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Western snowy plover use of managed salt ponds at Eden Landing, Hayward, CA

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WESTERN SNOWY PLOVER USE OF MANAGED SALT PONDS
AT EDEN LANDING, HAYWARD, CA

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by
Caitlin W. Robinson
May 2008

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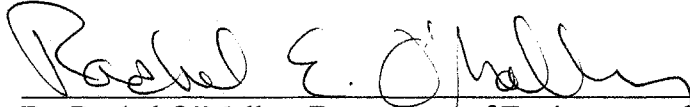
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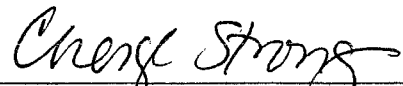
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ABSTRACT
WESTERN SNOWY PLOVER USE OF MANAGED SALT PONDS
AT EDEN LANDING, HAYWARD, CA

by Caitlin W. Robinson

The South Bay Salt Pond Restoration Project will restore 15,100 acres of former San Francisco Bay salt ponds which will affect the federally threatened western snowy plover (*Charadrius alexandrinus nivosus*), a species that has adapted to nesting on dry salt ponds. In 2006 and 2007, managed wildlife ponds and seasonal control ponds were monitored for plover use, nest abundance, and nest success. The mean nests per hectare on managed ponds was higher (0.122 ± 0.044 SE, $n=7$) than on control ponds (0.082 ± 0.026 SE, $n=13$). Nests were often associated with vegetation and water in managed ponds. The mean distance plovers flushed off their nest when approached was 174.9 m. This study indicates that land managers may be able to increase the number of nesting plovers by managing large ponds to have wet and dry areas and avoiding ponds that are adjacent to trails or tidal marsh.

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INTRODUCTION

Historically, the San Francisco Bay had over 190,000 acres of salt marsh, yet now approximately 14,000 acres remain (Goals Project 1999). Over the last 150 years, much of this area was converted to salt evaporation ponds. In 2003, Cargill Salt sold 15,100 acres of their salt production ponds to the California Department of Fish and Game (DFG) and the United States Fish and Wildlife Service (USFWS). The South Bay Salt Ponds Restoration Project (SBSP) is a large scale restoration project that aims to restore the former salt ponds to a mix of wetland habitats, provide flood protection and management for the South Bay, and provide a variety of recreational opportunities to the public (EDAW et al. 2007). One of the objectives of the SBSP is to maintain the current bird numbers that use the salt pond habitat, while converting some or most of the salt ponds to tidal salt marsh (South Bay Salt Pond 2004). The restored tidal marsh will be critical for the recovery of the endangered California clapper rail (*Rallus longirostris obsoletus*) and the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*) (EDAW et al. 2007). The managed wildlife ponds will provide nesting habitat for terns and shorebirds, including the federally threatened western snowy plover (*Charadrius alexandrinus nivosus*), and migratory and wintering habitat for hundreds of thousands of shorebirds and waterfowl.

To support the current waterbird numbers that use the salt ponds, the SBSP is presently managing former salt ponds, now called managed wildlife ponds, at Eden Landing Complex, owned and managed by DFG. The management goal for

managed ponds is to create seasonal habitats that support numerous species. To achieve this, the DFG manages water levels by flooding some ponds for the shorebirds and waterfowl that winter in the Bay and then draining some ponds to create a drier area for shorebirds, such as western snowy plovers, that breed on the ponds in the spring and summer.

Beginning in 2008, the SBSP will start with the project's initial restoration activities, which includes breaching levees to return certain areas to tidal action, installing new water control structures to improve water management, and adding recreational features, such as new trails. Eden Landing will be affected by the initial activities (Phase 1) of the SBSP (EDAW et al. 2007). Three ponds (E8A, E8X and E9) will be restored to tidal action as well as a section of old crystallizer ponds on the east side of Eden Landing. Ponds E12 and E13 will be divided into a small "salt pond system" with water at varying salinities. These ponds will also have islands constructed in them for shorebirds to roost and forage on. This action will reduce the area available to snowy plovers for foraging and nesting by 209.2 hectares.

At Eden Landing, recreational trails and a kayak launch will be added and some of the new trails will be adjacent to ponds managed for plovers. Currently, Eden Landing is closed to the public, which protects plovers from most human disturbance during their nesting season. The proposed trails include sections of trail that will be open to the public year round. In highly sensitive areas, the trails will be closed seasonally, during plover breeding season.

This study compares use of managed salt ponds by western snowy plovers to their use of ponds that dry seasonally and are not drained specifically for snowy plovers. I observed plover nest abundance and nest success at each pond and collected data on the distances that plovers nest from micro-habitat features within the ponds such as water, vegetation and levees. In addition, I examined soil colors and changes in micro-topography at nest sites and compared them to random bordering plots. Data on avian predators was collected to understand the pressures they place on the plovers in managed and seasonal ponds. In addition, I recorded the distance plovers flushed off their nest when I approached to estimate how the addition of trails will affect plovers at Eden Landing. The findings of this study can help land managers determine which practices will encourage western snowy plover nesting and survival. By comparing the plover use of the managed and seasonal ponds, this study will assess whether the DFG can effectively manipulate the ponds to offer high quality plover habitat and maintain, if not increase, the San Francisco Bay's plover population.

RELATED RESEARCH

Avian Use of Salt Evaporation Ponds

In the South Bay, approximately 85% of historic tidal marsh habitat was lost to urbanization and salt ponds (Goals Project 1999). This habitat loss mirrors wetland habitat loss worldwide. Tidal marsh habitat losses have major impacts on migratory bird populations (Dolman and Sutherland 1995, Weber et al. 1999, Masero 2003). In response to the habitat loss, some birds have started using anthropogenic

habitats for foraging, roosting and nesting (Weber et al. 1999, Masero 2003).

Examples of these substitute habitats are rice fields (Elphick and Oring 1998) and salt ponds (Warnock et al. 2002). If birds can effectively use these substitute sites, then the effects of habitat loss on some populations may be lessened (Weber et al. 1999).

Human created salt evaporation ponds provide important waterbird habitat worldwide (Warnock et al. 2002, Collazo et al. 1995, Masero 2001, Lane 1987). Waterbirds roost, forage, and nest on salt ponds and the ponds provide valuable stopover areas for migrating birds. Three of the ten most important areas for shorebirds in Australia are salt evaporation ponds (Lane 1987). The Cabo Rojo salt flats in Puerto Rico are the most important area for shorebirds in Puerto Rico (Collazo et al. 1995). This area consists of lagoons used to hold water that is channeled into the nearby evaporation ponds. Twenty-eight species of waterbirds use the salt flats, including nesting snowy plovers. Collazo found 29% of the peak numbers of migrating birds in the Caribbean used the salt flats. Masero (2003) studied small shorebird use of salt ponds in southwest Spain. He concluded that managing salt ponds for birds is important for waterbird conservation because they provide much needed habitat. In particular, the salt ponds have very high numbers of aquatic invertebrates living in the saline waters, which are important food sources to migrating waterbirds. Masero (2003) suggested that the salt ponds could act as supplemental wetlands, mitigating the effect of the decline in the world's wetlands.

Salt ponds and salt pans also provide important nesting habitat for bird species, many of whom formerly nested on beaches (Catry et al. 2004, Martin and Randall 1987 and Eyster et al. 2003). In South Africa, the second largest colony of Caspian terns (*Sterna caspia*) is at the Redhouse Saltpan (Martin and Randall 1987). The saltpan also has nesting sacred ibises (*Threskiornis aethiopicus*), kelp gulls (*Larus dominicanus*) and white breasted cormorants (*Phalacrocorax carbo*) (Martin and Randall 1987).

Locally, the San Francisco Bay's salt ponds act in a very similar way, providing vital foraging and roosting habitat for waterbirds (Warnock et al. 2002). A mid-winter survey by the USFWS found that in the late 1980s there were over 700,000 waterfowl using the Bay and delta and over 300,000 individuals using the salt ponds (Goals Project 2000). The south bay salt ponds supported 76,000 individuals, or 27% of the estuary's total waterfowl population; this included 90% of the bay's northern shovelers (*Anas clypeata*) (Goals Project 2000). The large number of wintering waterfowl and shorebirds gives the Bay the distinction of being one of the 34 waterfowl habitat areas of major concern in the North American Waterfowl Management Plan by the USFWS (Goals Project 2000). In addition, there are regularly 31 species of shorebirds in the Bay that primarily feed on tidal mudflats and salt ponds (Goals Project 2000). The Western Hemisphere Shorebird Reserve Network lists the Bay as site of hemispheric importance to shorebirds, as it supports more than 900,000 shorebirds annually (Stenzel et al. 2002, WHSRN 2006).

Eyster et al. (2003) developed a management plan to improve nesting habitat for snowy plovers at former commercial salt ponds in the Moss Landing Wildlife Area in Monterey County. They suggested drawing down water levels in early March to create dry areas for nesting and recommended flooding certain areas of the ponds twice a month to create foraging habitat. By managing water levels at Moss Landing Wildlife Area, DFG staff was able to increase the number of plovers nesting. Although many of the recommendations made by Eyster et al. (2003) pertain to the salt ponds within the SBSP area, research is needed to provide local information on western snowy plover habitat management.

Western Snowy Plover Ecology

Snowy plovers (*Charadrius alexandrinus*) are small shorebirds that nest in open areas lacking large amounts of vegetation such as coastal sandy beaches, salt evaporation ponds, and alkaline areas of southern and western North America (Page et al. 1991, Page et al. 1995, Warriner et al. 1986). The western snowy plover subspecies (*Charadrius alexandrinus nivosus*) inhabits coastal beaches and ranges from Washington (Page et al. 1991) to the southern tip of Baja California (Palacios et al. 1994). Although not genetically distinct from the inland population, the western snowy plover is behaviorally distinct and therefore considered a separate subspecies (Funk et al. 2006).

Western snowy plovers are polyandrous, and usually have multiple broods in a season (Warriner et al. 1986). The female usually deserts the male and brood before the brood fledges to re-nest while the male attends the brood until they can fly

(Warriner et al. 1986). The chicks are precocial and leave the nest within a few hours of hatching (Page et al. 1995).

The western snowy plover population has declined since the late 1880s, and has suffered a 20% decline from the late 1970s to the late 1980s (Page et al. 1991). These declines were likely caused by habitat alteration and recreational use of beach habitat (Page et al. 1991, Page et al. 1995). The introduction of beach grass has also reduced the amount of the preferred open beach habitat (USFWS 2007). The population decline region wide can also be attributed to poor reproductive success of the species, in part due to the introduction of non-native predators as well as the increase in native predators due to human actions such as inadequate disposal of garbage (USFWS 2007). In response to the decline in this population, the federal government declared western snowy plovers a threatened species in 1993 (USFWS 1993).

The first record of snowy plovers breeding in the San Francisco Bay was in 1918 when they were reported nesting in the commercial salt ponds (Grinnell 1918). There are no records of western snowy plovers in the Bay prior to the construction of the salt ponds (Goals Project 1999). A census done in the late 1970s found approximately 351 breeding plovers in the Bay (Page et al. 1981). Over the past four years the number of plovers in the South Bay has varied from 72 in 2003 (Strong et al. 2003) to 207 in 2007 (Robinson et al. 2007b).

The recovery plan for the western snowy plover states that the San Francisco Bay should support 500 breeding adult plovers in order to meet the recovery goal

(USFWS 2007). Currently, the entire snowy plover habitat within the Bay is within the SBSP's area. The SBSP is planning to support 250 breeding adults within the project area (EDAW et al. 2007). Since many ponds will be converted to tidal marsh, to achieve this goal, project managers will need to increase the number of plovers within a smaller habitat footprint.

Snowy Plover Nest Site Selection

Snowy plovers usually nest in flat areas with sparse vegetation (Page et al. 1985). Plover nests are small depressions in the sand or soil and are decorated with shells, soil, or other small objects (Johnsgard 1981). The nests are cryptically colored to help camouflage them from predators. At Mono Lake, plovers often nested beside driftwood or other objects that may create a "disruptive effect" for predators searching for nests (Page et al. 1985). On the beaches of San Diego, plovers nested near vegetation or debris (Powell 2001). Within the salt ponds, ridges in the substrate may help camouflage the nests from predators (Marriott 2003).

In the San Francisco Bay, western snowy plovers nest on dry salt evaporation ponds and occasionally on the levees surrounding the salt ponds (Feeney and Maffei 1991, Goals Project 2000). Previous studies have found that they prefer to nest on substrates of colors that are similar to the color of their plumage (Feeney and Maffei 1991) and near ridges in the substrate (Marriott 2003). Nesting on substrate colors close to the coloration of their plumage may help with nest concealment and reduce the amount of depredation (Collias and Collias 1984).

Avian Predators of Snowy Plovers

One of the major factors limiting western snowy plover nest success is avian predator pressure. Numerous species are known to depredate adult plovers, chicks, and eggs including common ravens (*Corvus corax*) (Page et al.1985), American crows (*Corvus brachyrhnhos*), and northern harriers (*Circus cyaneus*) (USFWS 2007). Corvids (American crows and common ravens) are common predators throughout the plovers range and were the main cause of nest depredation in Oregon (Lauten et al. 2006). They are considered a predator of concern in the San Francisco Bay (Strong et al. 2004b).

Northern harriers were one of the primary predators of plovers at the Salinas National Wildlife Refuge in 2002 (USFWS 2002) and have been seen eating chicks at Moss Landing Wildlife Area (Eyster et al. 2003). They were responsible for only a 22% fledge rate for the years 1996-2000 at Moss Landing. Northern harriers were observed depredating plovers in the Bay in 2004 (Strong et al. 2004b) and depredating a nest and a chick in 2007 (Robinson et al. 2007b).

Various types of predator management techniques are used to reduce the pressure predators put on snowy plovers. One method involves placing a predator exclosure around the plover nest to protect the nest from being depredated (Nol and Brooks 1982, Melvin et al 1992). However, this method may cause greater amounts of adult mortality by bringing the nest to the attention of certain predators (Neuman et al. 2004).

The use of predator exclosures has increased the number of successful plover nests in many areas; however, they do not provide any protection for chicks (Neuman et al. 2004, Lauten et al 2006). In many areas, predator management methods include removing select predators from sensitive areas. For example, removing corvids has significantly increased the plover fledge rates in Oregon (Lauten et al. 2006). Methods for predator removal include trapping and translocation, and lethal removal (Strong et al. 2004b, Lauten et al. 2006).

Recreational Disturbance to Nesting Shorebirds

Ground nesting birds typically leave the nest when disturbed (Burger 1984). Human recreation activities along beaches disturb nesting plovers (Lord et al. 2001, Flemming et al. 1988). Responses may include getting off the nest, running away from the nest, and creating a distraction to lure the potential predator from the nest (Burger and Olla 1984). Typical distractions in snowy plovers vary from head bobbing to the injuring-feigning “broken wing” display (Burger and Olla 1984, Page et al. 1994).

The time the adult spends off the nest creating a distraction leaves the nest more vulnerable to predators (Bolduc and Guillemette 2003) and exposes the eggs to thermal stress. If adults are not incubating the nest, the eggs may cool or heat too much and develop more slowly or fail to hatch (Webb 1987).

The distance that birds flush off a nest varies by species and by the perceived threat. Recreational disturbances, such as walkers, joggers, and dogs are a threat to many nesting shorebirds, including snowy plovers. Nesting shorebirds on quiet

beaches tend to flush at longer distances than beaches with more use where birds are more acclimated to human disturbance (Lord et al. 2001, Page et al. 1977).

Human recreational activities also affect the ability of adult plovers to fledge chicks successfully. A study conducted in Nova Scotia found that the presence of humans within 160 meters of piping plover (*Charadrius melodus*) broods affected their behavior (Flemming et al. 1988). The amount of time adults spent brooding the chicks and the chicks spent foraging was significantly reduced when humans were present (Flemming et al. 1988). The chicks had significantly lower pecking rate during feeding while pedestrians were in the area (Flemming et al. 1988). Flemming et al. (1998) concluded that human disturbance altered chick behavior and made them more vulnerable to predators and inclement weather, therefore increasing mortality. Finney et al. (2005) found that golden plovers (*Pluvialis apricaria*) would not bring their broods within 200 m of recreational paths.

OBJECTIVES

This study will assess whether managing water levels in the former salt evaporation ponds for snowy plovers will increase the number of snowy plovers foraging, roosting, and nesting. Specifically, I will address these hypotheses and research questions:

HO₁: Ponds managed for western snowy plovers by lowering water levels in the spring and summer will not increase snowy plover use for a) roosting, b) foraging, c) nesting abundance, and d) hatching success.

HO₂: There is no relationship between micro-habitat features including water in channels, berms, furrows, vegetation, and anthropogenic features within the salt ponds and western snowy plover nest success.

HO₃: There is no relationship between the number of predators seen per week and the number of depredated western snowy plover nests.

Research Question 1: Do avian predation rates differ between before and after predator removal?

Research Question 2: Is there a relationship between microhabitat features including water in channels, berms, furrows, vegetation, and anthropogenic features within the salt ponds, and western snowy plover and nest site selection?

Research Question 3: What is the flush distance of the western snowy plover when approached by humans?

Research Question 4: What are the potential impacts on snowy plovers of adding recreational trails at Eden Landing?

METHODS

Study Area

This study was conducted at Eden Landing Complex in Hayward, California, which is approximately 2,225.7 hectares. Eden Landing is located on the east side of the San Francisco Bay (Figure 1) in Alameda County.

Formally, Cargill Salt owned the area and used it as commercial salt evaporation ponds (Goals Project 1999). DFG acquired the land and is currently managing some of the former salt ponds for shorebirds and waterfowl (Life Science!, Inc et al. 2005). The managed ponds are large, shallow, open areas of water surrounded by levees with an array of water control structures connecting them to the bay and other salt ponds (Figure 2). The ponds are relatively flat areas with minimal amounts of vegetation. The most common plant growing in the salt ponds is the native pickleweed (*Salicornia spp.*) and the introduced slender-leaf iceplant (*Mesembryanthemum nodiflorum*). Some ponds have wooden beams, metal pump remnants, and other anthropogenic structures left over from the salt works. Other features within the ponds are borrow ditches, furrows, berms, and channels.

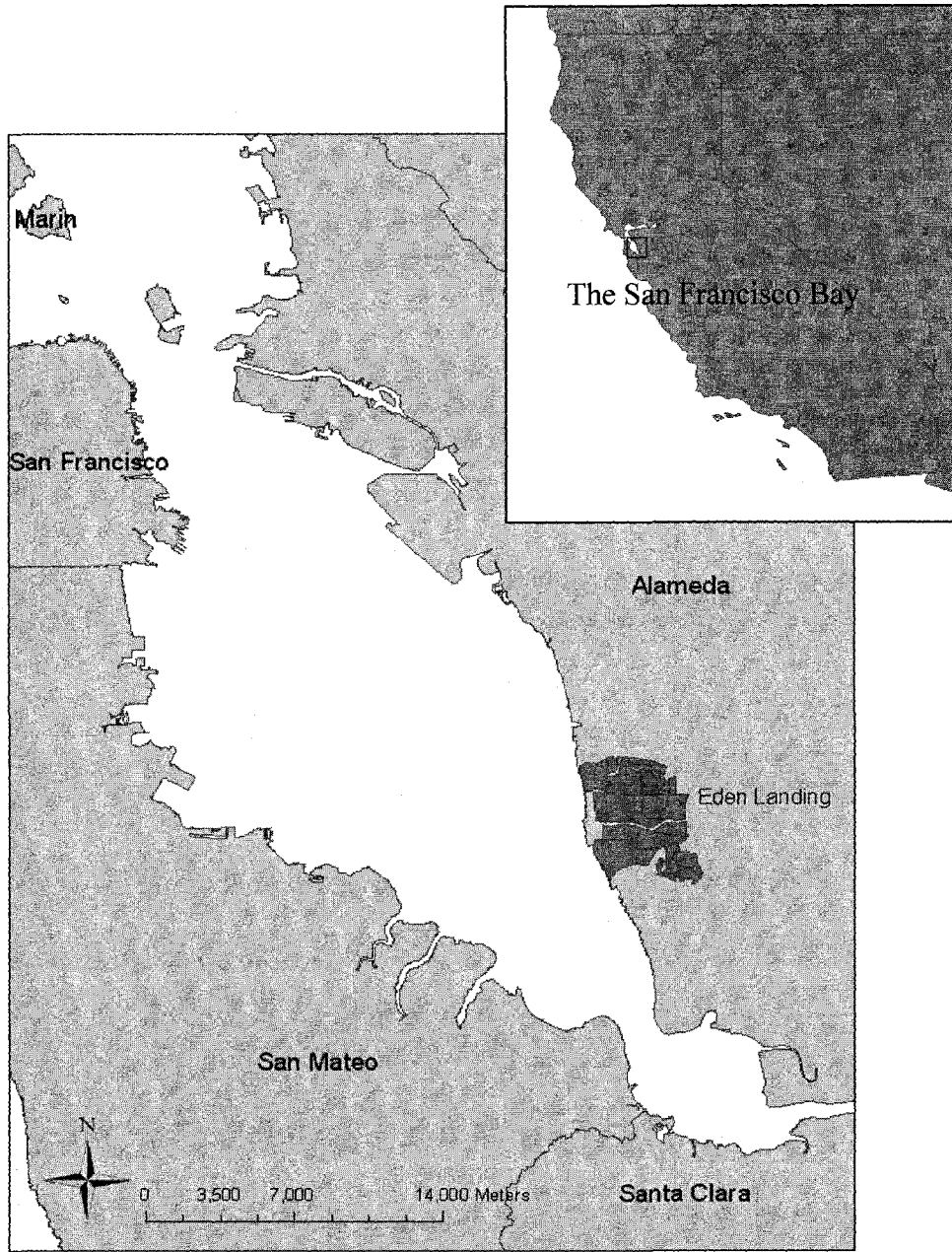


Figure 1. Study area: Eden Landing Complex, Hayward, CA.

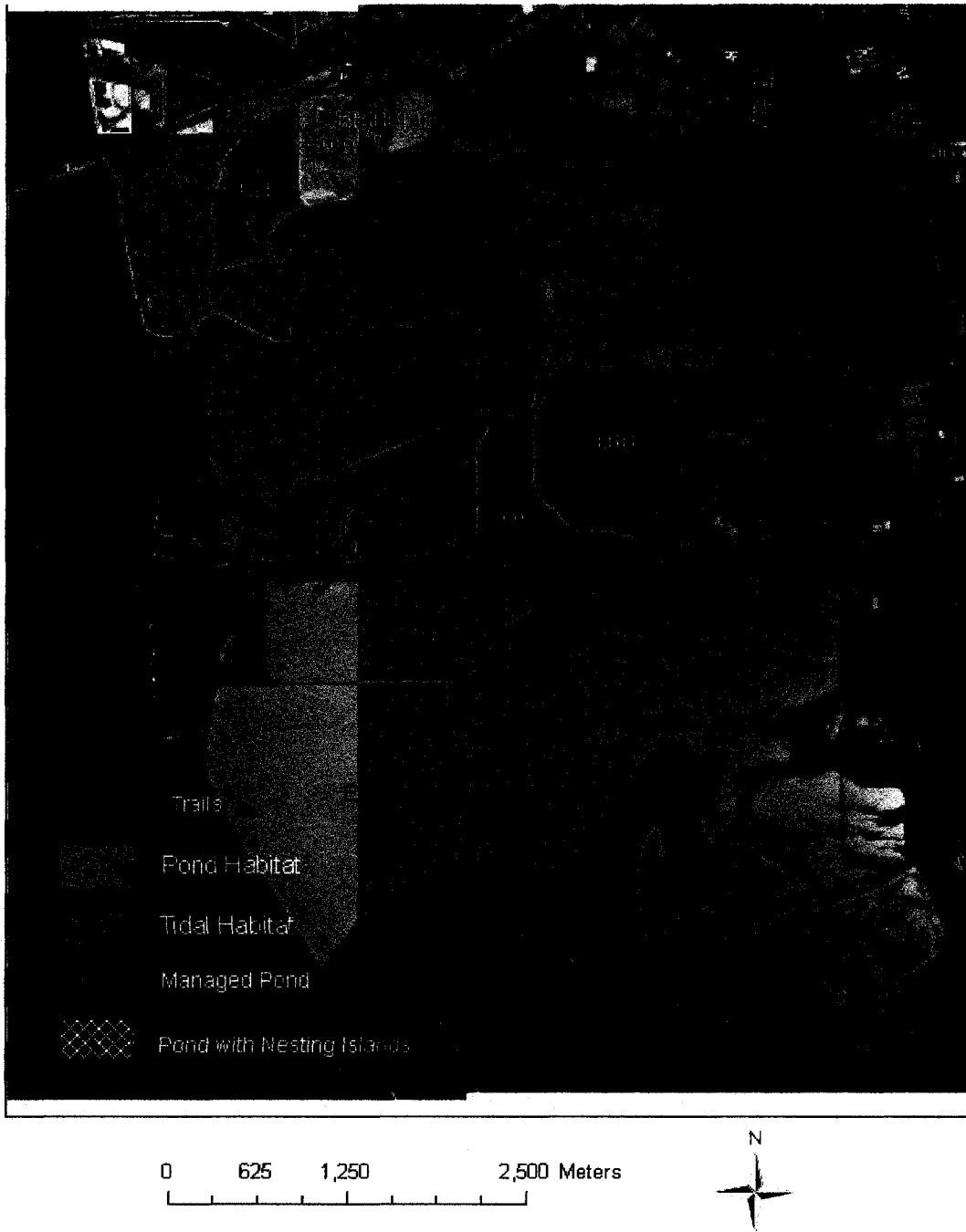


Figure 2. Eden Landing ponds colored with the SBSP Phase 1 habitat types.

The managed wildlife ponds monitored for this study in 2006 were E6A (137.6 ha), E6B (114.9 ha), E8A (103.6 ha), E8 (72.8 ha), E8X (12.1 ha) (Life Science!, Inc et al. 2005). The managed ponds in 2007 were E8A and E14 (63.1 ha) (Life Science!, Inc et al. 2005). DFG manages these ponds specifically for waterbirds and keeps the ponds at varying water levels throughout the year to suit different species needs. For example, the water levels are deeper in the winter for the wintering shorebirds and waterfowl, and partially dry in the summer for nesting shorebirds. The goal of managing ponds is to create pond habitat with suitable foraging areas for shorebirds in the winter and to create dry, salt pan habitat for birds such as the western snowy plover in the spring and summer (Life Science!, Inc et al. 2005).

Control (seasonal) ponds for the study differed between 2006 and 2007 because of varying amounts of rainfall each year. DFG managed these seasonal ponds to maintain open water habitat in the winter and have some drying in the summer. The control ponds for the 2006 field season were E4C (70.8 ha), E12 (93.5 ha) and E14 (63.1 ha) and E11 (47.7 ha) (Life Science!, Inc et al. 2005). The control ponds for the 2007 season were E4C, E11, E16B (33.2 ha), E12, E8, E8X, E6A, E6B and E6 (71.2 ha).

Hypothesis 1a - c: Western Snowy Plover Surveys

Methods for plover surveys, nest success, and predator surveys were based on the San Francisco Bay Bird Observatory's (the Bird Observatory) and USFWS snowy plover monitoring methods (Marriott and Schelin 2001, Strong et al. 2004b).

The Bird Observatory's plover and predator survey data in 2006 and 2007 was included in this thesis. I recorded the number and sex of the plovers as well as their behavior at each pond weekly. Plovers were recorded as males, females, or unknown. Plover behavior was grouped into four categories: roosting, foraging, sitting (on a nest), or other. I recorded habitat where the plovers were located as salt pond, levee, or other. Each plover observed was given an observation number and its location was noted on a map. I also recorded if the plover had a colored or silver band on its leg. Plover monitoring efforts on the coast color band the chicks to estimate fledge rates and keep track their movements. Each year a few of these birds make their way to the wildlife ponds in the San Francisco Bay.

Hypothesis 1d: Nest Success

If a plover was seen copulating, making a scrape, or seen sitting for more than 10 minutes, I assumed that they had an active nest (Marriott and Schelin 2001, Strong et al. 2004b). For the 2006 breeding season, I used data collected by the Bird Observatory data on nest success and Bird Observatory field assistants assisted in collecting some of the data for this study. In 2007, I located nests by walking onto ponds. Nest status was recorded as copulation/nest construction, incubation, hatchling (chicks before they can fly), or fledgling (young that can fly but still are with the males). Each nest was given an individual number, starting with the pond number followed by a consecutive number (E8-1, E8-2, E8-3, etc.). Its location was recorded with a global positioning device (GPS), either a Trimble GEO Xt in the 2006 field season or a Garmin GPS 60 in the 2007 field season.

When I first visited nests, I aged the eggs by floating them (Hays and LeCroy 1971). Each egg was placed in a container of distilled water and either the angle that it was resting on the bottom of the cup was recorded or the millimeters exposed above the water if it was floating (Hays and LeCroy 1971). If the eggs did not float, they were less than 8 days old. When the eggs were approximately 10-12 days old, they floated with roughly 4 mm of egg exposed above the surface of the water. As the egg ages, the amount of egg exposed above the surface of the water increased daily until just before hatching when around 18 mm of egg shell is exposed (Hays and LeCroy 1971). We floated eggs once a week until the nest hatched or failed. I used the data from floating the eggs to determine nest initiation dates for each of the nests.

Once the nest was finished, from hatching, predation, flooding, or abandonment, I examined the scrape for eggshell fragments (Mabee 1997). If I found fragments and it was near the predicted hatch date, I assumed the nest hatched. If no eggshell fragments or large damaged eggshell fragments or yolk were found, the nest was recorded as depredated (Mabee 1997). If the nest was intact with eggs still in it but no adults had been seen near it for 2 weeks, it was recorded as abandoned.

The observational portion of this study was permitted by the University Animal Care and Use Committee, permit 2006-B in 2006 and 2007. My handling of plover eggs in 2007 was conducted under the University Animal Care and Use Committee, permit 2007-C. I was granted access to Eden Landing Ecological

Reserve by the California Department of Fish and Game in 2006. In 2007, I was covered by the Bird Observatory's (the Bird Observatory) Eden Landing Ecological Reserve access permit. I was added as an independent researcher to the United States Fish and Wildlife Service's Don Edwards San Francisco Bay National Wildlife 10(A)1(a) Endangered Species Recovery Permit # TE-SFBNWR-19.

Hypothesis 3: Avian Predator Surveys

In order to determine the predation pressure on plovers and to identify species that depredate plovers and their nests, each pond was surveyed weekly for avian predators (USFWS 2007, Strong et al. 2004b). I recorded the following species: common raven, northern harrier, American crow, red-tailed hawk (*Buteo jamaicensis*), American kestrel (*Falco sparverius*), peregrine falcon (*Falco peregrinus*), white-tailed kite (*Elanus leucurus*), merlins (*Falco columbarius*), great blue herons (*Ardea herodias*), great egrets (*Ardea alba*), snowy egrets (*Egretta thula*), loggerhead shrikes (*Lanius ludovicianus*), and burrowing owls (*Athene cunicularia*). For each predator, I recorded the species, number of individuals, and behavior. The general location of each predator was recorded on a map.

Research Question 1: Predator Management

To reduce the impact of avian predators on nesting snowy plovers, USFWS and DFG collaborated with the United States Department of Agriculture - Wildlife Services to conduct avian predator management. In 2004, Wildlife Services started controlling American crows and common ravens at Eden Landing (Strong et al.

2004b). They began removing northern harriers in 2006 because of the concern that harriers were limiting plover nest success (Robinson et al. 2007a). I used the dates of these removals (2006-2007) to examine the effectiveness of predator removal on decreasing the amount of depredation of plover nests.

Hypothesis 2 and Research Question 2: Micro-habitat Preferences

To assess snowy plover use and nest site preference, in 2006 and 2007 I measured how close the birds nested to the following microhabitat features: water, levees, vegetation, furrows (trenches), berms (raised earth), and miscellaneous anthropogenic features such as wooden posts and metal structures left over from old salt works operations. Once all of the nests on each pond were completed, from hatching, predation, abandonment, or flooding, I stood at the nest and used a Bushnell Yardage Pro rangefinder to measure the distances to each of the features. The rangefinder's maximum distance was 500 m so if a feature was over 500 m away it was recorded as > 500 m. The snowy plovers in the south bay are not color banded, therefore there is no way to tell individuals apart. Although plovers are known to re-nest (Page et al. 1995) all nests were included in the analyses because there was no way to tell which nests were re-nests.

To further assess microhabitat preferences, in 2007 I placed a 1 m² quadrat on the ground, centered on the nest and compared micro-habitat features within nest quadrats to a random bordering quadrat that had no plovers nesting in it. The quadrat was divided into 9 sub-quadrats within each quadrat. I recorded the soil color using Munsell Soil Charts, the difference between the highest and lowest micro

elevation points, and the percent cover of vegetation in each quadrat that had a plover nest. I then chose a random bordering quadrat with at least 20% dry land and took the same measurements. The Munsell soil charts record three different color measurements: hue (H), value (V) and chroma (C) and are denoted as H V/C (Munsell 1988). Hue is represented by letters R, Y, G and B (red, yellow, green and blue, respectively) and a number 1-10. Value is represented by a number 1-10, 1 representing white and 10 representing black. Chroma is represented by a number 1-20 and signifies the saturation of the color (Munsell 1988).

Research Questions 3 and 4: Flush Distances and Disturbance from Trails

In the 2007 field season, I measured the distance that sitting plovers flushed off their nests as we approached. To do this, my field assistant watched a sitting bird as I walked out onto the pond to conduct weekly nest checks. When the bird flushed, my assistant used a two-way radio to alert me that the bird was off the nest. I then dropped a marker on the ground and I measured the distance from the nest to the item with a Bushnell Yardage Pro rangefinder. If the rangefinder was not effective, I walked back to the marker and used the GPS unit to measure the distance. If the bird flushed when we were still in the vehicle, I measured the distance from the nest to the vehicle with the rangefinder.

To assess the amount of habitat that might be compromised by the new proposed trails at Eden Landing, I mapped a buffer zone using the mean distance at which plovers flushed from their nests. This showed the amount of habitat that may not be used by plovers until they possibly become more habituated to trail users.

The second map shows a “worst case scenario” of compromised habitat with a buffer zone around the trail of the mean flush distance and one standard deviation away from the mean. To estimate the numbers of plovers that will be able to use the ponds with the reduction of the compromised habitat, I calculated the current densities of nests and plovers, using the mean of the two years. To estimate current densities of plovers I used a low count estimate and a high count estimate based on counts from weeks when all ponds were surveyed for plovers and nests. I took the lowest number of plovers from a complete survey week from each year and averaged them. I repeated this with the two high count weeks from the two years.

To estimate the number of plovers that will use the salt ponds with the reduced amount of habitat, I multiplied the current densities of plovers and nests per hectare by the number of hectares remaining with the buffer zones in place. I used four estimates of the available hectares: year round trails using the mean flush distance, and year round trails using the mean flush distance and one standard deviation.

Analytical Methods

Hypothesis 1: I performed a repeated measures ANOVA to compare the number of plovers foraging and roosting per hectare for the pond types each month throughout the season for each year. To analyze the nest data, I used a general linear model (GLM) to compare the nest densities in the two types salt ponds (managed and control) over the two years using the natural log of the nest densities in the

analysis. To compare the number of successful and depredated nests each year in both the pond types, I used a chi-square test.

Hypothesis 2: I used multiple logistical regression to model the probability of nest success based on the same habitat characteristics. Nest success was the dependent variable and it was a binomial response in the model, i.e. nests were either successful or failed. Only successful and depredated nests were considered for this analysis; abandoned, flooded or nests with unknown fates were not used.

Hypothesis 3: To analyze the relationship between the number of predators and the number of active plover nests I performed a simple correlation for each year of data.

Research Question 1: I calculated the mean number of plover nests, percent depredated nests and number of harriers per survey for the weeks before harrier removals and for the weeks after removals.

Research Question 2: I examined the relationship between nest site selection and habitat variables with a principle components analysis (PCA) using a verimax rotation. The habitat variables used in the analysis were distance to water, vegetation, furrows, berms, levees and anthropogenic features. The distance to furrows was log transformed for the analyses. I calculated the frequencies of the hue, value and chroma at nest plots and bordering plots. I also compared the habitat characteristics (percent vegetation and change in topography) between nest quadrats and a random quadrat with paired t-tests.

RESULTS

Hypothesis 1a and b: Snowy Plover Roosting and Foraging on Ponds

In 2006, the number of plovers roosting per hectare using managed ponds throughout the season was significantly higher ($n = 6$, $df = 4$, $F = 5.554$, $P = 0.005$) (Figure 3a), but the number of plovers foraging per hectare did not differ between managed and control ponds ($n = 6$, $df = 4$, $F = 0.916$, $P = 0.642$) (Figure 3b).

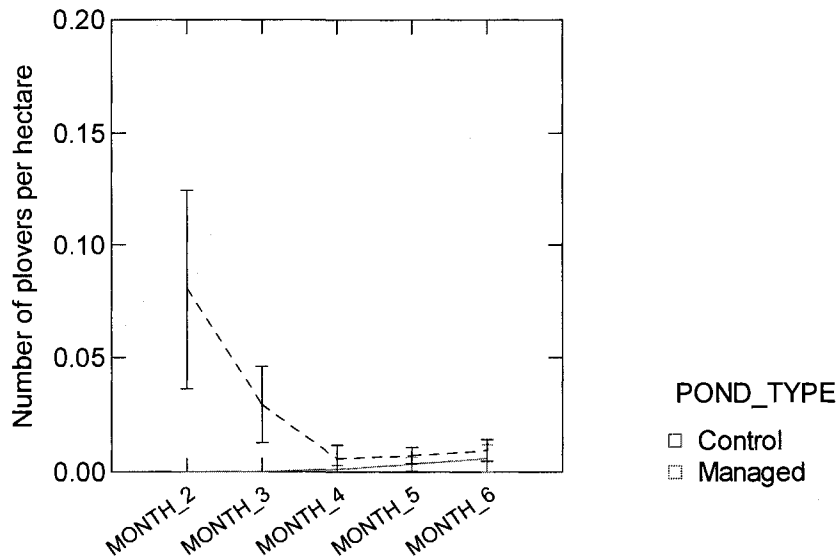
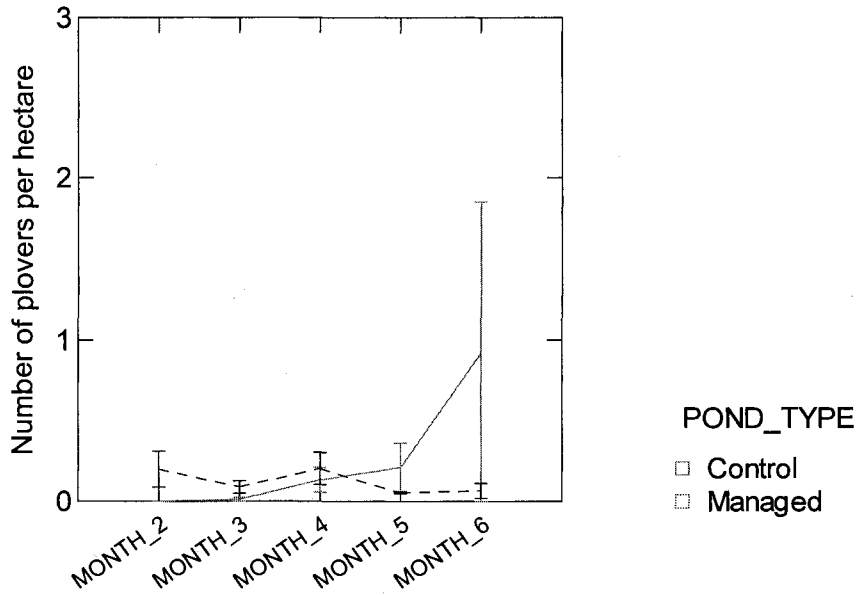


Figure 3a. Number of plovers per hectare roosting in both pond types in 2006. Months 2 through 6 are April through August.

In 2007, there was no significant difference in the number of plovers per hectare roosting throughout the season on managed and control ponds ($n = 10$, $df = 5$, $F = 0.510$, $P = 0.767$) (Figure 4a), while the number of plovers foraging on managed verses control ponds differed greatly ($n = 10$, $df = 5$, $F = 25.791$, $P < 0.001$) (Figure 4b).



3b. Number of plovers per hectare foraging on both pond types in 2006. Error bars depict standard error. Months 2 through 6 are April through August.

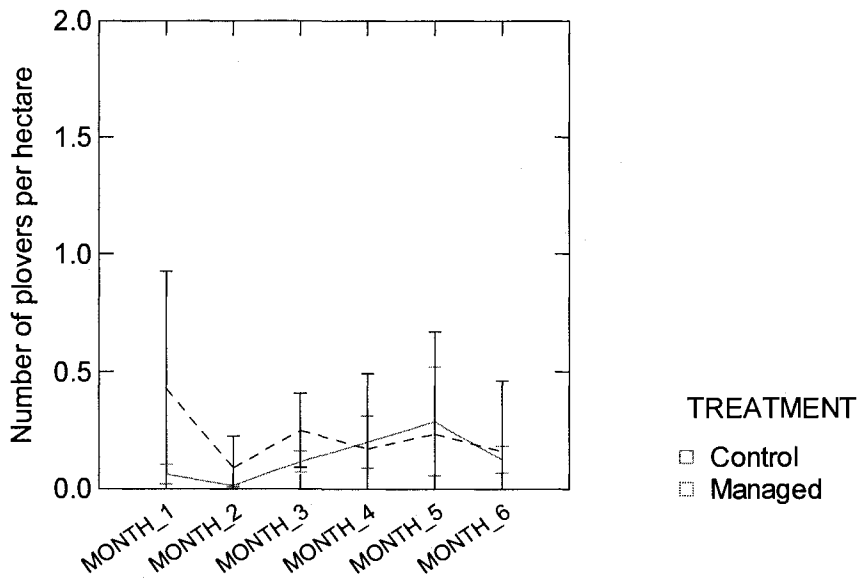
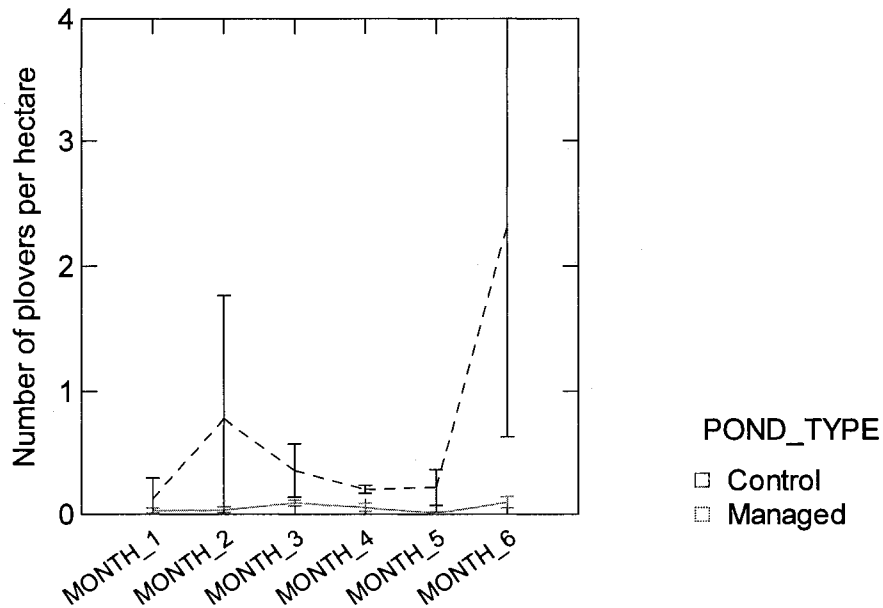


Figure 4a. Number of plovers per hectare roosting in each pond type in 2007. Error bars depict standard error. Months 1 though 6 are March through August.



4b. Number of plovers foraging per hectare for each pond type in 2007. Error bars depict standard error. Months 1 through 6 are March through August.

Combining the data from the two years showed that there was a significant interaction between pond management and year, and that more plovers were foraging in managed ponds ($n = 16$, $df = 4$, $F = 6.331$, $P = 0.031$). The numbers of plovers roosting per hectare did not differ significantly between the two years ($n = 16$, $df = 4$, $F = 0.002$, $P = 0.967$).

Hypothesis 1c: Snowy Plover Nest Densities

In 2006, 69 snowy plover nests were monitored at Eden Landing. The number of snowy plover nests in managed ponds (41) was almost twice that of plovers nesting in control ponds (28). The mean density of nests on managed ponds was 0.099 nests per hectare ($SE = 0.063$) and the mean density on control ponds was

0.057 nests per hectare (SE = 0.026) (Figure 5). Managed pond E8 had the most nests (23) and control pond E12 had the second greatest number of nests (22) (Figure 8, Table 1).

In 2007, 80 plover nests were monitored. The number of snowy plover nests in managed ponds (39) was very similar to the number in control ponds (41), but the mean density of nests in the two managed ponds was 0.228 (SE = 0.022) while the mean density in the six control ponds was 0.104 (SE = 0.043). Managed pond E8A had the most nests (26) and control pond E12 had the second most number of nests (14) (Figure 9, Table 2). The density of nests on managed ponds for 2006 and 2007 was not significantly different from control ponds ($n = 20$, $df = 1$, $F = 1.986$, $P = 0.180$) (Figure 5), possibly due to small sample sizes.

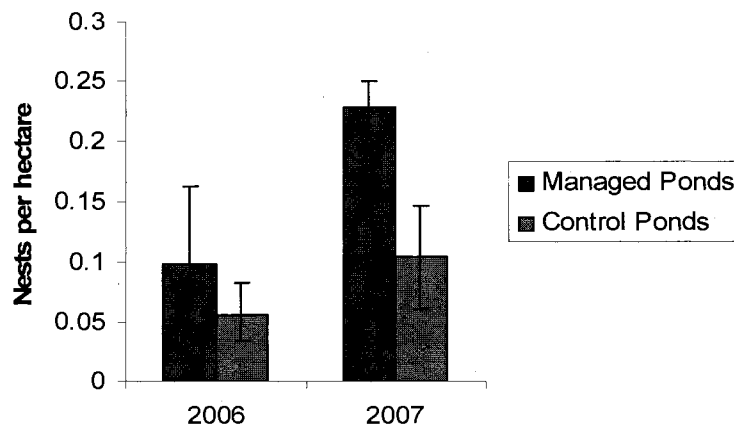


Figure 5. Nests density for 2006 and 2007 per pond type.

The range of nest initiation dates in the managed ponds in 2006 was April 9th – July 16th. The peak nest initiation week for managed ponds was April 23rd with 11 nests initiated. The range of nest initiation dates in the control ponds was May 21st

through July 16th. The peak nest initiation week for control ponds was July 2nd with 9 nests initiated (Figure 6). Active nests in managed and control ponds did not greatly overlap in time.

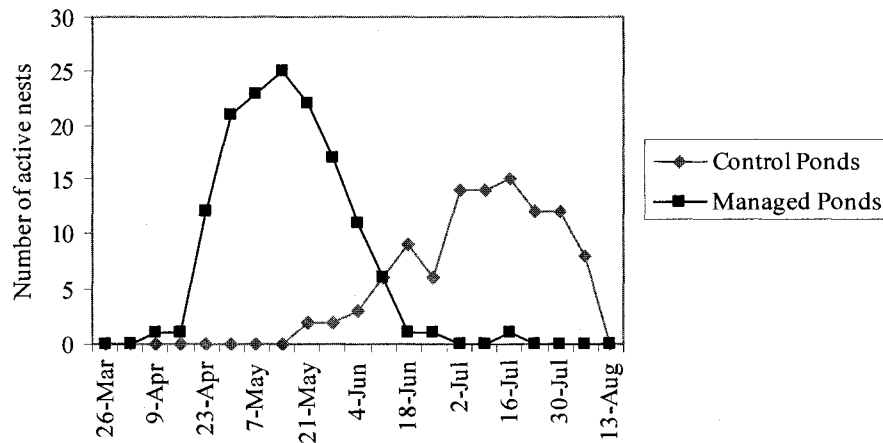


Figure 6. Number of active nests per week in the 2006 breeding season.

In 2007, the range of nest initiation dates in managed ponds was April 1st through July 8th. The peak nest initiation weeks for managed ponds were April 8th and April 22nd, with 6 nests initiated both weeks. The range of nest initiation dates for control ponds were March 25th through July 15th. The peak nest initiation weeks were June 17th and June 24th, with 8 nests initiated both weeks (**Figure 7**). In 2007, the number of active nests in managed and control ponds overlapped throughout the season, although as in 2006, more nests occurred on the managed ponds earlier in the season and more on the control ponds later.

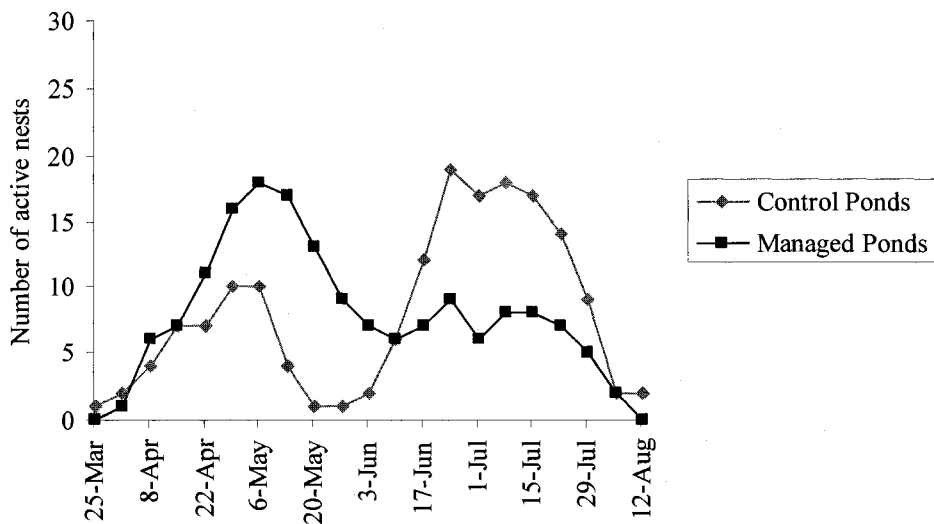


Figure 7. Number of active nests per week in the 2007 breeding season.

Hypothesis 1d: Nest Success

In 2006, within the control ponds, 17 nests hatched (62.9%), 7 were depredated (22.2%), 2 were abandoned (7.4%) and 2 had an unknown fate (7.4%) in 2006 (Figure 8, Figure 10). Within the managed ponds in 2006, 20 nests hatched (48.7%), 15 were depredated (36.5%), 2 were abandoned (4.8%) and 4 were flooded (9.7%) (Figure 8). The number of successful and depredates nests were not significantly different between the managed and control ponds ($\chi^2 = 1.141$, $P = 0.285$).

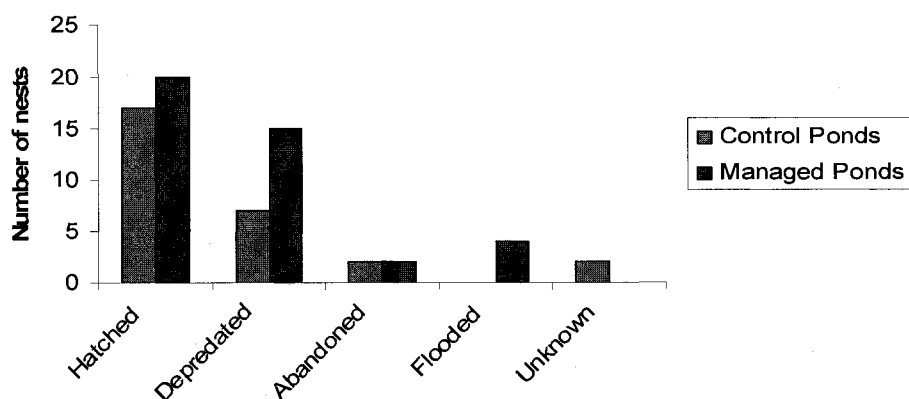


Figure 8. Nest fates on control and managed ponds in 2006.

Table 1. Nest success for the 2006 breeding season.

2006 Breeding Season						
	Hatched	Depredated	Abandoned	Flooded	Unknown	Total nests
E6A	0	0	0	0	0	0
E6B	7	6	1	3	0	17
E8	13	8	1	1	0	23
E8A	0	1	0	0	0	1
E11	0	0	0	0	1	1
E12	14	6	1	0	1	22
E14	3	0	1	0	0	4
E4C	0	1	0	0	0	1
E8X	0	0	0	0	0	0
Total	37	22	4	4	2	69

In 2007, within the control ponds, 20 nests hatched (48.7%), 19 were depredated (46.3%), two were abandoned (4.8%) and no nests were flooded or had unknown nest fates (Figure 9, Table 2, Figure 11). Within the managed ponds 18 nests hatched (46.2%), 18 were depredated (46.2%), one was abandoned (2.5%), one was flooded (2.5%) and one had an unknown fate (2.5%) (Figure 9, Table 2). The

number of successful and depredated nests were not significantly different in the managed and control ponds ($\chi^2 = 0.021$, $P = 0.885$).

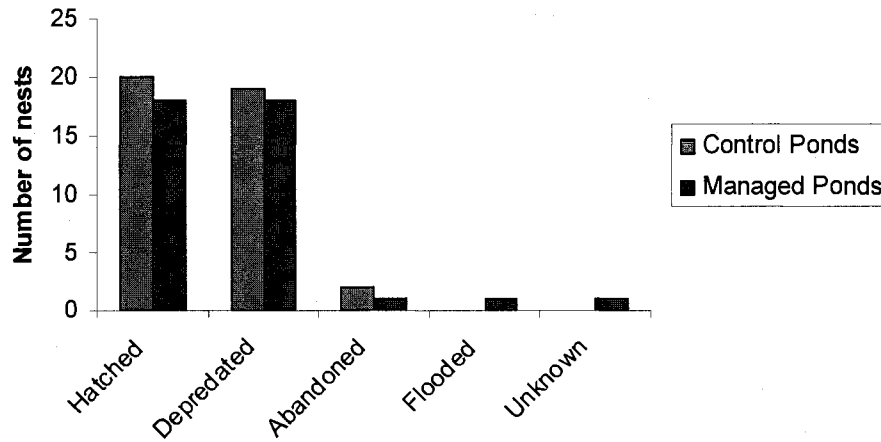


Figure 9. Nest fates on control and managed ponds in 2007.

Table 2. Nest success for the 2007 breeding season.

2007 Breeding Season						
	Hatched	Depredated	Abandoned	Flooded	Unknown	Total nests
E6A	0	0	0	0	0	0
E6B	2	1	1	0	0	4
E8	1	3	0	0	0	4
E8A	16	8	0	1	1	26
E8X	1	4	0	0	0	5
E11	3	3	1	0	0	7
E12	9	5	0	0	0	14
E14	2	10	1	0	0	13
E16B	0	2	0	0	0	2
E4C	0	0	0	0	0	0
E6	4	1	0	0	0	5
Totals	38	37	3	1	1	80

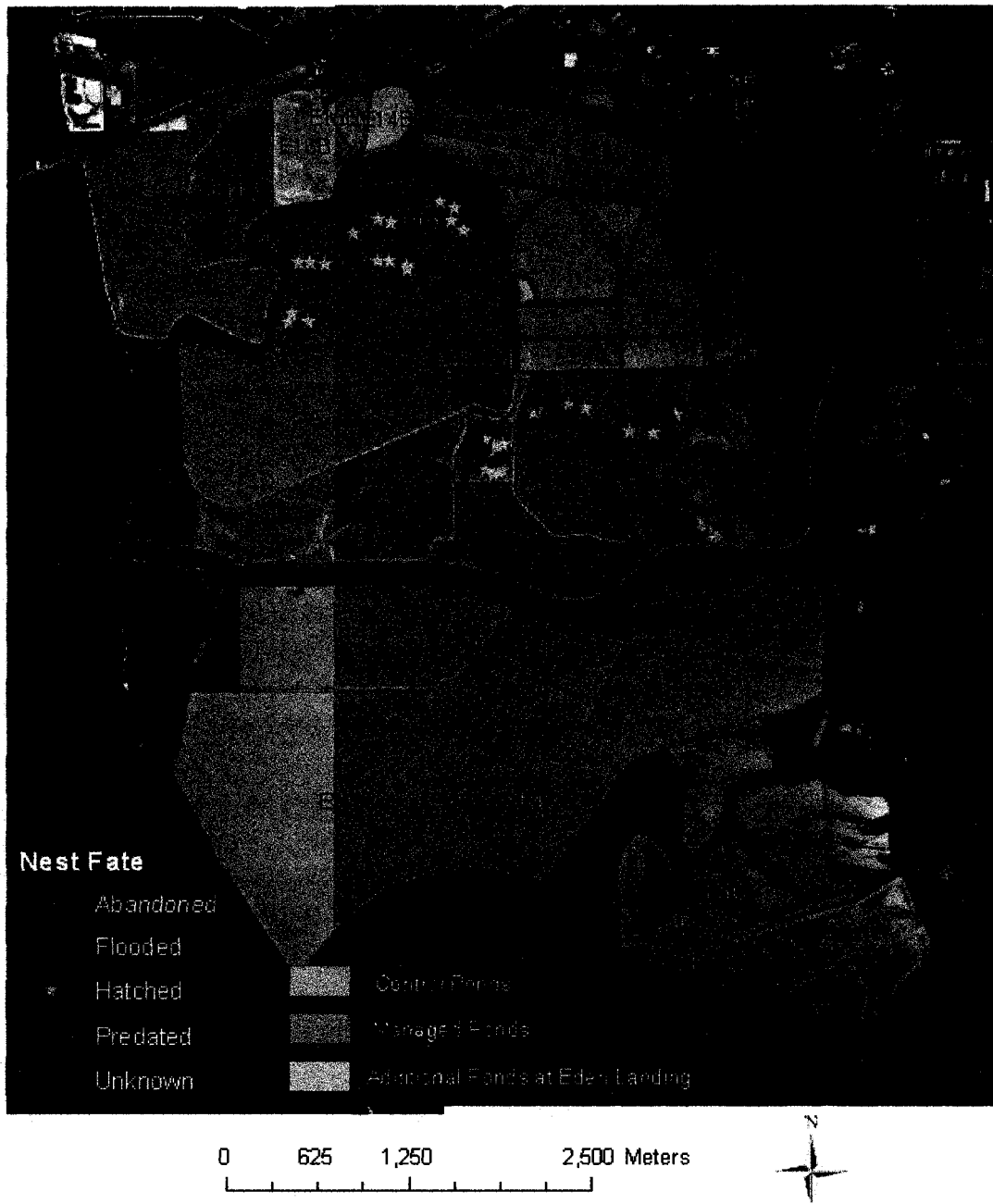


Figure 10. Locations and fates of nests in 2006.

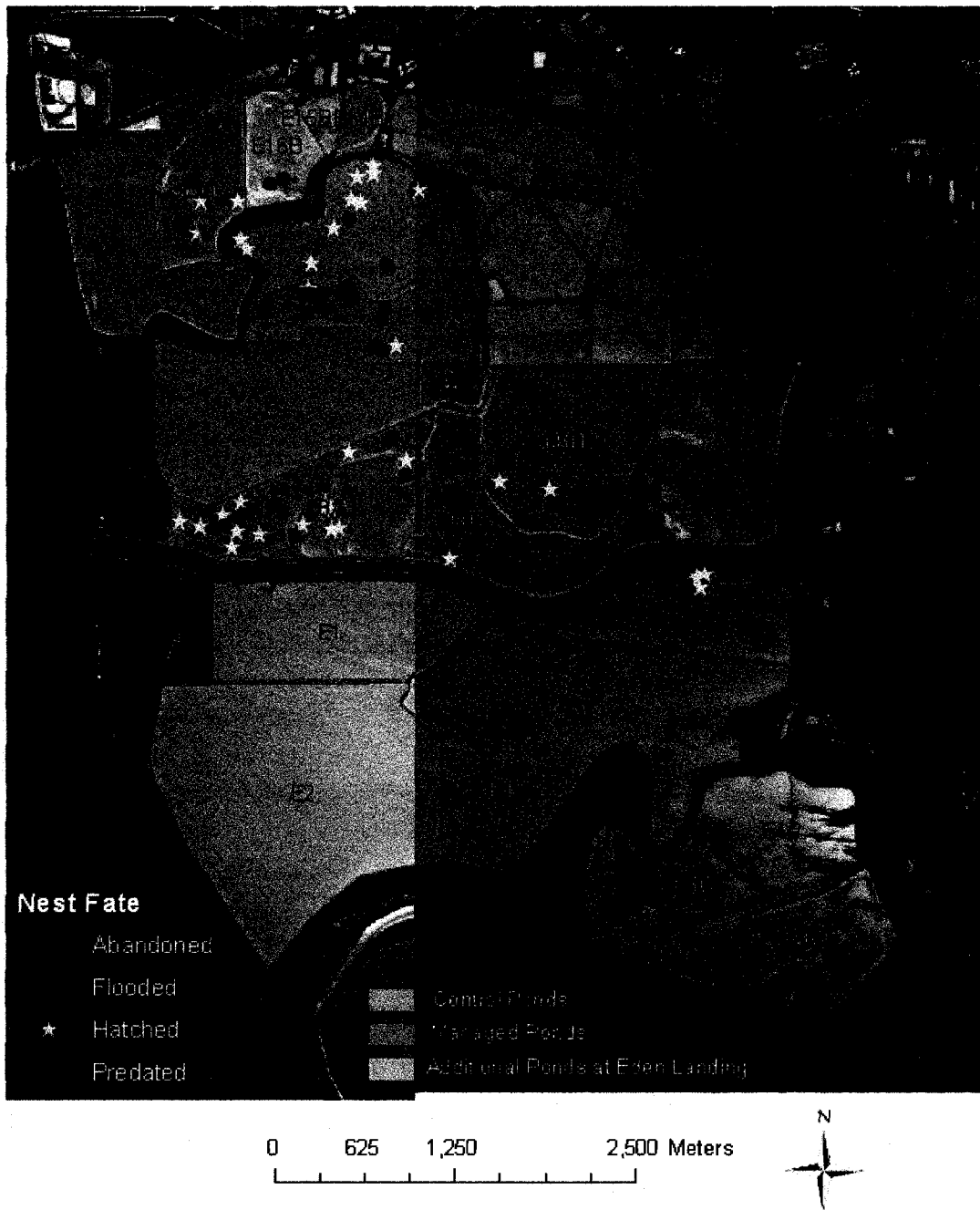


Figure 11. Locations and fates of nests in 2007.

Hypothesis 3 and Research Question 1: Avian Predators

The mean number of predators seen per survey hour in 2006 was 34.7 (n=45) and in 2007 was 16.9 (n=82), excluding gulls. The mean number of corvids (American crows and common ravens) and northern harriers seen per survey hour in 2006 was 1.76 (n=45) and in 2007 was 1.42 (n=82).

In 2006, there was no correlation between the number of predators observed per week and the number of plover nests ($r=0.229$, $P=0.292$) and the number of depredated snowy plover nests ($r=0.271$, $P=0.211$). In 2007, there was no correlation between the number of plover nests in 2007 ($r=0.077$, $P=0.0721$), or the number of depredated snowy plover nests ($r= -0.314$, $P=0.135$).

Wildlife Services removed American crows, common ravens and northern harriers from Eden Landing both years after we observed depredated plover nests (Figure 12 a and b). The harriers that were removed were targeted individuals that had been observed hunting ponds with nesting plovers or killing plovers. In 2006, removing harriers slightly reduced the number of harriers observed per survey (pre-removal mean harriers = 1.95, SE = 0.37; post removal mean harriers = 1.42, SE = 0.27). The percentage of depredated nests per week dropped after selective removal (pre-removal: mean = 5%, SE = 1.5%; post removal mean = 0%, SE = 0%), even though total active nests per week across both managed and control ponds stayed roughly comparable (pre-removal: mean =12.7, SE = 3.0; post removal mean = 10.4, SE 2.1) (Figure 12a).

In 2007, there were two predator removal events, one in May and another in July. The removal reduced the pre-removal mean number of harriers seen per survey from 2.2 (SE = 1.2) to 0.84 (SE = 0.15) seen per survey after the first removal. The percent depredated nests dropped slightly, from 7% to 6%. The total active nests increased after the removals, from 11.1 (SE = 3.6) nests per week to 15.9 (SE = 2.34) nests per week.

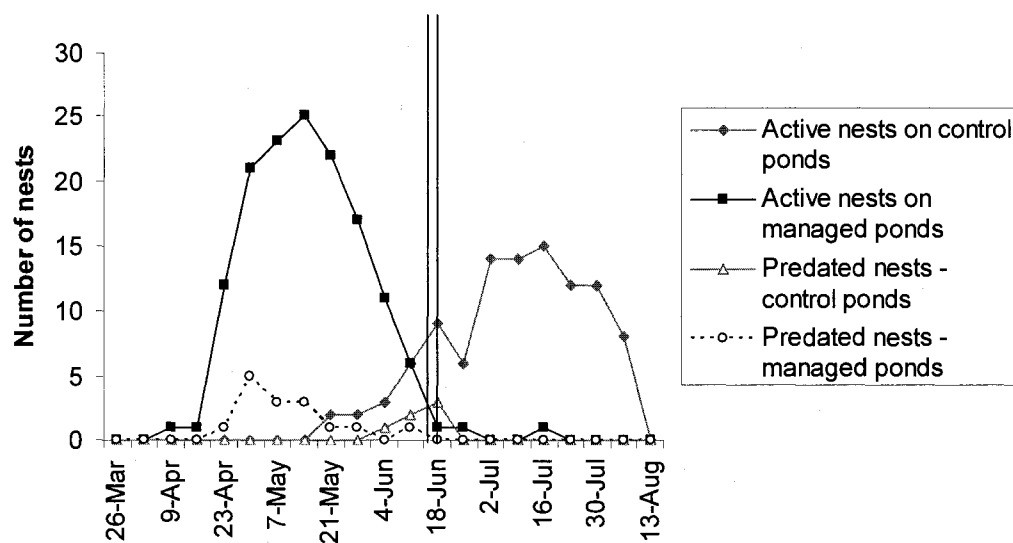
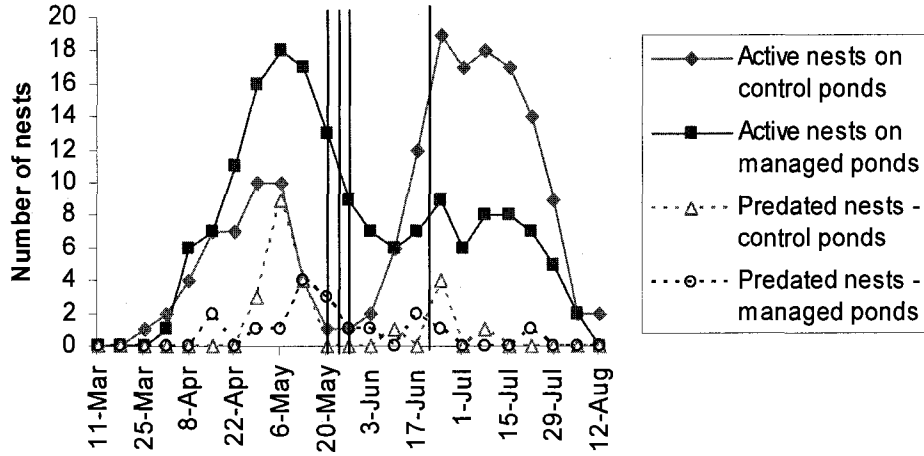


Figure 12. a) The percent of depredated snowy plover nests in a) 2006 and b) 2007. Vertical lines depict when northern harriers were removed from Eden Landing.



b) The percent of depredated snowy plover nests in 2007. Vertical lines depict when northern harriers were removed from Eden Landing.

Hypothesis 2: Micro-habitat Preferences and Nest Success

No micro-habitat variable was important in predicting whether a nest was successful or depredated (n=125 nests). Distance to vegetation was the only significant variable (P=0.019) but the logistic regression had an odds ratio of 1.008 indicating no relationship between the variable and nest success (Table 3).

Table 3. The results of the microhabitat variable and nest success logistic regression.

	t-ratio	p-value	odds ratio	95% confidence limits	
				upper	Lower
Distance to water	0.000	0.902	1.000	1.006	0.994
Distance to levee	-0.003	0.228	0.997	1.002	0.991
Distance to vegetation	0.008	0.019	1.008	1.014	1.001
Distance to berm	0.001	0.893	1.001	1.008	0.993
Distance to anthropogenic feature	0.009	0.365	1.009	1.028	0.990
Distance to furrow	-0.188	0.241	0.828	1.035	0.605

Research Question 2: Microhabitat Preferences and Nest Site Selection

Principal component one accounted for 30.4% of the total variation in microhabitat features preferred by nesting birds. The factor loadings indicated that water was highly positively correlated with factor 1 scores while anthropogenic features and berms were highly negatively correlated with factor 1 scores (Table 4). Nests in control ponds were often closer to water while those in managed ponds were often farther away (Figure 13). Principal component two accounted for 27.6% of the total variation. Loadings for this factor indicated that distance to levees and vegetation were strongly associated in factor 2.

Table 4. Component Loadings for the principle components analysis.

	PC 1	PC 2
Water	0.701	0.197
Levee	-0.124	0.849
Vegetation	0.337	0.770
Berm	-0.694	-0.176
Anthropogenic Feature	-0.773	0.003
Furrow	0.352	0.552

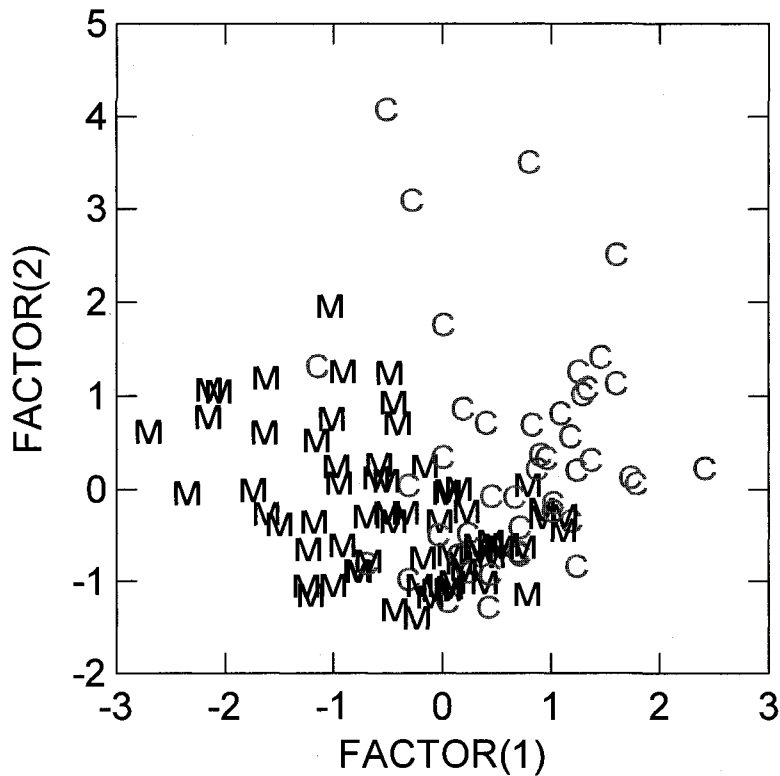


Figure 13. Principle components analysis graph. Nests in control ponds were often closer to water while those in managed ponds were often farther away (Factor 1).

There was no significant difference in the change in topography in the nest plots (mean = 3.743, cm SE = 0.337) and random bordering plots (mean = 3.028 cm, SE = 0.374) ($n = 60$, $df = 59$, $t = -1.804$, $P = 0.076$). There was no significant difference in the percent vegetation in the nest and bordering plots ($n = 60$, $df = 59$, $t = 0.168$, $P = 0.867$). The most common hue of soil in the nest plots was 10YR, occurring at 67% of the sub-quadrats. This was also the most common hue at the bordering plots, occurring at 68% of the sub-quadrats (Table 5). The most frequently occurring value at nest plots were 6 (35%) and 5(27%). At the bordering plots, 6 and

7 were the most frequently occurring values, occurring at 38% and 22% of the sub-quadrats, respectively. The chromas that were the most common on nest plots were 1 (56%) and 2 (38%). The chromas that were the most common on bordering plots were also 1 and 2, both occurring on 47% of the sub-quadrats (Table 5).

Table 5. The percent hue, value and chroma for nest plots and bordering plots.

Hue	Nest Plot			Bordering Plot		
	Value	Chroma	Hue	Value	Chroma	Hue
10YR	67%	<1%	10YR	68%	<1%	1
7.5YR	16%	8%	7.5YR	19%	8%	2
5YR	15%	27%	5YR	11%	21%	3
2.5Y	2%	35%	2.5Y	1%	38%	4
		22%			22%	5
		8%			10%	6
					<1%	7
					<1%	

Research Questions 3 and 4: Flush Distances and Disturbance from Trails

The mean distance that plovers flushed when approached was 174.9 m ($n = 24$, $SD = 70.44$, range = 55 to 296 m). The number of nests potentially affected by disturbance was calculated a nest density of 0.11 nests/ha. This was calculated based on an area of 685.6 hectares available to plovers and a mean number of nests of 74.5 over the two years (Table 6). Using the mean low count of 91.5 birds per week and the mean high count was 233.5 birds per week over the two years, I calculated the number of birds potentially affected by disturbance.

Reductions in the pond area available to birds based on different trail configurations and the mean flush distance and the mean flush distance plus one standard deviation) showed that with a buffer the size of the mean flush distance (174.5 m) birds will lose approximately 300 ha of available habitat. With a buffer the size of the mean flush distance and one standard deviation (245.4m) birds will lose an additional 25 ha (Tables 6 and 7, Figure 14 and 15).

Table 6. The hectares remaining after subtracting the buffer zones for year round trails. * Ponds listed as 0 because they will be unavailable to plovers after Phase 1 actions.

Pond	Current hectares available	Year round trails and mean flush distance	Year round trails with mean flush distance + 1 SD
B11	47.752	47.752	47.752
B12*	93.482	0	0
B14	63.13	55.41	58.27
B16B	33.2	27.9	25
B6A	137.593	80.6	64.5
B6B	118.05	117.5	115.8
B8	72.843	68.29	63.1
B8A*	103.599	0	0
B8X*	12.14	0	0
B14B	8.6	4.4	2.6
B15B	12.9	3.5	1.2
Total	703.289	401.852	378.222

Table 7. The estimated number of plovers using the habitat after the buffer zones and Phase 1 actions are taken into consideration.

	Current numbers	Mean Flush Distance	Mean Flush Distance + 1 SD
Number of nests	74.5	51.03	47.73
Number of plovers (low estimate)	91.5	62.67	58.62
Number of plovers (high estimate)	233.5	159.94	149.59

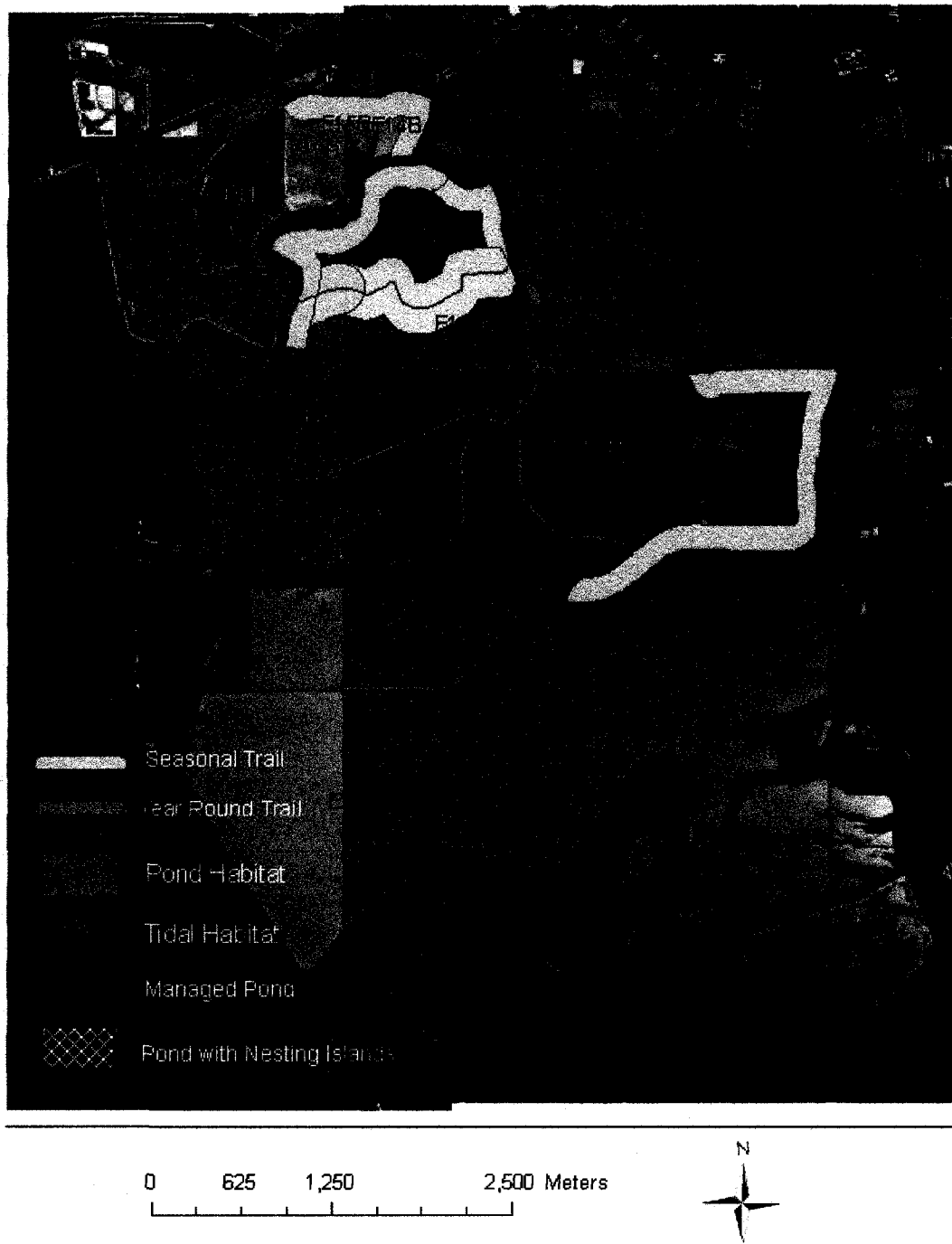


Figure 14. Compromised pond habitat adjacent to trails using the mean flush distance (174.9 m) and Phase 1 habitat types.

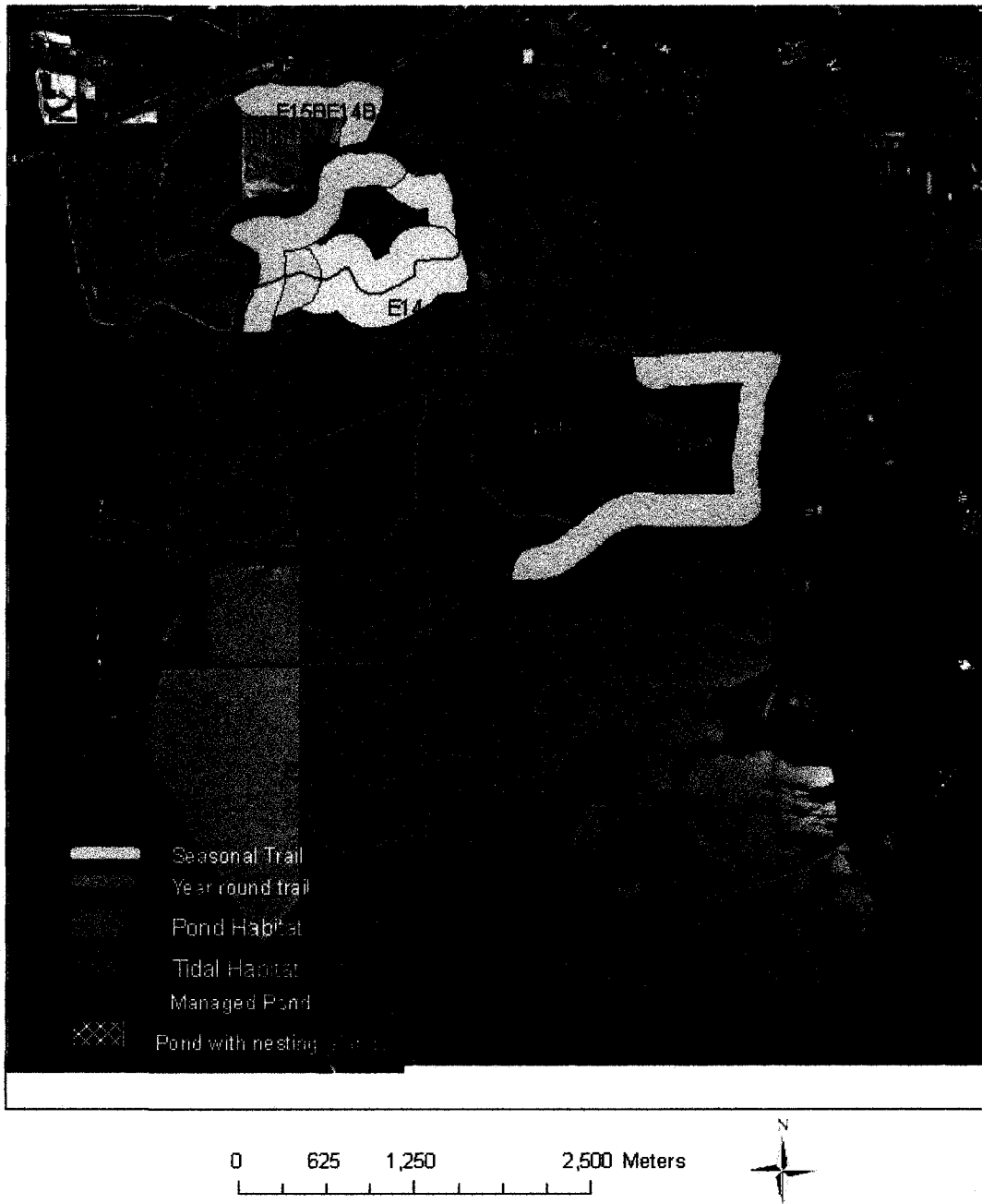


Figure 15. Compromised pond habitat adjacent to trails using the mean flush distance and one standard deviation (245.4 m) and Phase 1 habitat types.

DISCUSSION

In the Eden Landing area, two years of managing water levels in former salt ponds nearly doubled the density of nesting western snowy plovers and increased the number of birds foraging in managed ponds over ponds where water levels were not managed. During this two-year period, managed ponds also provided critical nesting habitat early in the season in years with large amounts of rainfall. Continuing this management at more ponds and for more years will be needed to determine if higher nesting and foraging numbers can be maintained. The South Bay Salt Pond Restoration Project has a goal of supporting 250 nesting plovers in the project area. At the managed pond nest densities observed in this study, the South Bay Salt Pond Restoration Project would need to manage approximately 764.5 ha of ponds to reach this goal.

Water Management and Snowy Plover Use of Ponds

Salt evaporation ponds can act as substitute nesting habitat for beach nesting birds (Catry et al. 2004). In Portugal, little terns (*Sterna albifrons*) previously nested primarily on beaches. Due to habitat destruction and disturbance, most of the country's little terns now nest on salinas (Catry et al. 2004). Western snowy plovers primarily nested on beaches, and some moved to salt ponds after they were constructed (Page et al. 1995, Grinnell 1918). Within the salt ponds, snowy plovers prefer to nest on ponds that have a mosaic of wet and dry habitats, which can be achieved by managing water levels (Strong et al. 2004b, Eyster et al. 2003). The managed ponds at Eden Landing, which had this mix of wet and dry areas, had a

significantly higher number of plovers per hectare foraging than control ponds in 2007 and higher density of plovers nesting both years. Although difference in nest density between managed and unmanaged ponds was not significant either year, it is biologically important that water management was able to double the nest density at the managed ponds.

The amount of rainfall varied greatly in 2006 and 2007, which affected the amount of habitat available to the snowy plovers at Eden Landing. In the winter of 2005-2006, the Bay Area received a large amount of rain: San Jose received 55.62 cm compared to the yearly rainfall average of 38.30 cm (San Jose Weather Station 2008). Since DFG staff drew down the water levels in the managed ponds in February and March to provide dry areas for foraging and nesting, these ponds provided the only available nesting habitat in the beginning of the breeding season and were used exclusively for nesting over the control ponds. The control ponds started to dry later in the season, around May and June and once these areas were dry enough to support plovers, plovers moved to these ponds and started nesting. Thus, the managed ponds provided nesting habitat earlier in the season than would have been available otherwise.

In contrast, the Bay Area received very little rain in 2007; San Jose had 23.57 cm of rain (San Jose Weather Station 2008). Thus, many ponds, both managed and control, were dry enough for plovers to nest at the beginning of the breeding season, resulting in plovers nesting in both pond types from the start of the breeding season. The managed ponds had water moving through them all season, and plovers nested

on them consistently throughout the season. This pattern illustrates the importance of having dry areas in close proximity to quality foraging habitat available to plovers throughout the season. Combining the two years showed that plovers forage more on managed ponds when faced with both wet and dry years.

Snowy Plover Nest Success

The control ponds had a higher percent of nests that were successful than the managed ponds in both breeding seasons. In both seasons, the peak number of active nests in the control ponds was approximately two months later than the peak number of active nests in the managed ponds. Later plover nests most likely benefit from returning migratory shorebirds, which serve as a potential food source to predators that had a more limited amount of prey earlier in the season. The nests later in the season also benefited from active predator management throughout the season (Robinson et al. 2007a and Robinson et al. 2007b). Providing early season nesting habitat is beneficial, however these nests seem to be more likely to be depredated.

The percent of successful nests in all ponds decreased from 2006 to 2007. This is part of a larger downward trend in nest success in the San Francisco Bay, for example nest success in 2004 was 85% and 84% in 2005 (Robinson et al. 2007a). The predators responsible for the depredated nests in the majority of the causes were unknown. We saw numerous kinds of evidence of depredation, for example the eggs were gone weeks before the estimated hatch date, there were broken eggs with yolk and blood in the nest or there were no egg shell fragments in the scrape (Mabee

1997). We observed a northern harrier and a common raven depredate two nests in May and June of 2007.

Pond bottom topography varies little, which can result in flooded nests when the water level is increased slightly or even in high wind events (Eyster et al. 2003). In 2006, four nests were flooded in the managed ponds. The flooding events occurred during high tide cycles when more water entered the ponds through the water control structures than was anticipated. Water management techniques improved in 2007 with only one nest getting flooded during a high tide event.

Avian Predators

Predator management has increased nest success in Monterey Bay (Neuman 2004) and along the coast of Oregon (Lauten 2006). At Eden Landing, there was no relationship between the number of predators and the number of depredated nests, which indicates that individual predators may be the problem, not the number of predators in the ponds. The percentage of depredated nests decreased after targeted individual northern harriers were removed each year, which suggests that certain individual harriers are cueing in on the salt ponds as a source of food. Similar to other areas along the plovers range, nest success increased once predators were removed.

In 2006, there were more predators of concern in the managed ponds. This may have to do more with the location of the managed ponds rather than the predators seeking them out. Managed ponds E6A, E6B E8 and E8A are all adjacent to Old Alameda Creek, where harriers nested both years. Just north of E6A is a

small patch of pickleweed marsh that also supported one harrier nest each year. In contrast, the majority of the control ponds were in the northern section of Eden Landing, along Mount Eden Creek. This creek did not have nesting harriers either year but harriers foraged along it.

The number of avian predators was higher in the control ponds than managed ponds in 2007. This may be due to the reduced amount of acreage that was managed for plovers in 2007. In addition, the ponds that were managed in 2006 that were near the prime harrier nesting habitat were treated as control ponds in 2007, with the exception of E8A.

The California gull population in the south bay has increased exponentially over the past twenty years (Strong et al. 2004a). Gulls are opportunistic feeders and are documented predators of shorebird eggs and chicks in the south bay (Ackerman et al. 2006). As the gull population continues to grow, they could become a larger threat to the snowy plovers. The Coyote Hills gull colony is approximately 2 km south of Eden Landing and many gulls fly over Eden Landing throughout the day. In June of 2007, there was a large influx of gulls roosting and foraging in the Eden Landing ponds. If the gulls start to nest there, they could have a very negative impact on the nesting plovers.

Plover Habitat Preferences with the Salt Ponds

Snowy plovers nest in relatively flat areas with sparse vegetation (Page et al. 1995, Wilson-Jacobs and Meslow 1984) and often nest on substrates similar in color to their plumage (Marriott 2003, Feeney 1991). This study showed that proximity to

cover (vegetation) and foraging (water) were important to the plovers when selecting nest sites. Within the managed ponds, snowy plovers preferred to nest in areas that were closer vegetation and water. The proximity to vegetation is consistent with the findings of previous studies that showed plovers like to nest near cover (Page et al 1985, Powell 2001). Nests within the control ponds were farther away from vegetation and water. This may be because there was less vegetation within the control ponds because they are flooded for longer periods, which suppresses most vegetation growth. There is also more water in the managed ponds as part of the management regime in the managed ponds.

None of the habitat variables measured in this study helped predict whether a nest would be successful. Each year we had relatively high predation rates (32% in 2006 and 46% in 2007). This indicates that the predators are cueing in on other habitat variables or something else, such as the motion of plovers flushing off the nest as predators fly over. Powell (2001) found that habitat variables did not predict nest success on beaches in San Diego.

The substrate colors that snowy plovers preferred to nest on in the ponds were similar to what previous studies have found; plovers prefer to nest on substrate with colors that are similar to the color of the plumage on their back (Feeney 1991, Marriott 2003). Feeney (1991) found that the most common plumage hues were 10YR and 2.5 YR, which occurred 62% and 34% of the birds, respectively, which is similar to the findings of this study.

Plovers preferred to nest where the substrate had slightly varying topography such as the small ridges in the salt pond substrate. Other studies have found that plovers prefer to nest next to objects such as driftwood or vegetation (Page et al. 1985 and Powell 2001). The salt ponds do not have large amounts of driftwood or vegetation so the ridges in the substrate may serve the same function of concealing nests given since nest plots had a significantly greater amount of change in topography.

Trails and Their Impact to Snowy Plovers

Eden Landing Complex is currently closed to the public; however, certain trails may open to the public as early as 2009. Many of the trails planned at Eden Landing are adjacent to ponds managed for nesting snowy plovers. With the addition of trails into Eden Landing, human disturbance to nesting snowy plovers will increase. This study found that plovers currently flush off their nests at an average of 174.9 m from an approaching human. Flushing off nests due to human disturbance is a major problem for snowy plovers in areas of high use. Snowy plovers nesting on beaches at Point Reyes flushed off the nests 34% of the time when people were 100-250 meters away, 65% of the time when people were 50-100 meters away and 78% of the time when people were within 0-50 meters (Page et al. 1977). Plovers on less used beaches flushed when people were much farther away, including one bird that flushed when a walker was 200 meters away (Page et al. 1977).

Increased human disturbance from trails may also adversely affect broods on the salt ponds. Human recreation is known to lower snowy plover chick survival rates on beaches (Ruhlen et al. 2003, Colwell et al. 2007). Human disturbances to chicks decrease their foraging and brooding time and cause an increase in the amount of time chicks were sitting or acting vigilant (Flemming et al. 1988). Decreases in brooding time leave chicks susceptible to severe weather conditions and more susceptible to predation (Flemming et al. 1988).

Mapping flush distances of 175 m and 245 m in ponds adjacent to trails and public access proposed for Eden Landing indicated that much of the current habitat in the snowy plover nesting ponds is likely to be affected and potentially become unusable for nesting. Although research does show that shorebirds can become habituated to human disturbances (Burger and Gochfeld 1991, Baudains and Lloyd 2007), it is unclear how long that will take with the plovers in the salt ponds. Tangential approaches by trail users, as is likely to occur with the Eden Landing trails, might make a difference in disturbance distance to nesting birds. Studying effects of tangential approach to nesting plovers would add more information important for managing trail use. Eventually some of the mapped buffer zones will likely be used by nesting and foraging plovers, but how the reduced habitat might impact snowy plover recovery is unknown.

Bird nests in salt ponds in South Africa are often victim to humans entering the ponds. Martin and Randall (1987) suggested creating 10 m wide channels around the islands that the birds were nesting on to protect them from humans.

Some of the ponds at Eden Landing have deep ditches next to the levee that serve the same purpose.

MANAGEMENT RECOMMENDATIONS

The South Bay Salt Pond Restoration Project has a goal of supporting 250 breeding plovers within the project area. To reach this goal, the number of plovers will need to increase in a smaller habitat footprint. The pond management that DFG started in 2006 has the potential to increase the number of plovers nesting on managed ponds. The area available to plovers at Eden Landing will be greatly reduced with the implementation of the SBSP Phase 1 actions, which calls for restoring significant acreage of current dry salt ponds to tidal salt marsh and adding trails. Not only will the physical hectares be reduced with the return of ponds that are current used by snowy plovers to tidal action, but the remaining hectares will be compromised with the addition of trails adjacent to portions of the remaining ponds. Using the nest density observed in this study in the managed ponds, the SBSP will need to manage 764.5 ha for plovers, in order to reach the goal of supporting 250 plovers. Eden Landing can provide about 400 ha of habitat for snowy plovers and the SBSP should look to managing additional areas for plovers outside of Eden Landing.

The results of this study suggest the following specific recommendations:

1. Manage water levels in large ponds for snowy plovers into the future. Water management appears to be effective in increasing the amount of plovers

nesting on the managed ponds. Specifically, manage ponds so some are dry at the beginning of the breeding season and some dry later in the season.

2. Managed ponds should not be adjacent to trails. Based on current information, nesting plovers are susceptible to disturbance by recreational trails. Land managers should take the amount of compromised habitat into consideration adjacent to trails when planning the amount of habitat available to nesting plovers
3. Managed ponds should be as far from tidal marsh habitat as possible due to Northern harriers, a species known to depredate plovers, which nest in tidal marsh.
4. Add channels to the interior of ponds that have few such interior channels. Water should be maintained in these channels to provide prey for snowy plover adults and chicks throughout the pond and the season.
5. Reconfigure existing channels, especially borrow ditches, to facilitate foraging by adults and chicks. In some ponds, there is a large drop off from the pond bottom to the borrow ditch, which creates poor foraging habitat and ponds are not heavily used by plovers.
6. Fill in large fissures in the substrate of ponds. These fissures, which exist in some ponds, the pose a major threat to the survival of plover chicks hatched in those ponds as eggs and chicks can get caught in the cracks.

7. Completely flood with bay water those ponds with vegetation growing on the pond bottom, as large amounts of vegetation reduce snowy plover habitat quality. Salt water may inhibit growth of most vegetation in the ponds.
8. Remove perches that avian predators might use from the interior of the plover nesting ponds. These include old telephone poles and other shorter poles in and around the pond.
9. Prevent California gulls from nesting at Eden Landing or other areas where snowy plovers nest.
10. Create deep, 10 m wide borrow ditches around the perimeter of the managed ponds to discourage humans from going out onto the plover nesting ponds and potentially stepping on nests and chicks.
11. Recommended future studies:
 - a. Continue monitoring the managed and control ponds to determine if water management is increasing the number of plovers using the ponds.
 - b. Study the effect of tangential trail use on nesting plovers.
12. Examine the relationships between gradients within and between the ponds and nest site selection.

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