and Permanente creek increased over the year. Those areas make up only a small percentage of the total marsh area and are located next to trails and bridges both for vehicles and recreational activities such as biking, roller-skating, jogging, and walking. The birds were often disturbed by those activities and even by the observer in one case due to the short proximity from the water to the trail and bridge. The inner marsh is now off-limits to recreational activity which may help improve heron and egret use.

Given that the Great Blue Heron and the Great Egret both had highest frequencies in PA, and the Snowy Egret had the highest frequencies in salt pond A2W, it appears that a mosaic of habitats types including mudflats, islands, open water, and marshes with water channels, sloughs and ponds with low to medium water levels, gently sloping shorelines, and vegetation (plus wide shoreline buffers from disturbance) may help to

sustain heron and egret foraging and even non-foraging habitat. These considerations may be important when restoring salt ponds if the goal is to provide quality foraging habitat for top predators like the herons and egrets in the South San Francisco Bay.

Further surveys on abundance, foraging behavior and success, and disturbance to foraging for the Great Blue Heron, Great Egret and Snowy Egret should be conducted to determine how the salt pond restoration process is affecting their distribution. Though herons and egrets may not be the focal species for salt pond restoration, as they are not currently listed as threatened or endangered, their populations have been negatively effected in the past. Restoration plans that maintain quality foraging and breeding habitat will ensure that heron and egret populations are healthy and stable in the future.

RECOMMENDATIONS

In conclusion, when considering wading bird foraging habitat in the salt pond restoration process the following main goals should be targeted.

1) Tidal flow that brings in a sufficient amount of prey is important for foraging and maintaining prey density. Lonzarich (1989) suggests that seasonal closure to tidal action reduces the value of pond habitats while rapid movement of water (resulting in salinity ranges of 30-40 ppt) may increase fish and invertebrates and algae.

2) Algae appeared to have a positive effect on the increase of foraging substrate and prey for the Snowy Egret and Great Egret. Algae are also a source of food for fish and invertebrates so it is suggested that macroalgae be allowed to grow, at a controllable rate, in some areas of the ponds. However, large amounts of algae may reflect nutrient pollution or eutrophication, so the growth rate and amount of algae should be closely monitored. Prey types and density should be sampled to maintain quality habitat for wading birds.

3) Water levels of not more than 20 cm should be available. This does not imply that the entire site needs to be kept at a 20 cm water depth. It does mean there should be areas, within a site, that include pools, ponds, water channels, and/or sloughs that are available for foraging throughout the day or corresponding with tidal flow.

4) Presence of a variety of habitats and substrate types including mudflats, islands, open water, water channels, sloughs, and ponds with gently sloping shorelines are important so that birds can forage both from the shoreline or water channel banks as well as in open water.

5) Shorelines, banks or levees should have a sufficient buffer zone that keeps human disturbance at a minimum. Even though this study did not measure exact widths necessary to keep disturbance at a minimum other studies (Lafferty 2001*a*, 2001*b*, Thomas *et al.* 2003) have suggested a minimum 30-meter buffer zone between foraging habitat and recreational activities. Rodgers and Smith's (1995) study of set-back distances to protect nesting bird colonies from human disturbance in Florida recommended a set back of at least 100 meters, specifically from wading birds. Buffer zones may consist of native short and tall vegetation appropriate for the salinity level in each site. Native trees and shrubs may also be planted to provide nesting habitat near foraging areas.

6) The creation of islands in ponds may be the ideal habitat for heron and egret breeding colonies if water levels are not extremely increased during breeding season. For example, Duck Island in Lake Elizabeth in Fremont (East Bay) supported 192 heron and egret nests in 2005. This colony started to form in 2002 which may have been the result of human disturbance and/or habitat change in one of their nesting sites in nearby Quarry Lakes, Fremont, California, which caused the colony to move. Other island nesting sites in the San Francisco Bay includes Bair Island (one of the largest in South San Francisco Bay) and Lake Merritt in Oakland, California. Island habitats may prevent human, domestic, and wild animal disturbance to herons and egrets. Warnock, *et al.* (2002) noted that salt ponds, in general, serve as refuges for waterbirds in a disturbance-prone area.

LITERATURE CITED

- American Ornithologists' Union. 2005. Published on The American Ornithologists' Union website: <http://www.aou.org/>. The A.O.U. Check-list of North American Birds, 7th edition. Retrieved on 8/01/2005; <http://www.aou.org/checklist/index.php3#arde>
- Bancroft, G.T., D.E. Gawlick, and K. Rutchey. 2002. Distribution of Wading Birds Relative to Vegetation and Water Depths in the Northern Everglades of Florida, USA. *Waterbirds* 25 (3): 265-277.
- Biology and Habitats Existing Conditions Report. March 2005. South Bay Salt Pond Restoration Project.
- Blueford, J.R. 2003. Tule Ponds at Tyson Lagoon. Math/Science Nucleus Press. Fremont, California.
- Buchanan, S.C. 1990. Habitat Utilization by Great Blue Herons (*Ardea Herodias*) in Elkhorn Slough. California. Unpublished Master's thesis, San Jose State University, California.
- Butler, R. W. 1997. The Great Blue Heron. UBC Press, Vancouver, British Columbia.
- Brzorad, J.N., A.D. Maccarone, and K.J. Conley. 2004. Foraging energetics of Great Egrets and Snowy Egrets. *Journal of Field Ornithology*. 75 (3): 266-280.
- Conradson, D.R. 1996. Exploring Our Baylands. San Francisco Bay Wildlife Society. Tien Wah Press, Singapore.
- Custer, C.M. and J. Galli. 2002. Feeding Habitat Selection by Great Blue Herons and Great Egrets Nesting in East Central Minnesota. *Waterbirds* 25 (1): 115-124.
- Ehrlich, P.R., D.S. Dobkin, and D. Wheye. 1988. The Birder's Handbook. Simon & Schuster/Fireside, New York.
- Erwin, R.M., J.S. Hatfield, and T.J. Wilmers. 1995. The value and vulnerability of small estuarine islands for conserving metapopulations of breeding waterbirds. *Biological Conservation* 71: 187-19
- Gawlick, D.E. 2002. The Effects of Prey Availability on the Numerical Response of Wading Birds. *Ecological Monographs*. 72 (3): 329-346.

- Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals. First Reprint. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.
- Hancock, J. and J. Kushlan. 1984. *The Herons Handbook*. Harper and Row, New York.
- Hart, J. and D. Sanger. San Francisco Bay. 2003. University of California Press. Berkeley, Los Angeles and London.
- Hom, C.W. 1980. Resource Partitioning Among Three Species of Herons in a Southern San Francisco Bay Salt Marsh. Master's thesis, San Jose State University, California.
- Hom, C. W. 1983. Foraging ecology of herons in a southern San Francisco Bay salt marsh. *Colonial Waterbirds*. 6:37-44.
- Josselyn, M. 1983. The ecology of San Francisco bay tidal marshes: a community profile. U.S. Fish and Wildlife Service, Division of Biological Services, Washington D.C. FWS/OBS-83/23.
- Kasner, A.C. and T.P. Dixon. 2003. Aerial foraging over open water by Great Egrets and Snowy Egrets on schooling freshwater fish. *Wilson Bulletin*. 115 (2): 199-200.
- Kelly, J. P., H. M. Pratt, and P. L. Greene. 1993. The distribution, reproductive success, and habitat characteristics of heron and egret breeding colonies in the San Francisco Bay Area. *Colonial Waterbirds*. 16(1): 18-27.
- Kelly, J. F., D. E. Gawlick and D. K. Kieckbusch, 2003. An Updated Account of Wading Bird Foraging Behavior. *Wilson Bulletin*. 115(1), pp 105-107.
- Kushlan, J. A. 1978. Feeding behavior of North American herons. *Ecology*. n.57, p.821-825, 1976.
- Lafferty, K. D. 2001a. Birds at a Southern California beach: seasonality, habitat use and disturbance by human activity. *Biodiversity and Conservation* 10: 1949-1962.
- Lafferty, K. D. 2001b. Disturbance to wintering western snowy plovers. *Biological Conservation*. 101: 315-325.
- Lonzarich, D.G. 1989. Temporal and spatial variations in salt pond environments and implications for fish and invertebrates. Unpublished Master's thesis, San Jose State University, California.

- Pittman, B.T. 1996. A Survey of Inbenthic Macrofauna at a South San Francisco Bay Salt Marsh. Unpublished Master's thesis, San Jose State University, California.
- Pratt, H.M. 1970. Breeding Biology of Great Blue Herons and Common Egrets in Central California. *The Condor*. 72: 407-416.
- Pratt, H.M. 1974. Breeding of Great Blue Herons and Great Egrets at Audubon Canyon Ranch, California, 1972-1973. *Western Birds*. 5: 127-136.
- Pratt, H.M. 1972. Nesting Success of Common Egrets and Great Blue Herons in the San Francisco Bay Region. *The Condor*. 74: 447-453.
- Pratt, H.M. 1993. Herons and Egrets of Audubon Canyon Ranch. California. Audubon Canyon Ranch.
- Quinn, G.P. and M.J. Keough. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge University Press. Cambridge, United Kingdom.
- Rodgers, J.A. Jr. 1983. Foraging behavior of seven species of herons in Tampa Bay, Florida. *Colonial waterbirds*: 6: 11-23.
- Rodgers, J.A. Jr. and S.T. Schwikert. 2002. Buffer-Zone Distances to Protect Foraging and Loafing Waterbirds from Disturbance by Personal Watercraft and Outboard-Powered Boats. *Conservation Biology*. 16: 216-224.
- Rodgers, J.A. Jr. and H.T. Smith. 1995. Set-Back Distances to Protect Nesting Bird Colonies from Human Disturbance in Florida. *Conservation Biology*. 9: 89-99.
- Ryan, T.P. and J.L. Parkin. 1998. The status and distribution of herons and egrets in Southern San Francisco Bay from 1982 to 1997. Unpublished Report. San Francisco Bay Bird Observatory.
- South Bay Salt Pond Restoration Project Biology and Habitats Existing Conditions Report March 2005 1750.01.
- South Bay Salt Pond Restoration Project Description. August 11, 2005. Published on The South Bay Salt Pond Restoration Project website:
http://www.southbayrestoration.org/Project_Description.html
- Taniguchi, Michiko. 1996. A comparison of natural and restored salt marsh vegetation and soil characteristics. Unpublished Mater's thesis, San Jose State University, California.

- Thomas, K., R.G. Kvitek, and C. Bretz. 2003. Effects of human activity on the foraging behavior of sanderlings *Calidris alba*. *Biological Conservation* 109: 67–71.
- Trulio, L. and D. Clark. 2005. South Bay Salt Pond Restoration Project Draft Adaptive Management Plan.
- Warnock, N., G. W. Page, M. Ruhlen, N. Nur, J. Y. Takekawa, and J. T. Hanson. 2002. Management and conservation of San Francisco Bay salt ponds: effects of pond salinity, area, tide, and season on Pacific Flyway waterbirds. *Waterbirds* 25 (Special Publication 2): 79-92.

APPENDICES

APPENDIX 1. Density of birds per hectare in each study site. GBHE=Great Blue Heron, GREG = Great Egret, SNEG-Snowy Egret. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM= Mountain View Tidal Marsh, PA = Palo Alto, SCTM= Steven's Creek Tidal Marsh.

Study Site	Pond Size	GBHE	GREG	SNEG	Total
A1	38	0.34	1.63	8.45	10.42
A2W	63	0.48	1.43	4.62	6.53
CS	35	0.11	0.34	2.14	2.59
MVTM	4	3	1.5	4.5	9
PA	56	0.59	1.43	4.21	6.23
SCTM	10	0	0.3	2.2	2.5
Total	206				

(a) All Species

(b) Great Blue Heron

(c) Great Egret

(d) Snowy Egret

APPENDIX 2. Water depths while foraging for all three species alone in each site based on bird counts. Refer to Table 5. for test results using Chi-square. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM= Mountain View Tidal Marsh, PA = Palo Alto, SCTM= Steven's Creek Tidal Marsh.

(a) Salt Pond A1

(b) Salt Pond A2W

(c) Charleston Slough

(d) Mountain View Tidal Marsh

(e) Palo Alto

(f) Steven's Creek Tidal Marsh

APPENDIX 3. Salinity Ranges of each site from June 2004 - July 2005. Salinities in Salt ponds A1 and A2W are not tidal and fluctuated with season only. Salinities in Charleston Slough, Mountain View Tidal Marsh, Palo Alto and Steven's Creek Tidal Marsh fluctuated with daily tide cycles and season.

APPENDIX 4. Number of birds in each site by month. A1 = Salt Pond A1, A2W = Salt pond A2W, CS = Charleston Slough, MVTM= Mountain View Tidal Marsh, PA = Palo Alto, SCTM= Steven's Creek Tidal Marsh.

Month, Year	A1	A2W	CS	MVTM	PA	SCTM
June, 2004	5	2	1	0	2	1
July, 2004	11	3	0	0	25	0
August, 2004	165	96	11	7	80	7
September, 2004	33	49	4	4	17	1
October, 2004	31	90	4	0	41	5
November, 2004	62	40	0	0	5	0
December, 2004	16	12	16	1	16	2
January, 2005	13	24	29	9	27	2
February, 2005	9	27	9	3	5	3
March, 2005	9	16	5	2	17	3
April, 2005	14	24	0	2	15	0
May, 2005	3	10	2	3	19	0
June, 2005	5	13	8	4	47	0
July, 2005	2	5	2	1	33	1
Total	378	411	91	36	349	25

APPENDIX 5. Foraging behaviors and postures used by herons and egrets. GBHE = Great Blue Heron, GREG = Great Egret, SNEG=Snowy Egret.

A1	GBHE	GREG	SNEG
Stand and Wait	X	X	X
Walk Slowly	X	X	X
Peering	X	X	X
Walk Quickly		X	X
Crouching		X	X
Foot Stirring			X
Running			X
Hopping			X
Foot Raking			X
Foot Dragging			X
Diving			X
Jumping			X
Bill Vibrating			X
Crouch and Wait			X
Crouch and Walk			X
Probing			X
Wing Flicking			X
Total Behaviors	3	5	17

A2W	GBHE	GREG	SNEG
Stand and Wait	X	X	X
Walk Slowly	X	X	X
Peering	X	X	X
Walk Quickly		X	X
Crouching		X	X
Foot Stirring			X
Running			X
Hopping			X
Foot Raking			X
Dipping			X
Foot Dragging			X
Jumping from perch			X
Plunging			X
Total Behaviors	3	5	13

APPENDIX 5. (Continued) Foraging behaviors and postures used by herons and egrets in each site. GBHE = Great Blue Heron, GREG = Great Egret, SNEG=Snowy Egret.

Charleston Slough	GBHE	GREG	SNEG
Walk Slowly		X	X
Walk Quickly		X	X
Gleaning			X
Probing			X
Pecking			X
Total Behaviors		2	5

Mountain View Tidal Marsh	GBHE	GREG	SNEG
Stand and Wait	X	X	X
Walk Slowly	X	X	X
Peering	X	X	X
Neck Swaying		X	
Walk Quickly			X
Foot Raking			X
Foot Stirring			X
Running			X
Hopping			X
Total Behaviors	3	4	8

Palo Alto	GBHE	GREG	SNEG
Stand and Wait	X	X	X
Walk Slowly	X	X	X
Peering	X		X
Walk Quickly		X	X
Foot Stirring	X		X
Crouching	X		
Bill Vibrating			X
Gleaning			X
Crouch and Wait			X
Probing			X
Pecking			X
Running			X
Hopping			X
Jumping			X
Foot Raking			X
Hovering			X
Total Behaviors	5	3	15

APPENDIX 5. (Continued) Foraging behaviors and postures used by herons and egrets in each site. GBHE = Great Blue Heron, GREG = Great Egret, SNEG=Snowy Egret.

Steven's Creek Tidal Marsh			
	GBHE	GREG	SNEG
Stand and Wait		X	X
Walk Slowly		X	X
Hovering		X	
Crouching		X	
Bill Vibrating			X
Crouch and Wait			X
Hopping			X
Pecking			X
Foot Stirring			X
Foot Raking			X
Walk Quickly			X
Running			X
Probing			X
Peering			X
Total Behaviors		4	12

APPENDIX 6. Study sites

Salt Pond habitats: The two salt ponds in this study, A1 and A2W located in the Alviso complex, have salinities below 40 (ppt) and support high abundance of macroscopic green algae (mostly *Rhizoclonium* spp. and *Enteromorpha* spp.) microscopic algae and diatoms. There are numerous nematodes, polychaete worms, rotifers, arthropods, and crustaceans. Common fish of these ponds, which feed benthic and pelagic invertebrate prey, include topsmelt (*Atherinops affinis*), yellowfin goby (*Acanthogobius flavimanus*), longjaw mudsucker (*Gillichthys mirabilis*), rainwater killifish (*Lucania parva*), and staghorn sculpin (*Leptocottus armatus*) (Lonzarich 1989, Biology and Habitats Existing Conditions Report 2005).

The vegetation in the perimeter of the pond and on the inner levee and shorelines consists of pickleweed, salt grass, peppergrass and coyote bush. Salt marsh habitat occurs on the outboard levees along the western extent of the Alviso complex.

Common birds in the low salinity salt ponds and adjacent habitats (at medium to high tide) include terns, cormorants, gulls, Canada Geese (*Branta canadensis*), White Pelicans, Black Skimmers (*Rhynchops niger*), American Avocets, Black-necked Stilts, several species of dabbling and diving ducks, Black-crowned Night Herons, Snowy and Great Egrets, Great Blue Herons, Northern Harriers (*Circus cyaneus*), White-tailed Kites (*Elanus caeruleus*), Red-winged Blackbirds (*Agelaius phoeniceus*), House Finches (*Carpodacus mexicanus*), Lesser Goldfinches (*Carduelis psaltria*), Barn Swallows (*Hirundo rustica*) and Cliff Swallows (*Petrochelidon pyrrhonota*). California ground

squirrel (*Spermophilus beecheyi*) and black-tailed jack rabbit (*Lepus californicus*) have also been seen frequently on the pond levees.

Salt pond A1

Pond A1 was historically the intake pond for the Alviso complex. It is considered a 'system pond' by the SBSP. The total hectares are 110 with approximately 5,684 meters of shoreline. However, in this study, the pond was surveyed from the Shoreline at Mountain View trail and approximately 55 hectares of the pond were observed in the surveys. The total distance of Shoreline trail near the pond is approximately 1172 meters. The total distance of U.S. Fish and Wildlife access roads to the levee and levee roads is 5,684 meters. These numbers are included as they could be relevant to the potential human disturbance factor in the surveys. There is one small island located in the southeast corner of the pond that is used for nesting by California Least Terns and by herons, egrets and other shorebirds for foraging and roosting during the rest of the year. There are numerous human-made features in the ponds such as old duck blinds, boat docks, concrete rip-rap around the shoreline, tires, and wooden posts.

Pond bathymetry was surveyed by USGS on 10/22/03. During the survey the top of the staff gauge (read 4 ft) was surveyed to be 2.39 ft NGVD29 and was converted to 5.08 ft NAVD88 using the program CorpsCom ($\text{NAVD88} = \text{NGVD29} + 2.69 \text{ ft}$). Depths, collected in meters, were converted to feet and then referenced to NAVD88 by subtracting water depth from NAVD88 water height (staff gauge reading 2.9 ft = 3.98 ft NAVD88). Summary: NAVD88 min = -2.96 ft; max = 3.65 ft; mean = 1.71 ft; mode = 1.63 ft; stdev = 0.40 ft.

Salt pond A2W

Pond A2W is situated immediately east of the A1 pond in the Alviso complex. The total hectares are 174 with approximately 6,074 meters of shoreline. However, the pond was surveyed from the Shoreline at Mountain View trail and approximately 87 hectares of the pond were observed in the surveys. The total distance of Shoreline trail near the pond is approximately 1,458 meters. The total distance U.S. Fish and Wildlife access road to the levee and levee roads is 6,074 meters. These numbers are included as they could be relevant to the potential human disturbance factor in the surveys. There are two series of Pacific Gas and Electric Towers and access docks in the pond. There are also numerous human-made features in the ponds such as old duck blinds, boat docks, concrete rip-rap, tires, and wooden posts.

Pond bathymetry was conducted by USGS on 10/28/2003 and 10/29/2003. There was no staff gauge. A temporary water level marker was installed and was surveyed by laser level and rod from a temporary levee benchmark surveyed by Moffatt-Nichol (January 2004). The top of the temporary marker was surveyed to be 2.64 ft NGVD29 and was converted to 5.33 ft NAVD88 using the program CorpsCom (NAVD88 = NGVD29 + 2.69 ft). Depths, collected in meters, were converted to feet and then referenced to NAVD88 by subtracting water depth from NAVD88 water height (water level 2.19 ft from top of marker to water is 0.45 ft NGVD29 = 3.14 ft NAVD88).
Summary: NAVD88 min = -1.10 ft; max = 2.75 ft; mean = 0.42 ft; mode = 0.32 ft; stdev = 0.50 ft.

Fish surveys were completed in March, June, September and November 2004 in salt pond A2W by USGS. The following species were captured: Bay pipefish, unidentified goby, longjaw mudsucker, leopard shark, rainwater killfish, staghorn sculpin, topsmelt and yellowfin goby.

Charleston Slough

Charleston Slough (referred to as CS) is located immediately west of salt pond A1 and is considered to have two regions; the inner slough and the outer slough. In this study only the inner slough was monitored, which consists of 41 hectares surrounded by levees or trail, that were restored to tidal circulation through one tide gate on the north end. The outer slough consists of tidal marsh that receives full tidal action. Charleston Slough, historically, was a part of the South Bay tidal marshes but was diked in the early to mid-1900's to create a salt evaporation pond owned by Leslie Salt Company. In June of 1980, ownership and the restoration responsibility was transferred to the City Of Mountain View under a permit that authorized the City to remove water from the inner slough to create a Shoreline lake (Pittman 1996). The slough, a shallow pond, was to be restored to tidal marsh and in 1996 the project was initiated to create vegetated pickleweed and cordgrass tidal marsh. Currently, the inner slough, at 41 hectares, is mostly mudflats with pickleweed near the shoreline. Two human-made islands provide shorebird nesting and roosting habitat. Located at the south end is a pump station and an observation deck.

Inner Charleston Slough is surrounded by total 3,736 meters of trail or levee, in which 1,754 of the meters is public trail, called the Adobe Creek trail or the Bay Trail.

Currently, The Association of Bay Area Governments (ABAG) is conducting the Bay Trail Project's "Wildlife & Public Access Study" to determine the possible effects of human disturbance on wildlife, specifically, shorebirds.

Charleston Slough is a popular foraging site for many shorebirds, such as sandpipers, curlews, dowitchers, plovers, stilts and avocets, especially at low tide. During low tide there are a few smaller sloughs that contain water where a few herons and egrets may forage. During high tides dabbling ducks can be found foraging in the slough and herons and egrets are infrequently found in the pickleweed around the shoreline. The average salinity is 24 (ppt).

Mountain View Tidal Marsh

Mountain View Tidal Marsh (referred to as MVTM) was restored as a mitigation project after the U.S. Army Corps of Engineers issued a permit in 1973 requiring that city of Mountain View restore 50 acres of vegetated salt marsh after the creation of a 50 acre Shoreline Sailing lake within the park (Taniguchi 1996). (Steven's Creek Tidal Marsh was also part of this mitigation.) MVTM consists of 5 hectares located just south of A1 and A2W salt ponds. A trail encompasses about half of the site with an observation deck on the eastern end of the marsh. Permanente Creek flows into Mountain View slough which then runs into the bay. It was reopened to tidal action when the levee that separated the marsh from Mountain View Slough and the bay was breached. There are several small water channels within MVTM surrounded by pickleweed, cordgrass and gumplant. At the beginning of the research reconnaissance surveys, water channels were apparent in the east end of the marsh from the observation deck and all three focal species

were seen at one time or another foraging in the channels or in the pickleweed at high tide. However, during the study the marsh appeared to become more vegetated and fewer ardeids were seen during the 18 months of the study. Also during the time of the study, inner MVTM was fenced off to hikers and bikers to help restoration efforts. Therefore access to observe the inner water channels was also restricted and only the main trail could be used to observe the marsh and creek. Black-shouldered Kite (*Elanus Caeruleus*), marsh wrens, Black Phoebes (*Sayornis nigricans*), are seen within the marsh and ardeids, American Coots, Mallard ducks and a few other shorebirds species use Permanente Creek and Mountain View Slough to forage in.

All 5 hectares of MVTM were observed in this study with approximately 1,356 meters of shoreline, 1,245 meters of public trail in which 939 meters are used as a vehicle road for access to the salt pond levee. Salinity averages 20 (ppt) within Mountain View Slough.

Palo Alto Baylands

The Palo Alto Baylands is the most natural of all six sites. Palo Alto Baylands totals 785 hectares which is the largest tract of undisturbed marshland remaining in the San Francisco Bay. The area observed in this study is referred to as the Palo Alto Flood Basin and is located west of Charleston Slough as Adobe Creek Trail sits in between the two sites. There is a floodgate located on the south end adjacent to the pumphouse at Coast Casey Forebay within Shoreline at Mountain View Park. Adobe Creek trail is a popular spot for hikers, bikers, joggers, bicyclists and dog walking. It is the only trail where dogs are allowed on leash in this study.

The Palo Alto study site is the most diverse in terms of land elevation, water channels, plants and birds. It also contains the most vegetated land, water channels and sloughs within the site that are protected from human disturbance. However, disturbance by unleashed and leashed dogs can occur here unlike the other study sites. Plants in this site include cordgrass, cattail, pickleweed, alkali heath, dodder, salt grass and several non-native grasses and weeds inter-dispersed between mudflats and vegetated land masses. Both the California Clapper Rail and Salt Marsh Harvest Mouse has been observed here. The Duck Pond, located in the northwest Baylands has supported a small Snowy Egret and Black-crowned Night Heron colony. This is one of the closest rookeries near the study sites (pers. observation).

The area observed in the Palo Alto Baylands marsh is approximately 60 hectares with 4,305 meters of shoreline, 2,848 meters of trail in which 2,229 is also a vehicle road for maintenance. The average salinity is 3 (ppt).

Steven's Creek Tidal Marsh

Along with Mountain View Tidal Marsh, Steven' Creek Tidal Marsh (also referred to as SCTM) was part of the mitigation for the creation of the Shoreline Sailing lake. This 12 hectare site was set aside for restoration, which began in 1983. The City of Mountain View attempted to restore SCTM by opening the area to partial tidal action. After two culverts were installed in the eastern levee separating the marsh from the adjacent Steven Creek tidal exchange occurred with the Bay. Marsh elevations increased as silt was brought by the incoming tides and mudflats were formed from 1983 to 1992 pickleweed started to colonize at higher elevations near the south end of the marsh. In

1992, the Army Corp of Engineer issued another permit for two additional culverts to be installed for increased tidal fluctuation to accelerate vegetation growth. Currently, there are deep water channels with cordgrass, pickleweed, salt grass and gumplant growing densely throughout the marsh.

Ducks use the pond near the observation deck on the eastside of the marsh during high tide. During low tide curlews and sandpipers can be found foraging on the mudflats. During the reconnaissance surveys, both Snowy and Great Egrets were observed using this pond for foraging, though, never in great numbers.

The area observed in this study is approximately 12 hectares with 1,505 of shoreline, 1,274 near public trail in which 537 is used for vehicles to access salt pond A2W levee. There are two series of PG&E transmission towers that extend to salt pond A2W. Average salinity in the marsh is 15 (ppt).

APPENDIX 7. Heron and egret life histories.

Hérons and egrets are relatively large, wading birds that are characterized by their long legs, sturdy bills, and long necks in which the sixth vertebra is elongated so that the upper part of the neck can arch back. The sexes are similar in plumage color however females are usually smaller than males. The length of the culmen or bill can be used to distinguish the sexes as the length of the male culmen (129-146 mm), which are longer than the female's culmen (112-131mm). Robert Butler (1997) uses a method to assign sex to live Great Blue Herons at a distance by comparing the lengths of culmens measured against a graticule scale in the eyepiece of a telescope. In most herons, both parents build the nest, incubate and attend to the young. Asynchronous hatching of the young may lead to varying mortality rates. Both herons and egrets form pair bonds however they are also known have extrapair copulations with females outside of the pair bond (Pratt 1993).

The Great Blue Heron, *Ardea herodias*, the largest of American herons, stands 97-137 cm tall with an average bill length of 13 cm (Hom 1983) which is yellow. There are two distinct color morphs; a dark morph and an all white morph confined to Florida, West Indies and the Caribbean coast (Hancock and Kushlan 1984, Butler 1997). The dark morph adult plumage is dark grey with a white crown, cheeks and throat. There is a black strip on the side of the crown, which merges into a long occipital crest. The back is bluish grey and the sides are blackish with a grey belly striped with white. The irises are yellow and the lores are green. The legs are greenish brown with dark feet. The adult breeding plumage consists of long plumes on the back and lower neck, which are light

grey. The iris reddens and the lores turn lime-green with pinkish legs during courtship (Hancock and Kushlan 1984). The juvenile plumage is darker with a dark crown and no crest. The bill color is greyish with a yellow lower mandible and the iris and lores are yellow. The eyelids are pale blue and the irises are yellow and legs and toes are olive green on top with a yellowish color below (Butler 1997). The coloring on the throat is a pinkish blue (Hancock and Kushlan 1984). Yearlings, age 12-24 months, have an intermediate plumage where the crown strip is small and the body plumage is short with a small chestnut or rufous colored shoulder patch (Butler 1997).

Great Blue Herons build nests into large platforms of sticks over 1 meter across mostly in tall trees. Kelly, *et al.* (1993) found Great Blue Herons nesting in *Eucalyptus* spp., *Sequoia sempervirens*, *Pinus sabiniana*, and other native trees as well as in *Scirpus* spp., and in ducks blinds around the San Francisco Bay. Nests have also been found in old windmills and power transmission towers in South San Francisco Bay (Ryan and Parkin 1998). The onset of nesting activity in the San Francisco Bay region starts in mid-February to mid-March (Pratt 1993). Twigs for the nest are presented before, during and after the courtship. The eggs are pale blue and have a size ranging from 61.3-65.6 x 41.9-46.5mm. The clutch size can vary from 3 to 7 eggs and incubation by both parents takes about 28 days. Pratt (1972) found that the average clutch size was 3.6 and hatching success was 86%. Hatching occurs 25-29 days after incubation. Pratt (1993) found that young nestlings at the Audubon Canyon Ranch Preserve were actually fed by eating regurgitated food from the parent dropped into the bottom of nest. By 21 days the nestlings can walk across the nest and by 7 weeks they can take short jump flights. In 60

days the nestlings can take sustained flight and abandon their nests between 64-91 days. Banding returns from a Bair Island colony suggest that the Great Blue Herons disperse throughout the Bay area to spend winters where there is suitable habitat (Pratt 1993).

The Great Blue Heron can be found throughout North and Central America, the Caribbean, the Great Antilles and the Galapagos. While Great Blue Herons from the northern North America are migratory, the southern populations are more sedentary and migrate more locally (Kushlan and Hancock 1984). They disperse widely after nesting. Great Blue Herons can be found in many habitats ranging from ocean beaches, rivers, lakes, freshwater and saltwater marshes and swamps to dry agricultural lands and parks.

The Great Egret, *Ardea alba*, is in the family Ardeidae, order Ciconiiformes (American Ornithologists' Union 2005). Many prefer to place it in the genus, *Egretta* to emphasize its similarities to other species in that genus (Pratt 1993) while others place it in the *Casmerodius* genus. However, the *Ardea alba* nomenclature will be used in this study.

The Great Egret stands 85-102 cm tall with all white plumage, dark legs and feet and a yellow to blackish bill with yellow or green lores and a yellow iris (Hancock and Kushlan 1983). The breeding adults develop long plumes that extend from the shoulder to the back. Their lores turn from yellow to lime green while the upper mandible becomes dark. Juveniles can be distinguished from the adults by their yellow bills that have black tip and white plumage without ornamental plumes.

Nests are made of sticks less than 1m in diameter and sometimes lined with finer material. Snowy Egrets and Black-crowned Night Herons frequently nest in the same

colony or nearby trees and shrubs. Clutches range from 2-5 eggs and are incubated for 27-28 days (Pratt 1993). Like the Great Blue Herons, Great Egrets feed their young by regurgitating food into the nest. As egret nestlings grow older, they take food directly from the parents bill and may therefore be less dependant on the nest platform for feeding that Great Blue Heron chicks (Pratt 2003).

The Great Egret occurs throughout most of North America, Central and South America and some distribution in Europe as well as Africa, Asia and Australasia (Hancock and Kushlan 1984). Populations in the Western United States migrate to Mexico and Central America although some remain in Oregon and California.

The Snowy Egret, *Egretta thula*, stands 56-66cm, has all white plumage, black legs with yellow feet, a black bill and yellow lores. During the breeding season the white plumes on their head, neck and back are obvious while the toes become orange-red and the lores turn reddish-pink (Hancock and Kushlan 1984). Juveniles can be identified by a yellowish stripe on their dull black legs and bluish bills.

Snowy egrets usually nest in colonies with other heron or egret species (Kelly 1993). Males are territorial and defend their nests by raising their crests. Depending on their nesting habitats, nests are about 60cm in diameter and made of a variety of materials with a stick foundation. The clutch size varies from 3-5 and both sexes incubate and care for the young (Hancock and Kushlan 1984).

Snowy Egrets are distributed in areas throughout the United States and is a resident species mostly along the coasts. Snowy Egrets were considered to be extinct in California in the 1900's after mass slaughter for their feathers and eggs, which the Great

Egret also endured. In 1908, it was legally protected and the population began to slowly recover (Pratt 1993). In 1927, they were known as a rare straggler to the Bay area, and in 1952, Sibley referred to them as uncommon. Their populations have increased substantially since that time but are starting to decline once again (Ryan and Parkin 1998).