Impact of Salt Pond Restoration on California Gull Displacement and Predation on Breeding Waterbirds

Report for the South Bay Salt Pond Restoration Project and Resources Legacy Fund

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Executive Summary

Overview

- The California Gull (*Larus californicus*) population in the South San Francisco Bay has increased from fewer than 200 breeding Gulls in 1982, to a peak of 52,172 in 2012. Specific to this study, there were 46,030 breeding Gulls in 2010 and 37,716 breeding Gulls in 2011.
- The expanding California Gull population may negatively affect other ground nesting birds in the South Bay through harassment, encroachment on nesting sites, and predation on eggs and chicks.
- We investigated the effects of California Gulls on other breeding waterbirds within the South Bay Salt Pond Restoration Project area. We examined predation by California Gulls on Forster's Tern (*Sterna forsteri*) chicks (**Objective 1**) and Western Snowy Plover (*Charadrius alexandrinus nivosus*) eggs (**Objective 2**). We also examined the distribution of color-marked California Gulls

after Pond A6 was breached to tidal flow and flooded (**Objective 3**), and population growth and location of breeding California Gulls within South San Francisco Bay (**Objective 4**).

- Elsewhere, we have investigated predation by California Gulls on the two other most numerous nesting waterbirds in the South Bay, American Avocets (*Recurvirostra americana*) and Black-necked Stilts (*Himantopus mexicanus*) (Ackerman et al. 2006b), so those species were not included in this study.

Objective 1: Forster's Tern chick survival in relation to California Gull predation

Overview

- We radio-marked and tracked 212 Forster's Tern chicks at 7 colonies in 2010 (*N*=110) and 2011 (*N*=102). We also banded an additional 891 Tern chicks at seven colonies in 2010 and 358 Tern chicks at five colonies in 2011, none of which received radio transmitters.
- After excluding chicks with radios that failed prematurely and whose fate could not be determined (*N*=35), 80% of radio-marked Forster's Tern chicks died (*N*=141) and only 20% fledged or were presumed to have fledged (*N*=36).

Predators of Forster's Tern Chicks

- Of the 85 (54 in 2010 and 31 in 2011) radio-marked Forster's Tern chicks with a known mortality cause, 54% (29 of 54) were depredated by California Gulls in 2010, but only 10% (3 of 31) of Tern chicks were depredated by California Gulls in 2011. However, many of the radio-marked Tern chicks simply went missing from their nesting colony before they were old enough to have fledged (*N*=56), and this suggested additional predation by aerial predators such as California Gulls.
- If we assume that all Tern chicks that simply went missing from their island nesting colonies were actually depredated by California Gulls, then 64% (44 of 69) of Tern chick deaths may have been

caused by California Gulls in 2010 and 61% (44 of 72) may have been caused by California Gulls in 2011.

- In total, we found 31 radio-transmitters formerly attached to Tern chicks within California Gull colonies that were carried there by Gulls. We also recovered 59 bands at the Pond A6 California Gull colony from Tern chicks that were banded at their nesting colonies in 2010, but which were never fitted with radio transmitters.
- In 2010, when the Pond A6 California Gull colony existed, Forster's Tern chicks at the Pond A7 Tern colony appeared to be more susceptible to predation by California Gulls from the A6 Gull colony than did chicks at the other Tern colonies, including Pond A2W which was the other main Tern nesting colony that existed in both 2010 and 2011. Among radio transmitters that were attached to Forster's Tern chicks in 2010, 56% (20 of 36) of those from the Pond A7 Tern colony were recovered in the Pond A6 California Gull colony compared to only 14% (8 of 59) recovered from all the other Tern colonies. Similarly, in 2010, 20% (33 of 165) of bands from non-radio-marked Forster's Tern chicks in Pond A7 were recovered in the Pond A6 California Gull colony compared to only 4% (26 of 726) recovered from non-radio-marked chicks at all other Tern colonies.
- It appeared that some individual California Gulls specialized on depredating Forster's Tern chicks. Of the 32 radio-marked Forster's Tern chicks that were depredated by California Gulls, 13 of these instances had multiple bands and/or transmitters recovered at the same site. This included times where 2 (four times), 3 (5 times), 6, 7, 8, and 11 Forster's Tern chicks were recovered at the same location and presumably depredated by the same California Gull.

Survival Rate of Forster's Tern Chicks

- Forster's Tern chick survival (*N*=205) from hatching to fledging at 26 days of age was 0.19 (standard error [SE]=0.03) overall, and 0.23 (SE=0.04) in 2010 and 0.15 (SE=0.04) in 2011. Fledging success ranged from 3% to 67% among colonies.
- Forster's Tern chick daily survival rate increased 10% during the fledging period from 0.88 (95% confidence limits=0.85-0.91) at one day of age to 0.98 (0.96-0.99) at 26 days of age. The average age of Forster's Tern chicks when they were (confirmed) depredated by California Gulls was 4.7 days old, with a range from 1 to 13 days of age.
- The best model describing Forster's Tern chick survival rates contained the year × colony site interaction term, and was 78.8 times more likely than the same model but without this interaction term. The overriding importance of the year × colony site interaction term indicated that changes in Tern chick survival rates between years were not consistent among Tern colony sites. Specifically, Forster's Tern chick survival rates at two of the largest Tern colonies, that were consistently used for nesting in both 2010 and 2011 (Pond A2W and Pond A7), differed markedly before (2010) and after (2011) the relocation of the Pond A6 California Gull colony.
- Forster's Tern chick fledging success at reference Pond A2W was similar between years (24% in 2010 and 18% in 2011), whereas Tern chick fledging success at Pond A7 increased dramatically from 3% in 2010 to 35% in 2011 after the relocation of the nearby Pond A6 California Gull colony. In particular, compared to the reference Tern colony at Pond A2W, daily survival rates of Tern chicks at Pond A7 increased between years more among younger Tern chicks (<15 days old) , which are more vulnerable to Gull predation, than for older Tern chicks, which are less vulnerable to California Gull predation due to greater size and mobility.

Gull Predation Pressure and Tern Chick Fledging Success

- To further examine the influence of California Gull colonies on predation rates of Forster's Tern chicks, we examined whether Tern colony's fledging rates were related to the distance, direction, and abundance of nearby Gull colonies.
- Forster's Tern fledging success tended to increase as the distance to the nearest California Gull colony increased.
- We developed Gull predation pressure indices that incorporated the distance and abundance of Gull colonies from each Tern colony. Forster's Tern fledging success tended to be higher when this Gull predation pressure index ($GPP_2 = \sum \frac{logN_j}{D_j}$) was lower, indicating that having fewer Gulls at nearby Gull colonies or having Gulls further away from the Tern colony improved Tern fledging success.

Summary of Forster's Tern Chick Survival

- Our results indicate a high mortality rate for Forster's Tern chicks in South San Francisco Bay, and the Tern chick survival rate to fledging (0.19) was just slightly higher than those of American Avocet chicks (0.14 in 2005 and 0.05 in 2006) and lower than those of Black-necked Stilt chicks (0.32 in 2005 and 0.56 in 2006) studied at nearby sites in South San Francisco Bay (Ackerman et al. 2006b). As with our current study on Forster's Tern chick survival, predation on Avocet chicks by aerial predators, primarily California Gulls, was responsible for the majority of chick losses, whereas fewer Stilt chicks were depredated by California Gulls (Ackerman et al. 2006b). Differential use of habitats and lower nesting densities likely contributes to higher survival for Stilt chicks, compared to Avocet and Forster's Tern chicks.
- Forster's Tern nest survival (Ackerman and Herzog 2012) and chick survival from hatching to fledging (this study) appear to be limiting factors for population stability of the Forster's Tern

breeding population in South San Francisco Bay, more so than postfledging survival (Ackerman et al. 2008c). Combining the data for postfledging survival (Ackerman et al. 2008c) with our current study's estimate for overall Tern chick survival from hatching to fledging (0.19), provides an estimated probability of Forster's Tern chick survival from hatch to 35-days postfledging (61 total days after hatching) of 0.15.

Objective 2: Western Snowy Plover nest survival in relation to California Gull predation

Overview

- In order to determine the predators of Snowy Plover eggs, we placed camera systems at a subsample of nests at Eden Landing Ecological Reserve in 2009 to 2011.

Predators of Snowy Plover Nests

- We monitored 62 Snowy Plover nests with cameras at Eden Landing Ecological Reserve during 2009 to 2011. We recorded 16 depredation events and identified six different nest predators. We recorded California Gulls depredating 6 nests, Northern Harriers (*Circus cyaneus*) depredating 3 nests, Red-tailed Hawks (*Buteo jamaicensis*) depredating 3 nests, Common Ravens (*Corvus corax*) depredating 2 nests, and a Ruddy Turnstone (*Arenaria interpres*) and gray fox (*Urocyon cinereoargenteus*) depredating one nest each.

Survival of Snowy Plover Nests

- Snowy Plover nest survival was generally high: 0.67 in 2009, 0.44 in 2010, and 0.51 in 2011.
- Nest survival increased as nests aged, and nests with cameras present had higher daily survival rates than nests without cameras.

Summary of Snowy Plover Nest Survival

- California Gulls were documented to be the most important predator of Snowy Plover nests (38% of events), although Plover nest survival was generally high.

Objective 3: Color-mark California Gulls at Pond A6 to assess potential nesting distributions after Pond A6 was breached and flooded

Overview

- At the Gull breeding colony at Pond A6, we captured and marked 633 California Gull chicks in 2010 (of which 504 were also color banded), and 276 breeding adults in 2008, 222 breeding adults in 2009, and 100 breeding adults in 2010.

Re-sighting Color-Marked Gulls

- In 2009 and 2010, we re-sighted a total of 261 banded adult California Gulls during the breeding season at the Pond A6 colony. During that same period, we observed fewer than 20 banded adult Gulls at other colonies. After the breaching of A6 in December 2010, we re-sighted 32 of the banded adult Gulls at the A9/A10/A11/A14 colony (hereafter A14 colony), which was re-established in 2011 after being abandoned since 2006. We also observed 15 banded adult Gulls at the Coyote Hills colony, one banded Gull at the A5 colony, and one banded Gull at A22. We did not re-sight any of the California Gulls that were banded as chicks at South Bay colonies in 2011. We observed one of the Gulls banded as a chick at the A14 colony in 2012.

Growth of California Gull Chicks

- We estimated growth patterns for California Gull chicks at Pond A6 prior to the colony's relocation so that future studies can compare growth patterns at the newly established Gull colonies.

Summary of Re-sighting Color-Marked Gulls

- In general, California Gulls from the former A6 colony appeared to move and re-establish a new Gull colony at A14, as well as disperse to other existing colonies in the South Bay, particularly Coyote Hills and the Palo Alto Flood Control Basin.

Objective 4: California Gull colony surveys in South San Francisco Bay to document current population size and distribution

- In 2009 and 2010, the largest California Gull colony in the South Bay continued to be located at Pond A6, with 24,190 and 23,108 nesting Gulls (12,095 and 11,554 nests), respectively. After the Pond A6 levees were breached in December 2010 for tidal restoration, only 156 Gulls bred near A6 (on the A5 island), because the pond bottom and the islands were submerged at high tide.
- The largest California Gull colony in 2011 became the Pond A14 colony, with 11,956 breeding Gulls (5,978 nests).
- Other South Bay colonies also increased in size in 2011, including the Palo Alto Flood Control Basin colony (4,478 Gulls, a 163% increase), the N6/N7 colony (4,110 Gulls, a 64% increase), and the M4/M5 colony (6,068 Gulls, a 27% increase).

Conclusions and Management Recommendations

- The forced relocation of nearly 24,000 breeding California Gulls from the Pond A6 colony site by breaching the A6 levees to tidal flow in December 2010, led to the reestablishment of a nesting colony at A14 site in 2011. The breeding population size of California Gulls also decreased from 46,030 Gulls in 2010 to 37,716 Gulls in 2011. However, this decline was short lived as numbers increased in 2012 to 52,172.

- California Gulls were confirmed to be the predominant predators of Forster's Tern chicks and Snowy Plover nests, a finding similar to that previously documented for American Avocets and, to a lesser extent, Black-necked Stilts (Ackerman et al. 2006b).
- Despite California Gulls being the predominant predator of Snowy Plover nests, Snowy Plover nest survival was still very high (44-67%) for a ground-nesting shorebird.
- In contrast, Forster's Tern chick survival was low (19%) for a predominantly island-nesting species and indicated their high vulnerability to avian predators.
- Importantly, the relocation of the Pond A6 California Gull colony (following breaching of the Pond A6 levees) caused Forster's Tern chick fledging success at nearby Pond A7 to increase dramatically from 3% to 35%. Additionally, having fewer Gulls at nearby Gull colonies or having Gull colonies farther from Tern colonies improved Tern fledging success.
- A few individual California Gulls appeared to specialize on depredating Forster's Tern chicks, meaning that it might be possible to improve waterbird breeding success by focusing management specifically on these specialist Gulls through culling, or other means, as other studies on Gulls have documented. However, like most predator control, it is unclear if such practices would be feasible and effective over the long-term. Before such a practice was instituted, additional studies specific to this management practice would be warranted.
- Little is currently known about the actual breeding success of the California Gull population and whether their continued population increase in San Francisco Bay is due to local recruitment or immigration, and we recommend directly studying breeding success (nest and chick survival) of California Gulls.
- Improving nesting opportunities for breeding waterbirds by creating or enhancing islands suitable for nesting at several ponds located throughout the South Bay, at distances as far as feasible from the

largest California Gull colonies, would provide waterbirds with the opportunity to adapt to Gull predation pressure and would distribute the risk of breeding colony failures.

- Our findings suggest that the South Bay Salt Pond Restoration Project would benefit from the development and implementation of a long-term monitoring strategy for the reproductive success of nesting waterbirds in the South San Francisco Bay. As the South Bay Salt Pond Restoration Project moves forward, the information developed could be used to advise management actions including those related to predation pressure by California Gulls and other limitations to locally breeding waterbirds, especially American Avocets and Forster's Terns.

Acknowledgments

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Introduction

The California Gull (*Larus californicus*) population in the South San Francisco Bay (hereafter South Bay) has increased from fewer than 200 breeding Gulls in 1982, to a peak of 52,172 in 2012 (Strong et al. 2004; San Francisco Bay Bird Observatory, unpublished data; **Figure 1**). Yet breeding populations of California Gulls at other areas, such as Mono Lake, have not increased over the same time period (Wrege et al. 2006). The exponential increase in the South Bay may be closely related to the use of landfills and other anthropogenic sources of food, as there are at least three landfills (one now inactive) within a very short flight distance of the main breeding colonies (Ackerman et al. 2009a; **Figure 2**).

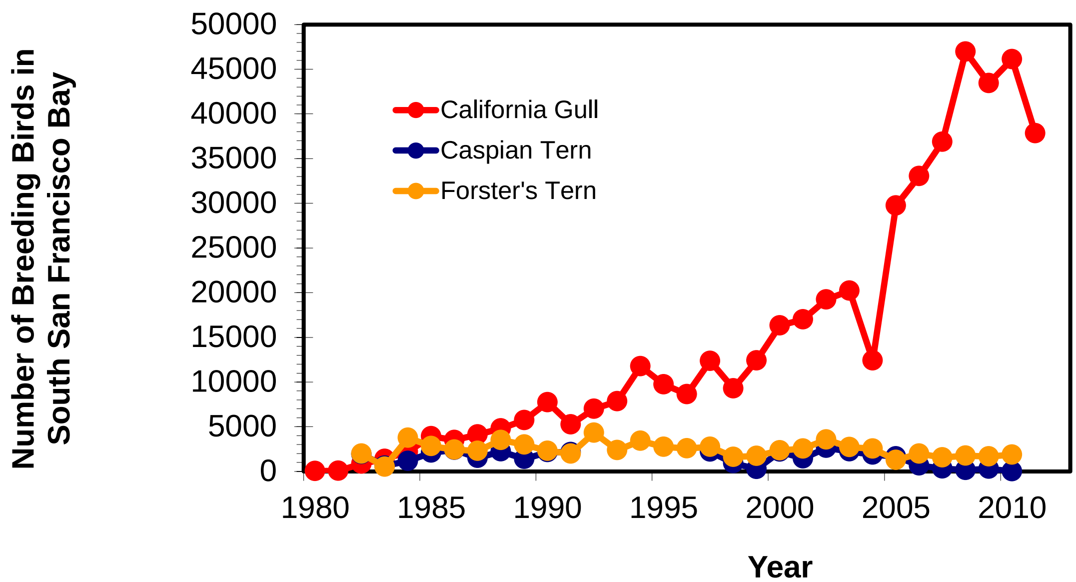


Figure 1. California Gull breeding populations in the South San Francisco Bay have increased rapidly over the past two decades while Caspian Tern and Forster's Tern populations have not.

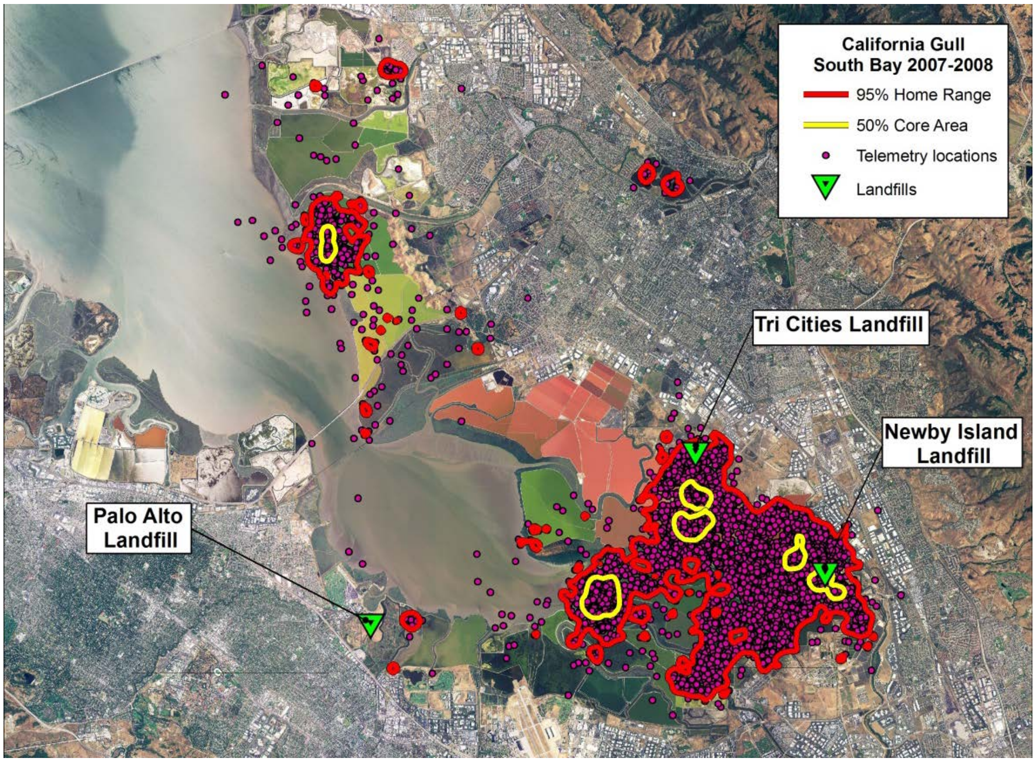


Figure 2. Radio-telemetry locations of California Gulls tracked during the 2007 and 2008 breeding seasons (Ackerman et al. 2009a).

The expanding California Gull population may negatively affect other ground nesting birds in the South Bay through harassment (Kakouros 2006), encroachment on nesting sites (Strong et al. 2004, Ackerman et al. 2009a), and predation on eggs and chicks (Ackerman et al. 2006a). For example, in 2005 and 2006, we documented that California Gulls were the cause of mortality for at least 61% of American Avocet (*Recurvirostra americana*) and 23% of Black-necked Stilt chicks (*Himantopus mexicaus*; Ackerman et al. 2006a), and 12% of Avocet nests (Herring et al. 2011). These data clearly indicated that California Gulls were depredating local waterbird chicks and potentially reducing overall reproductive success, however the extent of predation on other waterbirds breeding in the South Bay was unclear.

Two other species of birds that are abundant breeders in the South Bay might be impacted by Gulls to a larger degree due to their nesting habits. Forster's Terns (*Sterna forsteri*) and the federally threatened Western Snowy Plover (*Charadrius alexandrinus nivosus*) both nest on managed pond islands and pannes, in areas with limited vegetation and lack concealment from aerial predators. About 7% of the Pacific Coast population of Western Snowy Plovers breed in San Francisco Bay and, in 2007, 43% of the nests found in San Francisco Bay were depredated (Robinson et al. 2007). This estimate of apparent nest success is biased considerably high, because unsuccessful nests are less likely to be found (e.g., Mayfield 1961, 1975). Previous studies suggest that California Gulls may be important nest predators of Snowy Plovers in the South Bay (Robinson-Nilsen et al. 2009, 2010, Demers and Robinson-Nilsen 2012), like that found for breeding Snowy Plovers at Mono Lake (Page et al. 1983), but few quantitative data exist in San Francisco Bay. California Gulls also may be negatively affecting breeding Forster's Terns. Tern populations in the South Bay have been slowly declining over the past two decades (Strong et al. 2004), coincident with dramatic increases in California Gull populations (**Figure 1**). Further, Kakouros (2006) found that more than 90% of all predator intrusions on Forster's Tern colonies were by California Gulls, and she observed three instances where Gulls depredated Forster's Tern chicks and one time where Gulls depredated a Forster's Tern nest. Moreover, there is anecdotal evidence that an entire Tern colony was abandoned in response to Gull predation and harassment (Kakouros 2006). Therefore, in the present study, we assessed the impact of California Gull predation on Snowy Plovers and Forster's Terns to more fully document the impact of Gulls on breeding waterbirds in the South Bay and to guide future management actions.

There is also concern that California Gulls may displace other breeding waterbirds from preferred nesting sites as their population grows. In particular, the California Gull colony at Pond A6 (**Figure 3**) was the largest in the South Bay (>23,000 in 2010) and was displaced when the pond was breached to tidal action on December 6, 2010. Understanding Gull relocation, and thus displacement and predation of other breeding waterbirds, is also critical to informing management decisions related to maintaining habitat value for nesting waterbirds − a key restoration objective of the South Bay Salt Pond (SBSP) Restoration Project.

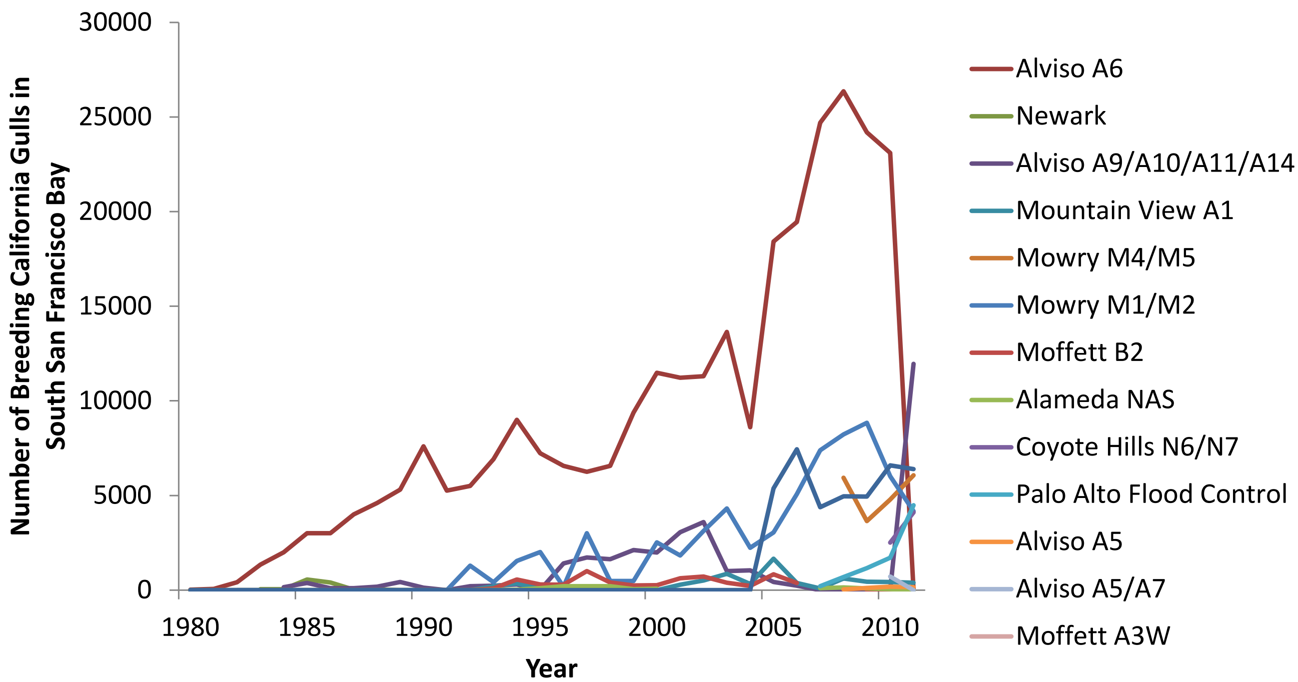


Figure 3. Growth of several California Gull colonies in the South San Francisco Bay since 1982.

Objectives

We investigated the potential effects of California Gulls on other breeding waterbirds within the SBSP Restoration Project area. We examined predation by California Gulls on Snowy Plover eggs and Forster's Tern chicks, population growth of breeding California Gulls within the South Bay, and the distribution of color-marked California Gulls after Pond A6 was breached and flooded. Specifically, we had four main tasks:

1. Examine Forster's Tern chick survival in relation to California Gull predation.
2. Evaluate Western Snowy Plover nest survival in relation to California Gull predation.
3. Color-mark California Gulls at Pond A6 to assess potential nesting distributions after Pond A6 was breached and flooded.
4. Continue our California Gull colony surveys in the South Bay to document current population size and distribution.

Objective 1: Forster's Tern chick survival in relation to California Gull predation

Methods

Study Area

The USGS examined survival of Forster's Tern chicks from hatch to fledging in South San Francisco Bay, California at the Don Edwards San Francisco Bay National Wildlife Refuge (37.4º N, 122.0º W). We monitored Tern chicks using mark-recapture methods at all seven of the known Tern breeding colonies in the South Bay in 2010 (Moffet Pond Complex: Ponds A1, AB1, AB2, A2W; Alviso Pond Complex: Ponds A7, A8, A16) and at all five known Tern breeding colonies in the South Bay in 2011 (Moffet Pond Complex: Ponds A1, A2W; Alviso Pond Complex: Ponds A7, A8, A16). We also estimated Tern chick survival using radio telemetry methods at six of the seven colonies in 2010 (Moffet Pond Complex: Ponds AB1, AB2, A2W; Alviso Pond Complex: Ponds A7, A8, A16) and four of the five colonies in 2011 (Moffet Pond Complex: Ponds A1, A2W; Alviso Pond Complex: Ponds A7, A8). Due to access restrictions, we did not monitor the Hayward Shoreline and Charleston Slough Tern colonies (50-150 nests estimated) located in other areas of the South Bay. There were no additional known Tern colonies in the South San Francisco Bay in 2010 and 2011, but there were potentially a few other small transient Tern colonies we did not identify. Each colony nested on one to five islands within former salt evaporation ponds that had little or no vegetation. This habitat structure enhanced our ability to recapture and relocate Tern chicks, using both mark-recapture and radio telemetry methods.

Mark-Recapture of Tern Chicks from Hatching to Fledging

We hand-captured Forster's Tern chicks weekly during the nesting season (May to August) until the last Tern chick fledged. We entered colonies each week, monitored each nest to locate newly hatched chicks, hand-captured every chick on the island nesting colony, banded newly hatched chicks with stainless steel U.S. Geological Survey leg bands, and recorded band numbers from previously banded and recaptured chicks. At each weekly colony visit, we weighed each chick with an electronic balance (±0.1 g with Scout Pro SP401, Ohaus Corporation, Pine Brook, New Jersey, USA), and measured short tarsus (tarso-metatarsus bone) and exposed culmen lengths with digital calipers (±0.01 mm with Fowler® electronic digital calipers, Newton, Massachusetts, USA) and flattened wing length with a wing ruler (±1.0 mm). We held chicks in shaded 5-gallon buckets or screen-lined poultry cages during processing and returned chicks back to the site of capture within 3 hrs.

Tern Chick Age Estimation

We estimated the age of each Tern chick at its initial capture. If we observed the hatching date for an individual chick during our routine nest monitoring visits, we calculated the chick's age at every subsequent capture event by subtracting the date of recapture from the date of hatching. For chicks with unknown hatch dates, we estimated chick age at initial capture using an age model based on morphometric measurements (Ackerman et al. 2011). We then calculated hatch date by subtracting the chick's model-estimated age from the date on which it was captured and measured for the first time.

For subsequent recaptures of the same chick, we estimated the chick's current age by subtracting the date it was recaptured from the estimated hatch date.

Radio-Marking Tern Chicks

We radio-marked only those Forster's Tern chicks that we considered to be recently hatched (mean±SD: 1.2±0.6 days of age, all <4 days), were found still in or near the nest bowl, and still had their egg tooth present (indicating that the chick had recently hatched). Because mortality can be correlated within broods, we used only one chick per brood for survival rate estimation (i.e., no radio-marked siblings were used in survival analyses). If there were >1 chick hatched in a nest during a visit, then we randomly selected one chick for radio-marking. We also radio-marked seven sibling chicks, but these data were only used to identify types of predators.

We radio-marked Tern chicks with radio transmitters containing thermistor switches (model BD-2T, Holohil Systems Ltd., Carp, Ontario, Canada) that improved detection of chick mortality and had an advertised lifespan range of 21-35 days. An increase or decrease in a chick's body temperature resulted in a corresponding increase or decrease in the radio transmitter's signal pulse rate. Transmitters (0.85 g) were ≤5% of initial chick body mass and <1% of chick body mass at fledging. We attached radio transmitters to a chick's back with sutures (Ethicon® Vicryl FS-2, 3-0, Ethicon Inc., Piscataway, New Jersey, USA, **Figure 4**) through front and rear channels, and a third suture was tied in the middle and over the top of the transmitter. Each suture was secured with 2-3 knots and cyanoacrylic glue (Loctite 422, Henkel Corp., Rocky Hill, Connecticut, USA).

Figure 4. A radio-marked Forster's Tern chick in South San Francisco Bay in 2010.

Radio-Tracking Tern Chicks

We tracked radio-marked Tern chicks daily to determine mortality and predator type. We determined locations of radio-marked chicks using trucks equipped with dual 4-element Yagi antenna systems (AVM Instrument Co., Colfax, California, USA) with null-peak systems to determine bearings via triangulation (Ackerman et al. 2008, 2010). We used an electronic compass (model Revolution, True North Technologies, Maynard, Massachusetts, USA) and triangulation software (Location of a Signal, version 3.0.1, Ecological Software Solutions, Schwägalpstrasse 2, 9107 Urnäsch, Switzerland) to calculate Universal Transverse Mercator (UTM) coordinates for each location. Periodically when chicks went missing, we also tracked radio transmitters by fixed-wing aircraft with dual 4-element Yagi antenna systems with left-right systems used to circle and pinpoint signals on either side of the plane (Gilmer et al. 1981). We located chicks daily by truck and periodically by aircraft from the time of radio attachment until their fate was determined (i.e., depredated, dead, or still alive at day 26 when they were expected to fledge [Ackerman et al. 2009b]). Within 24 hrs of when we believed a chick had died, we used a hand-held Yagi antenna and receiver to find the transmitter and chick. Radio-marked chicks that went missing were searched for each day until they were found or until the transmitter was estimated to have quit working (battery lifespan of approximately 21-35 days; see below for when failed radio transmitters were censored from survival analyses). Additionally, we periodically entered the largest nearby California Gull nesting colonies (Ponds A6, A14, and Mowry 4/5) on foot with hand-held Yagi antennas and receivers to search for missing transmitters that were potentially brought there by Gulls. Other California Gull nesting colonies were smaller and closer to roads and were able to be monitored via our normal truck-mounted telemetry system.

Fate of Radio-marked Tern Chicks

We considered a chick's fate to be either fledged, presumed fledged, depredated by a predator (including known and unknown predator types), died from exposure, or unknown fate due to the premature failure of the radio transmitter. Chicks were considered to have fledged if they were known to be alive ≥26 days after hatching using radio telemetry data. Chicks were presumed to have fledged if they were known to be alive ≥22 days after hatching using radio telemetry data, and there was no weekly chick capture event between age 22 and 26 days to determine whether the radio transmitter had failed after 22 days of age but before they fledged. Chicks were considered to have been depredated by a predator if we recovered the radio transmitter and chick remains away from the nesting island. Predators were identified to predator class (California Gull, wading birds [herons and egrets], or mammals) by using signs of predation near the recovered transmitter (such as tooth marks, scat, or a regurgitated pellet) and location of the recovered transmitter (such as within a California Gull colony, or wading bird roost). In particular, regurgitated Gull pellets that contained radio transmitters, bird bands, and other indigestible food items were often located within Gull colonies (**Figure 5**; see also Oro et al. 2005). We also considered chicks to have been depredated by an unknown type of predator if the chick went missing from the nesting island when it was too young to have fledged (<22 days of age). Many chicks that went missing from nesting islands were most likely depredated by avian predators and removed from the island. Chicks were classified as dying from exposure when they were recovered dead on the island where they had hatched, or in the water nearby, and there were no visible signs of trauma evident on the recovered corpse. Finally, radio transmitter failures were confirmed during weekly chick capture events when we would hand-capture every chick on the island nesting colony.

Figure 5. A radio transmitter, which was once attached to a live Forster's Tern chick, was recovered from a Gull pellet near a Gull nest at the Pond A6 California Gull nesting colony in South San Francisco Bay in 2010.

Survival Analyses of Radio-marked Tern Chicks

All analyses were performed within the R programming language (version 2.15.2; R Core Team 2012). We estimated the daily survival rates for radio-marked Forster's Tern chicks using known fate survival models. We built known fate capture histories based on detection information derived daily from radio telemetry data. We included age 0 to age 26 in the capture history, because Forster's Tern chicks begin to fledge at approximately 26 days of age (Ackerman et al. 2009b). We considered a chick to be alive if its radio transmitter provided a normal signal from the nesting island, and dead if the chick was found dead during telemetry surveys. In addition, since chicks were located on islands where dispersal was very unlikely until fledging age (Ackerman et al. 2009b), we assumed that a chick had been depredated by an unknown predator and considered it dead on the first day it went missing if (1) the chick was not of fledging age (i.e., <22 days of age), (2) was no longer detected during daily telemetry surveys, and (3) was no longer captured during weekly chick capture events. For radio transmitter failures, we right-censored chicks on the first day the chick was not detected during telemetry surveys, but was later confirmed to still be alive during weekly chick capture events. We also right-censored chicks that went missing on the first day the chick was not detected if they were ≥22 days of age because they were near the age when fledging could occur and we presumed they had fledged and that the radio transmitter battery had failed. In several cases, radio transmitters recovered from chicks that died soon after their initial deployment (i.e., a significant amount of transmitter battery lifespan was still available) were redeployed on another chick. Therefore, we also right-censored any chicks with redeployed transmitters if we could not detect them during daily telemetry surveys and the total number of days remaining on the transmitter battery lifespan was exceeded.

Statistical Design to Assess the Effect of Relocating the Largest Gull Colony on Tern Chick Survival Rates

We assessed the specific effect of the forced relocation of the largest California Gull nesting colony (23,998 adult California Gulls in 2010) on Forster's Tern chick survival, using a Before-After-Control-Impact (BACI) design. We tested the effect of the Gull colony relocation by examining the change in Tern chick survival between 2010 (when 23,998 Gulls nested at Pond A6) and 2011 (when

Gulls were relocated from Pond A6 and only 156 Gulls remained on an adjacent island) for each Tern colony. In particular, the Tern colony in Pond A7 was directly adjacent to the California Gull colony in Pond A6, whereas the other Tern colonies were 2.7-5.8 km away from this large Gull colony. The Tern colony at Pond A2W was >3.8 km away from the California Gull colony in Pond A6, and was our main reference site because it was one of only two sites (the other was Pond A7) where large numbers of Terns nested in both 2010 and 2011, thereby providing us opportunities to radio-mark Tern chicks at the same site in each year. Therefore, the Tern colony site × year interaction was an important variable in our analyses which represented the main test for an effect of the Gull colony relocation on Tern chick survival.

We built a candidate model set based on potential predictor variables, including Tern colony site, pond complex [either Alviso or Moffett], year, chick age, chick mass at the time of radio-marking, relative hatch date (hatch date was standardized each year using the median hatch date), and the interactions Tern colony site × year and Tern colony complex × year. Our final *a priori* candidate model set included all additive combinations of variables, and a null (intercept only) model (a total of 104 models).

We evaluated models using a second-order Akaike Information Criterion (AIC*c*) and considered the model with the smallest AIC*c* to be the most parsimonious (Burnham and Anderson 1998). We used the AIC*c* differences between the best model and the other candidate models ($\Delta AICc_i$) to determine the relative ranking of each model. We used Akaike weights (w_i) to assess the weight of evidence that the selected model was actually the best model within the set of candidate models considered. We also assessed the relative importance of each variable by summing Akaike weights across models that incorporated the same variable. We used evidence ratios to compare the relative weight of support between models. Presentation of model selection results was restricted to the set of top models that contributed 99% of all model weight.

We estimated model-averaged daily survival rates (S_i) for each Tern colony site and year using the RMark (version 2.1.4; Laake 2012) front-end to Program Mark (White 1999). Tern chick fledging success (FS) was defined as the probability of a chick surviving to 26 days of age, and estimated for each Tern colony (pond) and year as the cumulative 26-day product of daily chick survival rates. We used the delta method (Seber 1982) to estimate standard errors and 95% confidence limits for colony-specific fledging success.

Influence of Gull Predation Pressure on Tern Chick Fledging Success

In the next stage of our analysis, we examined how the proximity and abundance of California Gull colonies to Tern colonies influenced Tern fledging success. We calculated Tern fledging success rates for each Tern colony and then developed Tern colony-specific estimates of Gull predation pressure. Estimates of Gull predation pressure were calculated for each nesting island within a Tern colony (pond) and then pond-level indices were estimated as the average Gull predation pressure index of all islands within a pond, weighting each island-level estimate by the proportion of radio transmitters that were deployed on each of the islands within the pond. Thus, the Gull predation pressure index for each pond was estimated by weighting the nesting islands within the pond and was similar to how we weighted the estimate for the Tern colony's fledging success.

We tested seven indices that we believed could represent predation pressure by California Gulls on Forster's Tern chicks. First, we used distance to the *nearest* California Gull colony from the Tern colony as a simple index of Gull predation pressure based on the assumption that Tern chick survival would decrease with increased proximity to a Gull colony. Second, we also assessed a similar index of Gull predation pressure by using distance to the *largest* California Gull colony (23,998 adults at Pond

A6 Gull colony in 2010 and 11,956 adults at Pond A14 Gull colony in 2011). This index was based on the assumption that, because the largest single Gull colony each year represented 52% (2010) and 32% (2011) of all the nesting Gulls in South San Francisco Bay, the largest Gull colony might have a substantially larger impact on Tern chick survival rates than the smaller Gull colonies. We also hypothesized that in addition to the distance of a California Gull colony to Tern colony, that the number of California Gulls within the Gull colony could influence Gull predation pressure on Tern chicks. Therefore, the number of California Gulls at the nearest Gull colony also was used as a third index of Gull predation pressure. Next, we calculated the deviation of the Gull's main flight path, from their colony to the local landfill (Newby Island), to each of the Forster's Tern colonies (calculated as an angle). For this index of Gull predation pressure, we used our prior knowledge that the majority of California Gull movements from colonies are dictated largely by the location of a major landfill (Ackerman et al. 2009a), and that Tern colonies that were located further from a Gull's flight path to the landfill might experience lower Gull predation rates. Using this approach, our fourth index of predation pressure was the angle of the Tern colony to the *nearest* Gull colony's flight path to the landfill, and our fifth index of Gull predation pressure was the angle of the Tern colony to the *largest* Gull colony's flight path to the landfill. Finally, we developed two, more complex, indices of California Gull predation pressure which combined both the distance that Tern colonies were located from Gull colonies and the size of Gull colonies. These indices assumed that the Gull predation pressure experienced by a specific Tern colony would be a cumulative function of all California Gull colonies in the South San Francisco Bay region (7 in 2010 and 8 in 2011), and that the Gull predation pressure of any single Gull colony would decrease with increasing distance from the Tern colony. We tested two functional forms for the more complex Gull predation pressure index, each varying only in the rate at which the predation impact of a Gull colony depended on the number of adult Gulls in the colony. The first index assumed that Gull predation pressure was linearly related to each Gull colony's abundance, and inversely related to the Gull colony's distance from the Tern colony (equation *a*). Second, we hypothesized that the per-capita impact of a Gull colony based on its size might diminish as the size of the Gull colony increased, because additional Gulls added to an already large Gull population might have little additional effect on Tern chick predation rates. Thus, we used $\log_e$ of the Gull colony size to represent this diminishing impact at larger colony sizes (equation *b*). Gull predation pressure (GPP) at each of the Tern colonies was therefore modeled as either:

$$a)\ GPP_1 = \sum \frac{N_j}{D_j} \qquad b)\ GPP_2 = \sum \frac{logN_j}{D_j}$$

where:

$$N_j\ = \text{number of California Gulls at Gull colony } j$$

$$logN_j\ = \text{natural log (number of California Gulls at Gull colony } j\text{)}$$

$$D_j\ = \text{Distance from Forster's Tern colony to California Gull colony } j$$

Using these seven indices of Gull predation pressure, we built a candidate model set based on all possible additive combinations of the Gull predation pressure indices and year without any interactions. This model set was reduced by not allowing GPP_1 and GPP_2 to be in the same model, and combinations of the distance, abundance, and angle variables were required to match the specific Gull colony in question (i.e., if the distance was based on the *nearest* Gull colony, then the Gull abundance, and angle of the deviation from the Gull colony's flight path must also be for the *nearest* Gull colony). Our final *a priori* candidate model set included a null (intercept only) model and totaled 40 models. As described above, we evaluated models using AIC*c* scores and present the set of top models that contributed 99% of all model weight. All results represent model-averaged predictions from the full candidate model sets.

Results and Discussion

Predators of Tern Chicks

We radio-marked and tracked 212 Forster's Tern chicks at 7 colonies in 2010 (*N*=110) and 2011 (*N*=102; **Table 1**). In 2010, 59 chicks were marked at nesting locations in the Moffett pond complex and 51 chicks were marked in the Alviso pond complex. In 2011, 52 chicks were marked at nesting locations in the Moffett pond complex and 50 chicks were marked in the Alviso pond complex. A total of 35 radio transmitters failed prematurely (15 in 2010, 20 in 2011; **Table 1**), precluding the determination of fates of the 35 chicks carrying these radios. Thus, when calculating chick fates as percentages, we have excluded these 35 chicks and present values derived only from the 177 chicks for which fate was determined (**Table 2**). Also, as part of our normal chick banding operations, we banded an additional 891 Forster's Tern chicks at seven colonies in 2010 and 358 Forster's Tern chicks at five colonies in 2011 which did not receive radio transmitters.

Overall, 80% of radio-marked Forster's Tern chicks died (*N*=141) and only 20% fledged or were presumed to have fledged (*N*=36; **Tables 1-2**). Of the 141 radio-marked Tern chicks known to have died, 23% (*N*=32) were confirmed depredated by California Gulls, 5% (*N*=7) were confirmed depredated by wading birds (herons and egrets), 1% (*N*=1) were confirmed depredated by mammals, 40% (*N*=56) went missing from their nesting island before they were of appropriate age to fledge and were presumed to have been depredated by an unidentified predator, and 32% (*N*=45) died from exposure.

Of the 85 (54 in 2010 and 31 in 2011) radio-marked Forster's Tern chicks with a known mortality cause, 54% (29 of 54) were depredated by California Gulls in 2010, but only 10% (3 of 31) of Tern chicks were known to have been depredated by California Gulls in 2011 (**Tables 1-2**). However, many of the radio-marked Tern chicks simply went missing from their nesting colony before they were old enough to have potentially fledged (*N*=56; noted as “unknown predator” in **Tables 1-2**), and this often indicated predation by aerial predators such as California Gulls. For example, we found 31 radio-transmitters formerly attached to Tern chicks within California Gull colonies (either in Gull pellets [**Figure 5**] or attached to parts of depredated chicks) that were carried there by Gulls (**Figure 6**). We also recovered 59 bands at the Pond A6 California Gull colony from Tern chicks that were banded at their nesting colonies in 2010, but which were never fitted with radio transmitters (**Table 3**).

These results are similar to a previous study in 2005 and 2006 where American Avocet and Black-necked Stilt chicks radio-marked in the nest shortly after hatching, were recovered dead at California Gull colonies (especially the Pond A6 California Gull colony) located several kilometers away (Ackerman et al. 2006b). For example, 57 of 161 (35%) radio-marked Avocet chicks were depredated by California Gulls and carried to Gull colonies at Pond A6 and Pond N3A/N4AB, and 3 of 79 (4%) radio-marked Stilt chicks were depredated by California Gulls and carried to the Gull colony at Pond A6 (Ackerman et al. 2006b). Presumably, the Tern chicks (and their radio transmitters) were carried to the Gull colonies either to feed young Gulls or were ingested by the adult Gull and regurgitated as a pellet (**Figure 5**). Therefore, if we assume that all Tern chicks that simply went missing from their island nesting colonies were actually depredated by California Gulls, then 64% (44 of 69) of Tern chick deaths may have been caused by California Gulls in 2010 and 61% (44 or 72) may have been caused by California Gulls in 2011. This may, in fact, be closer to the actual number of depredations caused by California Gulls because of our low probability of finding Tern chicks (and transmitters) that had been depredated and carried away by Gulls.

In 2010, when the Pond A6 California Gull colony existed, Forster’s Tern chicks at the Pond A7 Tern colony appeared to be more susceptible to predation by California Gulls from the A6 Gull colony than did chicks at the other Tern colonies, including Pond A2W which was the other main Tern nesting colony that existed in both 2010 and 2011. Among radio transmitters that were attached to Forster's Tern chicks in 2010, 56% (20 of 36 [excludes failed radios]) from the Pond A7 Tern colony were recovered in the Pond A6 California Gull colony compared to only 14% (8 of 59 [excludes failed radios]) from all the other Tern colonies (**Tables 1 and 2**). Similarly, in 2010, 20% (33 of 165) of bands from non-radio-marked Forster's Tern chicks in Pond A7 were recovered in the Pond A6 California Gull colony compared to only 4% (26 of 726) of bands from non-radio-marked chicks at all other Tern colonies (**Table 3**).

In 2011, after the Pond A6 California Gull colony had been relocated, 7% (1 of 15 [excludes failed radios]) of radio-marked Tern chicks from the Pond A7 Tern colony were recovered in the new Pond A14 California Gull colony compared to 3% (2 of 67 [excludes failed radios]) from all other Tern colonies (**Tables 1**), and no bands from the 358 non-radio-marked chicks were recovered at any Gull colony. Due to the difficulty of finding these very small (<5 mm diameter) bands that were once attached to Tern chicks within the great expanse that was the Pond A6 California Gull colony (>100 ha), band recovery rates should be considered drastic underestimates of actual predation by the Pond A6 California Gull colony on Tern chicks in 2010. Nevertheless, these band recovery rates provide insight into just how widespread predation by the Pond A6 California Gull colony was on Tern chicks in 2010, and confirms the result of relatively greater predation pressure on Forster's Tern chicks at the Pond A7 Tern colony relative to the other Tern colonies in South San Francisco Bay, as was quantitatively observed using radio-marked chicks.

All but one of the 29 California Gull predation mortalities in 2010 were found at the Pond A6 California Gull colony (**Tables 1**; **Figure 6**). However, as a result of the breaching of levees at Pond A6 to tidal flow in December 2010 and the relocation of the A6 Gull nesting colony (23,998 adult Gulls; **Table 4**), none of the California Gull predation mortalities in 2011 were detected at the very small remaining California Gull colony (156 adult Gulls) at Pond A6 (**Figure 6**). In fact, we found just 3 depredated Tern chicks and associated transmitters in California Gull colonies in 2011, and all were recovered within the newly re-established California Gull colony at Pond A14 (**Figure 6**).

Survival Rate of Tern Chicks

Forster's Tern chick survival (*N*=205) from hatching to fledging at 26 days of age was 0.19 (standard error [SE]=0.03) overall (**Figure 7B**), and 0.23 (SE=0.04) in 2010 and 0.15 (SE=0.04) in 2011 (**Table 5**). Fledging success ranged from 3% to 67% among colonies. The most parsimonious model describing Forster's Tern chick survival rates included Tern colony site, year, age, and the year × site interaction, and had an Akaike weight of 0.29 (**Table 6**). Furthermore, models containing colony site, year, age, and the year × site interaction had a cumulative Akaike weight of 0.85. Three other models containing these variables plus either date at hatching, mass at hatching, or complex area were within a $\Delta AICc \leq 2.0$, but their addition did not improve model fit as indicated by no improvement in the model's log-likelihoods (**Table 6**). Therefore, date at hatching, mass at hatching, and complex were considered to be uninformative parameters (Arnold 2010) and were judged to have little effect on chick survival rates.

We estimated the relative importance of individual variables and found that the data strongly supported the effects of Tern colony site (relative variable importance = 1.00), year (0.99), year × site interaction (0.98), and age (0.88). In contrast, the other variables we investigated had little influence on chick survival rates, including complex (0.33), date at hatching (0.31), and mass at hatching (0.27). To further determine the importance of variables in the best model, we compared the best model to the same model structure but omitting one of the variables of interest. Using this evidence ratio approach, we estimated that the model including chick age was 6.8 times more likely than the same model without chick age (**Table 6**). Forster's Tern chick daily survival rate increased 10% during the fledging period from 0.88 (95% confidence limits=0.85-0.91) at one day of age to 0.98 (0.96-0.99) at 26 days of age (**Figure 7A**). The average age of Forster's Tern chicks when they were (confirmed) depredated by California Gulls was 4.7 days old, with a range from 1 to 13 days of age.

The best model contained the year × site interaction term, and was 78.8 times more likely than the same model but without this interaction term (**Table 6**). The overriding importance of the year × site interaction term indicated that changes in Tern chick survival rates between years were not consistent among Tern colony sites. Specifically, Forster's Tern chick survival rates at two of the largest Tern colonies, that were consistently used for nesting in both 2010 and 2011 (Pond A2W and Pond A7; **Table 5**), differed markedly before (2010) and after (2011) the relocation of the Pond A6 California Gull colony. Tern chick fledging success at reference Pond A2W was similar between years (0.24 in 2010 and 0.18 in 2011; -25% change), whereas Tern chick fledging success at Pond A7 increased dramatically from 0.03 in 2010 to 0.35 in 2011 (+1067% change) after the relocation of the nearby Pond A6 California Gull colony (**Figure 8**). In particular, compared to the reference Tern colony at Pond A2W, daily survival rates of Tern chicks at Pond A7 increased between years more among younger Tern chicks (<15 days old) , which are more vulnerable to Gull predation, than for older Tern chicks, which are less vulnerable to Gull predation due to their greater size and mobility (**Figure 9**).

Gull Predation Pressure and Tern Chick Fledging Success

To further examine the influence of California Gull colonies on predation rates of Forster's Tern chicks, we examined whether Tern colony's fledging rates were related to the distance, direction, and abundance of nearby Gull colonies. There were 7 California Gull colonies in 2010 and 8 colonies in 2011 after the relocation of the largest California Gull colony at Pond A6 (**Table 4**). The most parsimonious model describing fledging success for Forster's Tern colonies included only the distance to the nearest California Gull colony (adjusted R^2=0.34), and had an Akaike weight of 0.27 (**Table 7**). The second ranked model supported by the data (ΔAIC*c* = 0.54) included only the Gull predation pressure index ($GPP_2 = \sum \frac{logN_j}{D_j}$; adjusted R^2=0.30), estimated by combining all of the California Gull colony sizes and distances to each of the Forster's Tern colonies, and had an Akaike weight of 0.21. Using evidence ratios, the best model which included only the distance to the nearest California Gull colony was 1.7 times more likely than the null model, and the second ranked model which included only the Gull predation pressure index was 1.3 times more likely than the null model. The relative importance of individual variables was 0.35 for distance to the nearest Gull colony, 0.29 for Gull predation pressure index ($GPP_2 = \sum \frac{logN_j}{D_j}$), 0.10 for year, 0.09 for the angle of the Tern colony to the *nearest* Gull colony's flight path to the landfill, 0.06 for the angle of the Tern colony to the *largest* Gull colony's flight path to the landfill, 0.04 for the size of the nearest Gull colony, and 0.04 for Gull predation pressure index ($GPP_1 = \sum \frac{N_j}{D_j}$). Model averaged coefficients and standard errors for distance to the nearest Gull colony (0.0001±0.00008) and Gull predation pressure index ($GPP_2 = \sum \frac{logN_j}{D_j}$; -18.70±15.83) further indicated that the influence of these Gull predation pressure indices on Tern chick fledging success, while better than the null model, were weak. Nonetheless, Tern fledging success tended to increase as the distance to the nearest California Gull colony increased (**Figure 10A**). Similarly, Tern fledging success tended to be higher when the Gull predation pressure index was lower, indicating that having fewer Gulls at nearby Gull colonies or at a further distance from the Tern colony improved Tern fledging success (**Figure 10B**).

Our results indicate a high mortality rate for Forster's Tern chicks in South San Francisco Bay, and the Tern chick survival rate to fledging (0.19) was just slightly higher than those of American Avocet chicks (0.14 in 2005 and 0.05 in 2006) and lower than those of Black-necked Stilt chicks (0.32

in 2005 and 0.56 in 2006) studied at nearby sites in South San Francisco Bay (Ackerman et al. 2006b). As with our current study on Forster's Tern chick survival, predation on Avocet chicks by aerial predators, primarily California Gulls, appeared to be responsible for the majority of chick losses, whereas fewer Stilt chicks were depredated by California Gulls (Ackerman et al. 2006b). In San Francisco Bay, Forster's Terns and Avocets both nest primarily on islands within large ponds that are mostly devoid of vegetation that might conceal chicks from aerial predators, such as California Gulls (Ackerman and Herzog 2012). In contrast, most Stilt nests in San Francisco Bay are within marshes and nests are associated with vegetation structure (Ackerman and Herzog 2012) which likely conceals Stilt chicks from aerial predation (Ackerman et al. 2006b). This different use of habitats and lower overall nesting densities likely contributes to higher survival for Stilt chicks, compared to Avocet and Forster's Tern chicks.

Long-term colony census data suggests that the Forster's Tern breeding population in the South Bay may be declining (**Figure 1**). Relative to postfledging survival (Ackerman et al. 2008c), Forster's Tern nest survival (Ackerman and Herzog 2012) and chick survival from hatching to fledging (**Tables 5**) appears to be a limiting factor for population increase (and possibly population stability) for the Forster's Tern breeding population in San Francisco Bay. Once fledged, Forster's Tern cumulative survival rate during the subsequent 35-day postfledging time period was 0.81 (SE=0.09) in San Francisco Bay (Ackerman et al. 2008c). Combining these data for postfledging survival (Ackerman et al. 2008c) with our current study's estimate for overall Tern chick survival from hatching to fledging (0.19), provides an estimated Forster's Tern chick survival from hatch to 35-days postfledging (61 total days after hatching) of 0.15.

It appeared that some California Gulls specialized on depredating Forster's Tern chicks. Several times when we recovered a still functioning radio transmitter from a depredated Tern chick found within the Pond A6 California Gull colony, we also found additional bands that had been put on Tern chicks that had not been radio-marked. These multiple band recoveries of depredated Tern chicks at the same precise location within Gull colonies, and often near a California Gull nest, indicated that the same individual California Gull had depredated multiple Tern chicks. For example, of the 32 radio-marked Forster's Tern chicks that were known to be depredated by California Gulls, 13 of these instances had multiple bands and/or transmitters recovered at the same site. This included times where 2 (four times), 3 (five times), 6, 7, 8, and 11 Forster's Tern chicks were recovered at the same location within the Pond A6 Gull colony and presumably depredated by the same individual California Gull in each instance. Several other studies have also found that Gull predation on seabird chicks are often the consequence of just a few specialist Gulls. For example, Guillemette and Brousseau (2001) found that only five Gulls, or 0.8% of the breeding population of Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*Larus marinus*), were responsible for depredating an average of 63% of the Common Tern (*Sterna hirundo*) chicks that had hatched. Similarly, only 2% of a population of Herring Gulls were responsible for depredating approximately 10% of Ring-billed Gull chicks (*Larus delawarensis*; Southern and Southern 1984), 2-4% of a population of Herring Gulls were responsible for depredating approximately 21% of Lesser Black-backed Gull chicks (*Larus fucus*; Hario 1994), and 2% of a population of Western Gulls were responsible for depredating 65-77% of Common Murre (*Uria aalge*) eggs and chicks (Spear 1993). Accordingly, seabird productivity tends to increase in studies which lethally remove the few Gulls that specialize on depredating eggs and chicks (Hario 1994, Guillemette and Brousseau 2001, Riensche et al. 2012). In contrast, culling large populations of Gulls has met with more limited success for improving waterbird populations (Harris and Wanless 1997). Together, these data suggest that Gulls which depredate seabird chicks tend to specialize, and that only a very small proportion of a local Gull population is typically responsible for the majority of chick mortality by Gulls.

Table 1. Fate of Forster's Tern chicks radio-marked at hatching in nesting colonies in the Moffett or Alviso pond complexes in South San Francisco Bay, California, during 2010 and 2011.

						Depredated by					
Year / Pond	Chicks Radio-marked	Radio Failed, Fate Unknown	Chicks Radio-marked, Excluding Radio Failures	Chicks Fledged[1]	Chicks Presumed Fledged[2]	California Gull[3]	Heron/Egret[4]	Mammal[5]	Unknown Predator[6]	Died from Exposure[7]	Transmitters Recovered in A6 Gull Colony
2010											
A2W	27	7	20	2	2	3	0	0	4	9	3
AB1	28	2	26	7	6	3	0	0	3	7	2
AB2	4	0	4	0	0	2	0	0	2	0	2
Moffet Total	59	9	50	9	8	8	0	0	9	16	7
A7	42	6	36	1	1	20	1	0	6	7	20
A8	1	0	1	1	0	0	0	0	0	0	0
A16	8	0	8	2	4	1	0	0	0	1	1
Alviso Total	51	6	45	4	5	21	1	0	6	8	21
2010 Total	*110*	*15*	*95*	*13*	*13*	*29*	*1*	*0*	*15*	*24*	*28*
2011			0								
A1	26	6	20	1	1	1	0	1	11	5	0
A2W	26	6	20	1	2	0	0		12	5	0
Moffet Total	52	12	40	2	3	1	0	1	23	10	0
A7	19	4	15	3	1	1	3	0	3	4	0
A8	31	4	27		1	1	3	0	15	7	0
Alviso Total	50	8	42	3	2	2	6	0	18	11	0
2011 Total	*102*	*20*	*82*	*5*	*5*	*3*	*6*	*1*	*41*	*21*	*0*
2010-2011 Total	***212***	***35***	***177***	***18***	***18***	***32***	***7***	***1***	***56***	***45***	***28***

[1] Chicks were considered to have fledged if they were known to be alive at least 26 days after hatching.
[2] Chicks were presumed to have fledged if they were known to be alive at least 22 days after hatching and final fate was not observed.
[3] California Gulls were identified as the predator when transmitters that were attached to Tern chicks were recovered in a Gull colony (31) or were recovered near regurgitated pellets in an area used by Gulls (1).

[4] Herons or Egrets were identified as the predator when transmitters that were attached to Tern chicks were found in association with heron and egret feathers and regurgitations, and in areas frequently used by herons and egrets.
[5] Mammals were identified as the predator when transmitters that were attached to Tern chicks were recovered in mammal scat.
[6] Chicks that went missing from the nesting island when they were too young to have fledged were considered to have been killed by a predator of unknown type. These chicks were most likely depredated by avian predators and removed from the island.
[7] Chicks were classified as dead from exposure when they were recovered dead on the island where they hatched or in the water nearby and no visible signs of trauma were evident on the recovered corpse.

Table 2. Fate, as percentages excluding radio failures, of Forster's Tern chicks radio-marked at hatching in nesting colonies in the Moffett or Alviso pond complexes in South San Francisco Bay, California, during 2010 and 2011.

Year / Pond	Chicks Radio-marked	Radio Failed, Fate Unknown	Chicks Radio-marked, Excluding Radio Failures	Chicks Fledged[1]	Chicks Presumed Fledged[2]	Depredated by: California Gull[3]	Depredated by: Heron/Egret[4]	Depredated by: Mammal[5]	Depredated by: Unknown Predator[6]	Died from Exposure[7]	Transmitters Recovered in A6 Gull Colony
2010											
A2W	27	7	20	10%	10%	15%	0%	0%	20%	45%	15%
AB1	28	2	26	27%	23%	12%	0%	0%	12%	27%	8%
AB2	4	0	4	0%	0%	50%	0%	0%	50%	0%	50%
Moffet Total	59	9	50	18%	16%	16%	0%	0%	18%	32%	14%
A7	42	6	36	3%	3%	56%	3%	0%	17%	19%	56%
A8	1	0	1	100%	0%	0%	0%	0%	0%	0%	0%
A16	8	0	8	25%	50%	13%	0%	0%	0%	13%	13%
Alviso Total	51	6	45	9%	11%	47%	2%	0%	13%	18%	47%
2010 Total	*110*	*15*	*95*	*14%*	*14%*	*31%*	*1%*	*0%*	*16%*	*25%*	*29%*
2011			0								
A1	26	6	20	5%	5%	5%	0%	5%	55%	25%	0%
A2W	26	6	20	5%	10%	0%	0%	0%	60%	25%	0%
Moffet Total	52	12	40	5%	8%	3%	0%	3%	58%	25%	0%
A7	19	4	15	20%	7%	7%	20%	0%	20%	27%	0%
A8	31	4	27	0%	4%	4%	11%	0%	56%	26%	0%
Alviso Total	50	8	42	7%	5%	5%	14%	0%	43%	26%	0%
2011 Total	*102*	*20*	*82*	*6%*	*6%*	*4%*	*7%*	*1%*	*50%*	*26%*	*0%*
2010-2011 Total	***212***	***35***	***177***	***10%***	***10%***	***18%***	***4%***	***1%***	***32%***	***25%***	***16%***

[1] Chicks were considered to have fledged if they were known to be alive at least 26 days after hatching.
[2] Chicks were presumed to have fledged if they were known to be alive at least 22 days after hatching and final fate was not observed.
[3] California Gulls were identified as the predator when transmitters that were attached to Tern chicks were recovered in a Gull colony (31) or were recovered near regurgitated pellets in an area used by Gulls (1).

[4] Herons or Egrets were identified as the predator when transmitters that were attached to Tern chicks were found in association with heron and egret feathers and regurgitations, and in areas frequently used by herons and egrets.
[5] Mammals were identified as the predator when transmitters that were attached to Tern chicks were recovered in mammal scat.
[6] Chicks that went missing from the nesting island when they were too young to have fledged were considered to have been killed by a predator of unknown type. These chicks were most likely depredated by avian predators and removed from the island.
[7] Chicks were classified as dead from exposure when they were recovered dead on the island where they hatched or in the water nearby and no visible signs of trauma were evident on the recovered corpse.

Table 3. Number of bands from Forster's Tern chicks that had been originally banded at their natal colony (banded only; no radio transmitter attached) that were subsequently found in the A6 California Gull colony in South San Francisco Bay, CA in 2010. Although we similarly banded 360 Forster's Tern chicks in 2011, we did not find bands within any Gull colony in 2011 after the A6 California Gull colony had been relocated. No bands were recovered at any other Gull colony in 2010 or 2011.

Year / Pond	Number of Chicks Banded	Number of Bands Recovered in Pond A6 Gull Colony	% Bands Recovered in Pond A6 Gull Colony
2010			
A1	94	4	4%
A2W	187	11	6%
AB1	326	6	2%
AB2	23	2	9%
Moffet Total	630	23	4%
A7	165	33	20%
A8	46	0	0%
A16	50	3	6%
Alviso Total	261	36	14%
2010 Total	*891*	*59*	*7%*

Table 4. Number of breeding adults at each California Gull colony, estimated by assuming two adult birds per nest, in San Francisco Bay, California, during 2010 and 2011. The Gull sub-colonies at Pond A6, A5 island, and A5/A7 levee were combined into Pond A6's total due to their proximity.

	Colony Size (adults)	
California Gull Colony	**2010**	**2011**
A6	***23,998***	***156***
A9/A10/A11/A14	***0***	***11,956***
M1/M2	6,020	4,164
M4/M5	4,780	6,068
A1	428	390
Palo Alto Flood Control Basin	1,704	4,478
N6/N7	2,506	4,110
N3A/N4AB	6,594	6,394
Total	**46,030**	**37,716**

Table 5. Forster Tern colony locations, number of nests initiated, number of chicks banded, number of chicks radio-marked, and chick survival rates (±standard error) in South San Francisco Bay, California, during 2010 and 2011. The number of chicks radio-marked listed here for survival analyses did not include five radio-marked siblings in 2010 and two radio-marked siblings in 2011.

Complex, Pond, and Tern Colony Location	Number of Tern Nests		Number of Tern Chicks Banded		Number of Tern Chicks Radio-Marked		Tern Chick Survival	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Alviso Complex								
Pond A7	209	139	207	116	42	18	0.03 (0.02)	0.35 (0.13)
Pond A8	114	108	47	133	1	31	0.98 (0.04)	0.05 (0.03)
Pond A16	59	27	58	9	8	0	0.67 (0.19)	---
Moffet Complex								
Pond A1	76	103	94	77	0	25	---	0.08 (0.05)
Pond A2W	231	282	214	125	25	26	0.24 (0.09)	0.18 (0.08)
Pond AB1	252	8	354	0	25	0	0.40 (0.11)	---
Pond AB2	28	5	27	0	4	0	0.05 (0.08)	---
Total	**969**	**672**	**1001**	**460**	**105**	**100**	**0.23 (0.04)**	**0.15 (0.04)**

Table 6. Ranking of candidate model set describing radio-marked Forster's Tern chick daily survival (*N*=205 chicks) from hatching to fledging in San Francisco Bay, California during 2010 and 2011. Models are ranked by differences in Akaike's information criterion, corrected for sample size (AIC_c). Only the top models that represented 0.99 of total model weight are presented, along with the null model.

Model structure[a]	*k* [b]	-2logL	AIC*c* [c]	ΔAIC*c* [d]	Akaike weight (w_i)[e]	Evidence ratio[f]	Cumulative weight
Site + Year + Age + Year×Site	12	918.73	942.90	0.00	0.29	1.00	0.29
Site + Year + Age + Date + Year×Site	13	918.33	944.53	1.63	0.13	2.26	0.42
Site + Year + Age + Mass + Year×Site	13	918.72	944.92	2.02	0.11	2.75	0.52
Complex + Site + Year + Age + Year×Site	13	918.73	944.93	2.03	0.11	2.76	0.63
Site + Year + Age + Mass + Date + Year×Site	14	918.30	946.53	3.63	0.05	6.15	0.68
Complex + Site + Year + Age + Date + Year×Site	14	918.33	946.56	3.66	0.05	6.23	0.72
Site + Year + Year×Site	11	924.59	946.73	3.83	0.04	6.80	0.77
Complex + Site + Year + Age + Mass + Year×Site	14	918.72	946.95	4.05	0.04	7.59	0.80
Complex + Site + Year + Age + Year×Complex + Year×Site	14	918.73	946.96	4.06	0.04	7.61	0.84
Site + Year + Date + Year×Site	12	924.28	948.45	5.55	0.02	16.04	0.86
Complex + Site + Year + Age + Mass + Date + Year×Site	15	918.30	948.57	5.67	0.02	17.00	0.88
Complex + Site + Year + Age + Date + Year×Complex + Year×Site	15	918.33	948.59	5.69	0.02	17.22	0.89
Site + Year + Mass + Year×Site	12	924.58	948.75	5.85	0.02	18.67	0.91
Complex + Site + Year + Year×Site	12	924.59	948.76	5.86	0.02	18.71	0.93
Complex + Site + Year + Age + Mass + Year×Complex + Year×Site	15	918.72	948.99	6.09	0.01	20.97	0.94
Site + Year + Mass + Date + Year×Site	13	924.28	950.48	7.58	0.01	44.22	0.95
Complex + Site + Year + Date + Year×Site	13	924.28	950.48	7.58	0.01	44.22	0.95
Complex + Site + Year + Age + Mass + Date + Year×Complex + Year×Site	16	918.30	950.60	7.70	0.01	47.03	0.96
Complex + Site + Year + Mass + Year×Site	13	924.58	950.78	7.88	0.01	51.49	0.96
Complex + Site + Year + Year×Complex + Year×Site	13	924.59	950.79	7.89	0.01	51.60	0.97
Complex + Site + Year + Age + Year×Complex	11	929.45	951.59	8.69	0.00	77.14	0.97
Site + Year + Age	9	933.53	951.63	8.73	0.00	78.78	0.98
Complex + Site + Year + Mass + Date + Year×Site	14	924.28	952.51	9.61	0.00	122.05	0.98
Complex + Site + Year + Date + Year×Complex + Year×Site	14	924.28	952.51	9.61	0.00	122.06	0.98
Complex + Site + Year + Mass + Year×Complex + Year×Site	14	924.58	952.81	9.91	0.00	142.11	0.98
Site + Age	8	936.78	952.86	9.96	0.00	145.66	0.99
Complex + Site + Year + Age + Date + Year×Complex	12	929.28	953.45	10.55	0.00	195.41	0.99
Complex + Site + Year + Age + Mass + Year×Complex	12	929.44	953.61	10.71	0.00	211.73	0.99
Site + Year + Age + Mass	10	933.53	953.65	10.75	0.00	216.22	0.99
Intercept Only (null)	1	977.57	979.58	36.68	0.00	92119644.80	1.00

[a] The + denotes an additive effect and the × denotes an interaction.

[b] The number of parameters in the model, including the intercept.

[c] Akaike's Information Criterion (AIC*c*).

[d] The difference in the value between AIC*c* of the current model and the value for the most parsimonious model.

[e] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).

[f] The weight of evidence that the top model is better than the selected model, given the candidate model set.

Table 7. Ranking of candidate model set describing radio-marked Forster's Tern chick fledging success by pond (N=10 Tern colonies) in San Francisco Bay, California during 2010 and 2011. Models are ranked by differences in Akaike's information criterion, corrected for sample size (AIC_c). Only the top models that represented 0.99 of total model weight are presented, along with the null model.

Model structure[a]	k [b]	-2logL	AICc [c]	ΔAICc [d]	Akaike weight (w_i)[e]	Evidence ratio[f]	Cumulative weight
Distance to nearest gull colony	3	-1.29	8.71	0.00	0.27	1.00	0.27
∑(log Gull Abundance$_j$/Gull Distance$_j$)	3	-0.74	9.26	0.54	0.21	1.31	0.48
Intercept Only (null)	2	4.02	9.73	1.02	0.16	1.66	0.64
Angle from largest gull colony's flightpath	3	1.40	11.40	2.69	0.07	3.84	0.71
Year	3	2.47	12.47	3.76	0.04	6.54	0.75
Angle from nearest gull colony's flightpath	3	3.04	13.04	4.33	0.03	8.70	0.79
∑(Gull Abundance$_j$/Gull Distance$_j$)	3	3.43	13.43	4.71	0.03	10.55	0.81
Year + ∑(log Gull Abundance$_j$/Gull Distance$_j$)	4	-2.27	13.73	5.01	0.02	12.26	0.83
Gull abundance at nearest colony	3	3.93	13.93	5.21	0.02	13.56	0.85
Distance to largest gull colony	3	4.01	14.01	5.30	0.02	14.16	0.87
Distance to nearest gull colony + Angle from nearest gull colony's flightpath	4	-1.88	14.12	5.41	0.02	14.94	0.89
Angle from nearest gull colony's flightpath + ∑(log Gull Abundance$_j$/Gull Distance$_j$)	4	-1.83	14.17	5.46	0.02	15.31	0.91
Year + Distance to nearest gull colony	4	-1.56	14.44	5.73	0.02	17.55	0.92
Angle from largest gull colony's flightpath + ∑(log Gull Abundance$_j$/Gull Distance$_j$)	4	-1.39	14.61	5.90	0.01	19.09	0.94
Distance to nearest gull colony + Gull abundance at nearest colony	4	-1.30	14.70	5.99	0.01	19.95	0.95
Angle from largest gull colony's flightpath + ∑(Gull Abundance$_j$/Gull Distance$_j$)	4	-1.13	14.87	6.16	0.01	21.71	0.96
Year + ∑(Gull Abundancej/Gull Distancej)	4	0.06	16.06	7.35	0.01	39.45	0.97
Angle from nearest gull colony's flightpath + Angle from largest gull colony's flightpath	4	0.45	16.45	7.73	0.01	47.77	0.98
Year + Angle from largest gull colony's flightpath	4	0.74	16.74	8.03	0.00	55.46	0.98
Distance to largest gull colony + Angle from largest gull colony's flightpath	4	0.97	16.97	8.25	0.00	61.99	0.99
Year + Angle from nearest gull colony's flightpath	4	1.98	17.98	9.27	0.00	102.86	0.99

[a] The + denotes an additive effect and the × denotes an interaction.

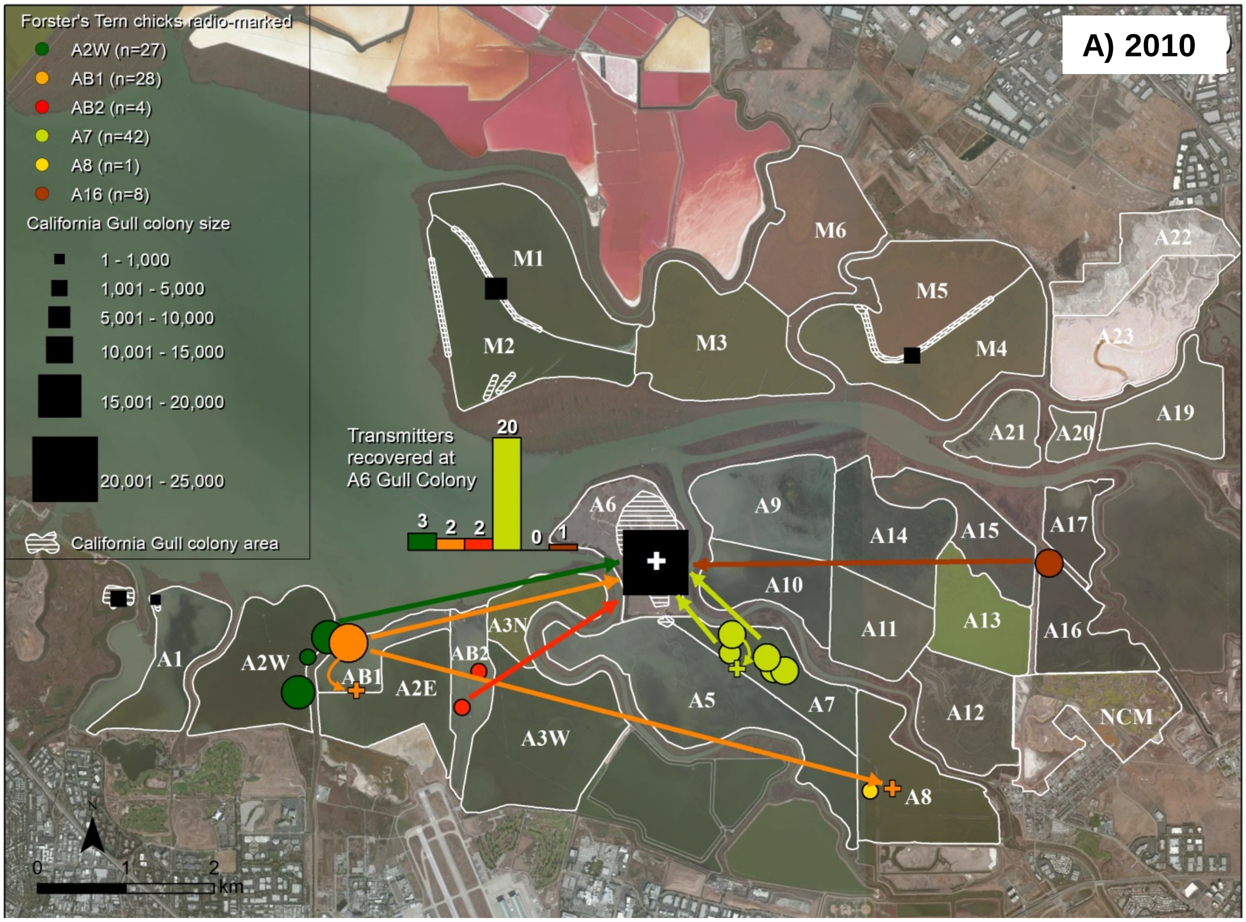
[b] The number of parameters in the model, including the intercept.

[c] Akaike's Information Criterion (AICc).

[d] The difference in the value between AICc of the current model and the value for the most parsimonious model.

[e] The likelihood of the model given the data, relative to other models in the candidate set (model weights sum to 1.0).

[f] The weight of evidence that the top model is better than the selected model, given the candidate model set.


A) 2010
Forster's Tern chicks radio-marked
A2W (n=27)
AB1 (n=28)
AB2 (n=4)
A7 (n=42)
A8 (n=1)
A16 (n=8)
California Gull colony size
1 - 1,000
1,001 - 5,000
5,001 - 10,000
10,001 - 15,000
15,001 - 20,000
20,001 - 25,000
California Gull colony area
Transmitters recovered at A6 Gull Colony
3
2
2
20
0
1
M1
M2
M3
M4
M5
M6
A1
A2W
AB1
AB2
A2E
A3N
A3W
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A19
A20
A21
A22
A23
NCM
0
1
2
km

B) 2011
Forster's Tern chicks radio-marked
A1 (n=26)
A2W (n=26)
A7 (n=19)
A8 (n=31)
California Gull colony size
1 - 1,000
1,001 - 5,000
5,000 - 10,000
10,001 - 15,000
15,001 - 20,000
20,001 - 25,000
California Gull colony area
M1
M2
M3
M4
M5
M6
A1
A2W
AB1
AB2
A2E
A3N
A3W
A5
A6
A7
A8
A9
A10
A11
A12
A13
A14
A15
A16
A17
A19
A20
A21
A22
A23
NCM
0
1
2
km

Figure 6. Forster's Tern chicks were radio-marked at their site of hatching (circles) and were recovered dead (crosses) after being depredated in South San Francisco Bay, CA in (A) 2010 and (B) 2011. Each cross represents one chick, except for the white cross in A6 in 2010 which represents the 28 chicks detailed in the histogram. The histogram indicates the number of chicks recovered at the A6 Gull colony in 2010 (histogram colors indicate site of marking). The relative size of circles indicates the number of Tern chicks that were radio-marked at each nesting site. Colors of recovery sites indicate the colony site where a chick was originally radio-marked in (A) 2010 and (B) 2011. Black squares indicate the location and population size of each California Gull nesting colony in South San Francisco Bay, CA in (A) 2010 and (B) 2011. The striped white areas denote the approximate area of each California Gull nesting colony.

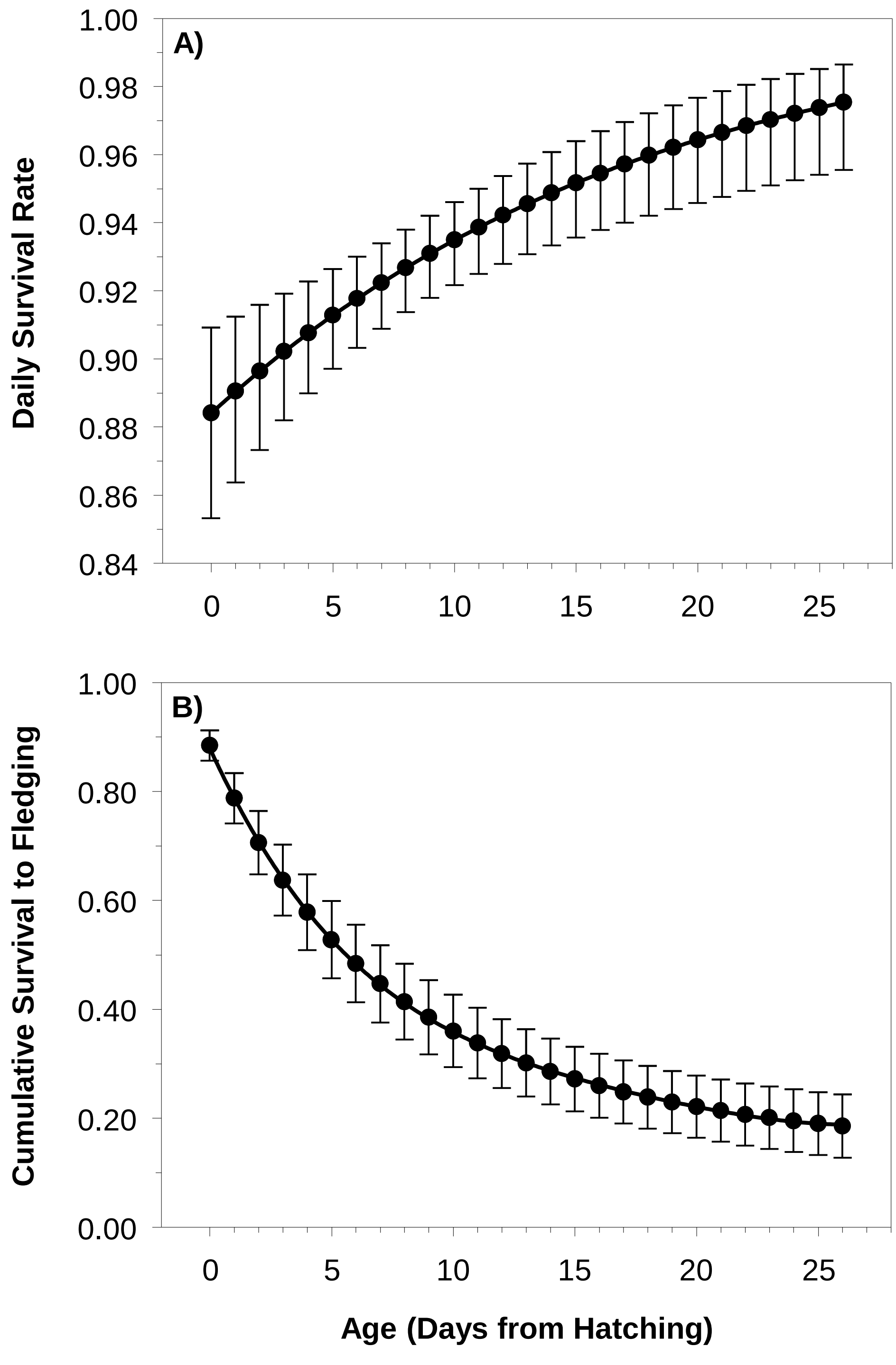


Figure 7. (A) Daily survival rate and (B) cumulative survival of 205 radio-marked Forster's Tern chicks from hatching (age=0 days) to fledging (age=26 days) in South San Francisco Bay, California. Error bars represent lower and upper 95% confidence limits.

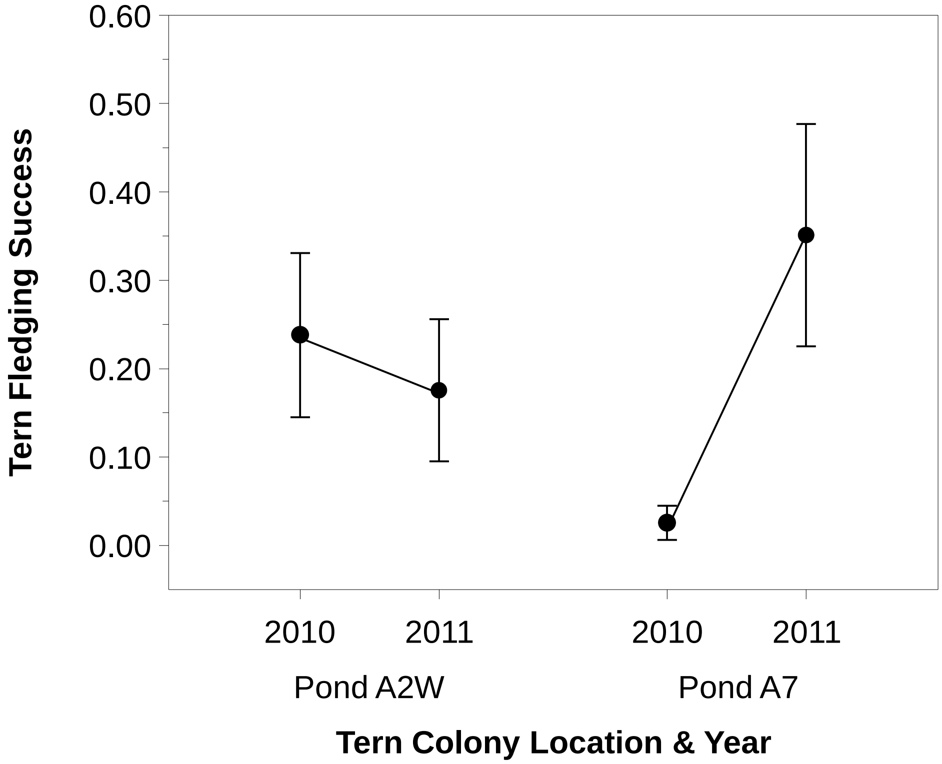


Figure 8. Survival to fledging (±standard error) of Forster’s Tern chicks radio-marked at hatching in South San Francisco Bay, California. The Pond A7 Forster’s Tern colony was located directly adjacent to the largest California Gull colony in 2010 at Pond A6, but Pond A6 was flooded in 2011 which forced the relocation of the Pond A6 California Gull colony. The Pond A2W Forster’s Tern colony acted as a reference site because it was >3.8 km away from the largest California Gull colony at Pond A6.

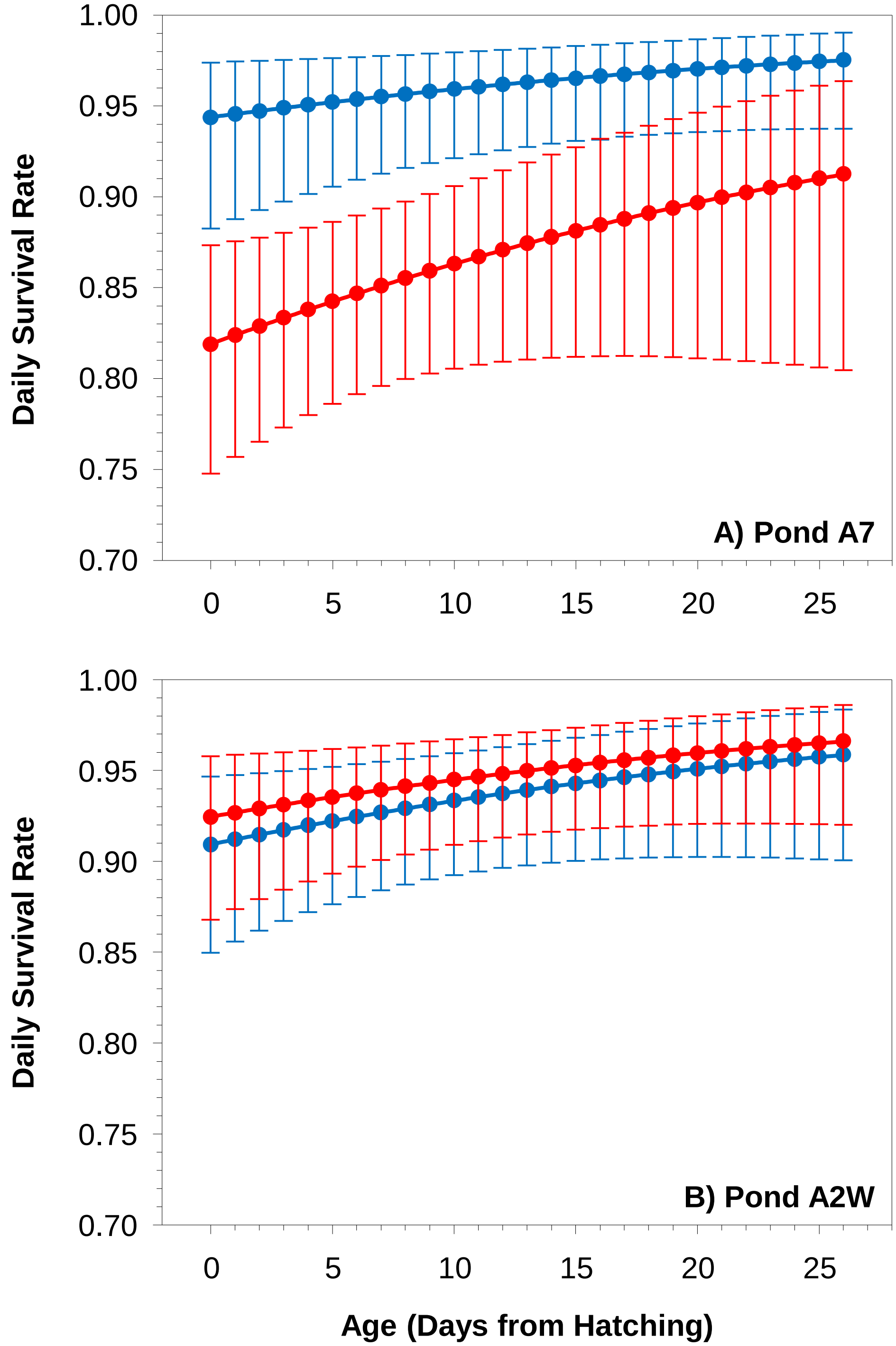


Figure 9. Daily survival rate of radio-marked Forster's Tern chicks from hatching (age=0 days) to fledging (age=26 days) in 2010 (red) and 2011 (blue) in South San Francisco Bay, California. The Pond A7 Forster's Tern colony (A) was located directly adjacent to the largest California Gull colony in 2010 but Pond A6 was flooded in 2011

which forced the relocation of the Pond A6 California Gull colony. The Pond A2W Forster's Tern colony (B) represented a reference site which was not adjacent to the largest California Gull colony at Pond A6. Error bars represent lower and upper 95% confidence limits.

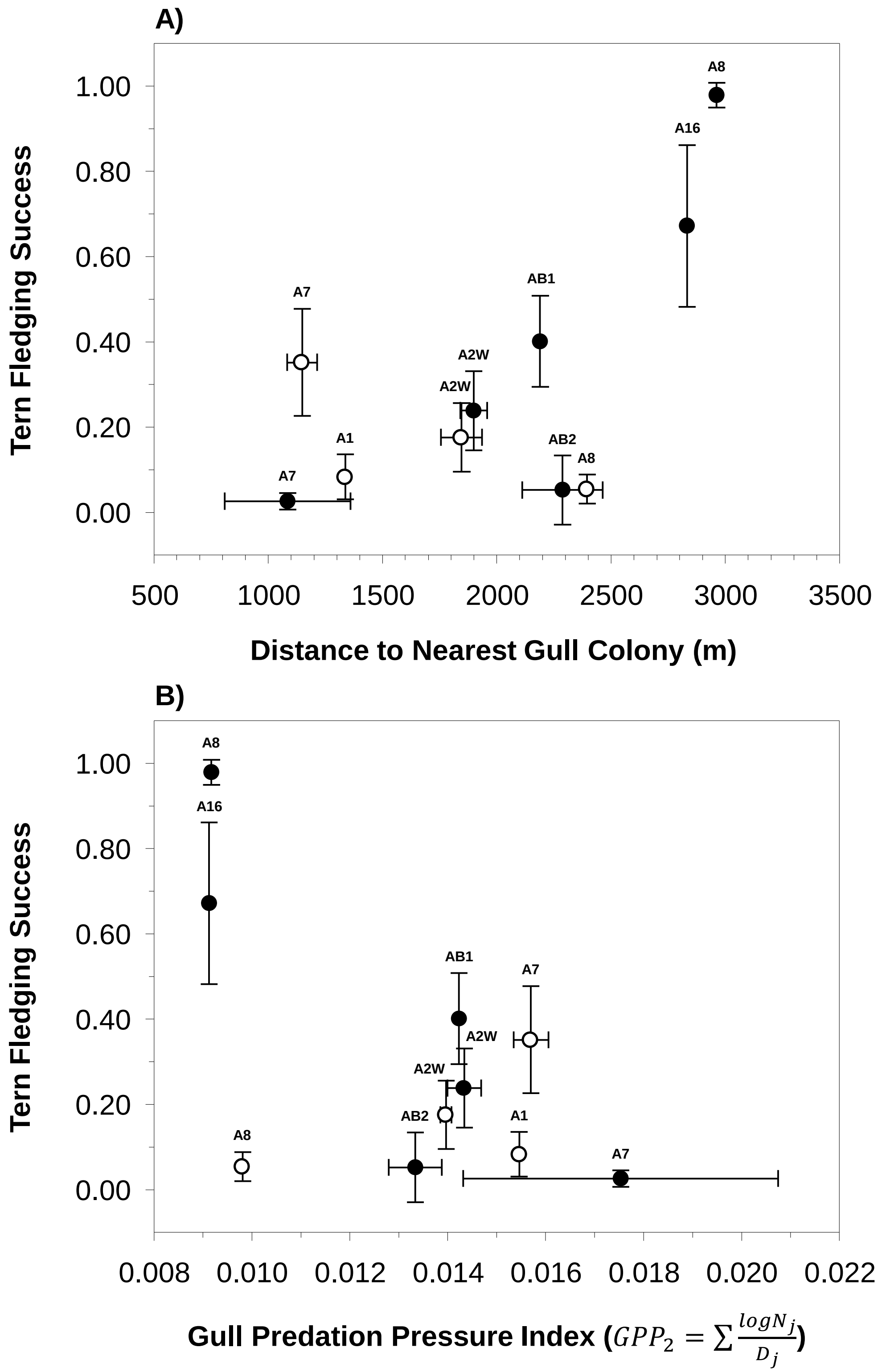


Figure 10. Survival to fledging (±standard error) of Forster's Tern chicks relative to (A) the distance to the nearest California Gull colony (±standard error) and (B) California Gull predation pressure index (±standard error)

calculated by summing all possible combinations for each Forster's Tern colony the $\log_e$ number of Gulls in a colony divided by the distance the Gull colony was located from the specific Forster's Tern colony. Forster's Tern chicks were radio-marked at six Tern colonies in 2010 (filled symbols) and four Tern colonies in 2011 (open symbols) in South San Francisco Bay, California. Forster's Tern colony locations are labeled for each pond.

Objective 2: Western Snowy Plover nest survival in relation to California Gull predation

Methods

SFBBO conducted weekly surveys of all suitable Snowy Plover nesting habitat in South San Francisco Bay throughout the entire breeding seasons of 2009-2011 (March 1 to September 15). We collected the UTM of each nest with a GPS (Garmin eTrex Venture HC) and floated eggs to determine the age of the nest (Hays and LeCroy 1971). We visited each nest once a week until there were no longer eggs in the nest, and at that point we assigned each nest a fate based on evidence seen at the nest (Mabee 1997). Nest fates were recorded as hatched, depredated, flooded, abandoned, lost at hatch, or unknown. We defined a successful nest as a nest that hatched at least one egg.

In order to determine the predators depredating Snowy Plover eggs, we placed camera systems at a subsample of nests at Eden Landing Ecological Reserve. We used security cameras (Q-See CCD QSB550SR) placed in camouflaged ammunitions boxes positioned 10 to 30 m from Snowy Plover nests (Demers and Robinson-Nilsen 2012). We used a coupled electrical and coaxial cable (300 m, directburial, RG-59 Siamese cable) to connect the cameras to marine batteries (12-V sealed, absorbed glass mat, deepcycle batteries MK 8A27, 92 AH/20 h) and a digital video recorder (DVR) unit (Archos 605 in 2009, COBRA IV in 2010 and 2011), which recorded the images collected at the nest. We stored the marine batteries and DVR units in plastic or wooden bins placed up to 300 m from the nest. The cameras were equipped with infrared to record images at night and ran 24-hrs continuously. We visited the storage bins every 2-3 days to download the data off the DVRs and changed the marine batteries twice a week. After rain storms, we were occasionally unable to access the camera systems due to poor access conditions. In those instances, we were not able to change the batteries or DVRs, and the system would temporarily fail due to lost power or reaching memory storage capacity.

To estimate daily nest survival of nests, we used a logistic exposure model (Shaffer 2004) in R (R Development Core Team 2011). We modeled daily nest survival as a function of pond site, year, nest initiation date (Julian date), the quadratic of nest initiation date, nest age at each visit, the quadratic of nest age at each visit, and camera (present or absent). We used the top ranking model to produce estimates of daily nest survival. We then estimated nest success as the product of daily nest survival over the complete life of the nest (33 days for Snowy Plover, Warriner et al 1986). In addition, we estimated overall Snowy Plover nest success using the Mayfield method for each year of the study (Mayfield 1961).

Results and Discussion

We monitored 62 Snowy Plover nests with cameras at Eden Landing Ecological Reserve during 2009 to 2011. We recorded 16 depredation events and identified six different nest predators. We recorded California Gulls depredating 6 nests, Northern Harriers (*Circus cyaneus*) depredating 3 nests, Red-tailed Hawks (*Buteo jamaicensis*) depredating 3 nests, Common Ravens (*Corvus corax*) depredating 2 nests, and a Ruddy Turnstone (*Arenaria interpres*) and gray fox (*Urocyon cinereoargenteus*) depredated one nest each (**Figure 11**).

Figure 11. Six species of predators were recorded depredating Western Snowy Plover eggs and chicks in the South San Francisco Bay, California, 2009-2011. The predators were (A) California Gull, (B) Common Raven, (C) Red-Tailed Hawk, (D) Northern Harrier, (E) Ruddy Turnstone, and (F) Gray Fox.

The top ranking model for nest success included nest age and the presence of the camera (**Table 8**). Nest survival increased as nests aged (**Figure 12**), and nests with cameras present had higher daily survival than nests without cameras until the nest reached 13 days of age (**Figure 12**). Demers and Robinson-Nilsen (2012) found no difference in nest survival between the Snowy Plover nests with cameras and the nests without cameras at Eden Landing Ecological Reserve in 2009 and 2010. However, in this analysis we included an additional year of data (2011). In 2011, we used a DVR that required downloading every 48 hours compared to the DVRs used in 2009 and 2010 which only needed to be downloaded every four days. The increased human activity may have deterred predators from the area and increased nest survival for nests with cameras. Likewise, Herring et al (2011) reported that a larger proportion of Black-necked Stilt nests monitored in the South Bay with both cameras and plasticine eggs hatched compared to nests with cameras or plasticine eggs alone, suggesting that the combination of treatments may have decreased likelihood of a predator depredating a nest. Additionally, we were limited by our USFWS 10a1A Endangered Species Take permit to keeping individual Plovers off of their nests for less than 20 minutes during camera set-up. Therefore, we placed cameras at nests that were easier to reach (i.e., did not require use of a boat). This may have biased the nests monitored by cameras and added to the difference in nest survival between camera and non-camera nests.

Using the Mayfield method to estimate nest survival, the probability that a nest survived the 33 days between nest initiation and hatching was 0.988^{33} or 0.67, 0.975^{33} or 0.44, and 0.98^{33} or 0.51 in 2009, 2010, and 2011, respectively. During the three years of this study, we recorded six California Gull depredation events at Snowy Plover nests. Although this was not a large number of recorded events, they were the most common predator recorded, and Gulls were the only predator recorded in every year. Furthermore, since the presence of cameras may have increased nest survival, the predation rate by California Gulls and other predators may be higher than our camera monitoring indicates. Overall Plover nest survival was high throughout the study, but lower in 2010 and 2011. California Gulls may be impacting the Plover nest survival more than our cameras were able to record. If the California Gull colonies at the Coyote Hills salt pond complex continue to grow, they could further impact nest survival at Plover breeding areas at Ravenswood and Eden Landing complexes.

Table 8. Model selection table for nest survival of Western Snowy Plovers at Eden Landing Ecological Reserve, Hayward, CA, 2009 – 2011.

Model	K	AIC	ΔAIC	Model Weight
camera * age	3	115536	0	092
camera * age^2	3	116016	48	008
pond + year + initiation date + camera	5	116945	1409	000
age	2	11737	1834	000
age^2	2	117612	2076	000
camera + initiation date^2	3	117833	2297	000
camera * initiation date^2	3	117867	2331	000
camera + initiation date	3	118138	2602	000
pond + year	3	118198	2662	000
camera * initiation date	3	118222	2686	000

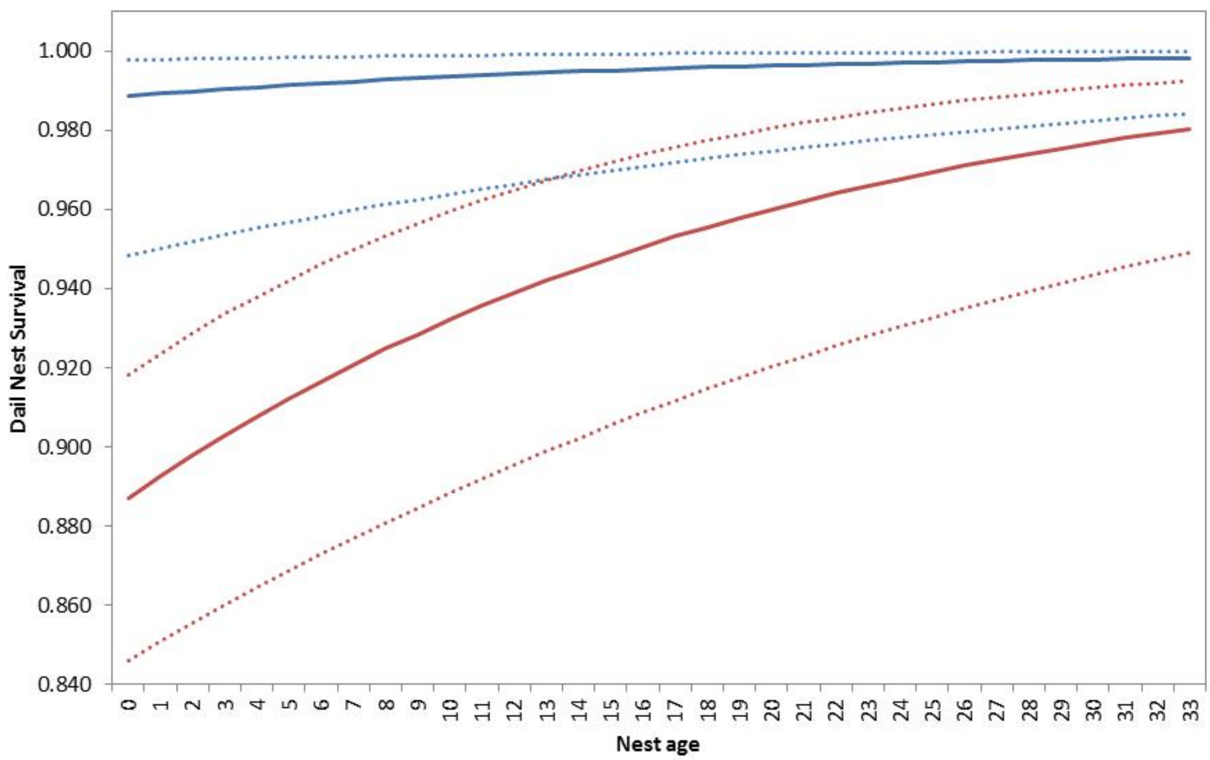


Figure 12. Daily survival rate (mean [solid lines] ± 95% CI [stippled lines]) of Western Snowy Plover nests in relation to nest age at Eden Landing Ecological Reserve, Hayward, CA, 2009 – 2011. Nests with predator cameras are in blue; nests without cameras are in red.

Objective 3: Color-mark California Gulls at Pond A6 to assess potential nesting distributions after Pond A6 was breached and flooded

Methods

In 2010, USGS and SFBBO captured and banded California Gull chicks at the Pond A6 colony prior to fledge from June 9 to June 21 (**Figure 13**). Additionally, we captured and banded breeding adult California Gulls in 2008, 2009, and 2010. To ensure that we captured and banded resident adult California Gulls breeding at the A6 colony, we trapped adult Gulls once the colony was well established (nests constructed, most nests with at least one egg) and concluded our efforts before the first chicks fledged. We captured adult Gulls using a noose mat constructed by tying nooses of 50 lbs test fishing line to a square of large-gauge chicken-wire, which we secured to the ground using garden staples. For bait, we used tortilla chips broken into small pieces. This forced the Gulls to walk over the trap to eat. Once trapped, we removed Gulls immediately and processed all Gulls within five minutes of capture. Chicks were captured by hand and processed within half an hour of capture.

Each breeding adult Gull and most chicks were affixed with a traditional USGS metal leg band, and a field-readable darvic leg band that was numbered on the lower left leg (Haggie Engraving, Crumpton, MD). In addition, chicks received leg bands that were colored yellow and had inset black numbering numbered from 2 through 548. Adults received leg bands that were colored black and had inset white numbers. Some numbers on color bands were skipped to aid re-sighting and reading of color bands in the field. We sealed the field-readable bands using brush-on superglue.

Trained SFBBO volunteers conducted banded Gull re-sighting surveys at locations known as current or former California Gull colonies (Coyote Hills ponds N2A/N3A and N6/N7; Alviso ponds A1, AB2, A6, and A14; and Palo Alto Flood Control Basin). Volunteers also conducted banded Gull re-sighting surveys throughout Eden Landing Ecological Reserve. Volunteers used spotting scopes to look for banded California Gulls, and recorded the date, time, location, and band number (if possible) of all sightings. From April to August, 2009 – 2011, volunteers conducted breeding season surveys weekly at colony sites and at Eden Landing Ecological Reserve. Volunteers conducted post-breeding surveys once per month at these sites, September to March, 2009 – 2011. Volunteers spent 30 to 120 minutes conducting each survey, and survey duration depended on the number of Gulls present. SFBBO staff also opportunistically re-sighted banded Gulls during colony walkthrough surveys (methods below).

Figure 13. California Gull chick marked with a field-readable color band in 2010 at Pond A6 in South San Francisco Bay.

Results and Discussion

Mark-Resight of California Gulls

At the breeding colony at Pond A6, we captured and banded 633 California Gull chicks in 2010 (504 were color banded), and 276 breeding adults in 2008, 222 breeding adults in 2009, and 100 breeding adults in 2010. In 2009 and 2010, we re-sighted 261 banded adult California Gulls during the breeding season (April-August) on the A6 colony (**Figures 14 and 15**). During that same period, we observed fewer than 20 banded adult Gulls at other colonies in the South Bay (**Figures 14 and 15**). After the breaching of Pond A6 in December 2010, we re-sighted 32 of the banded adult Gulls at the A14 colony that was re-established in 2011 (**Figures 16**). We also observed 15 banded adult Gulls at the Coyote Hills colonies, one banded Gull at the Pond A5 colony, and one banded Gull copulating on Pond A22 (**Figures 16**). We did not re-sight any banded California Gull chicks at South Bay colonies in 2011. We did observe one of the chicks at the Pond A14 colony during the colony walkthrough in the summer of 2012, but because of its young age, it was not yet breeding. California Gulls begin breeding in their 4th year, therefore chicks banded during this study may begin breeding at South San Francisco Bay colonies in 2014.

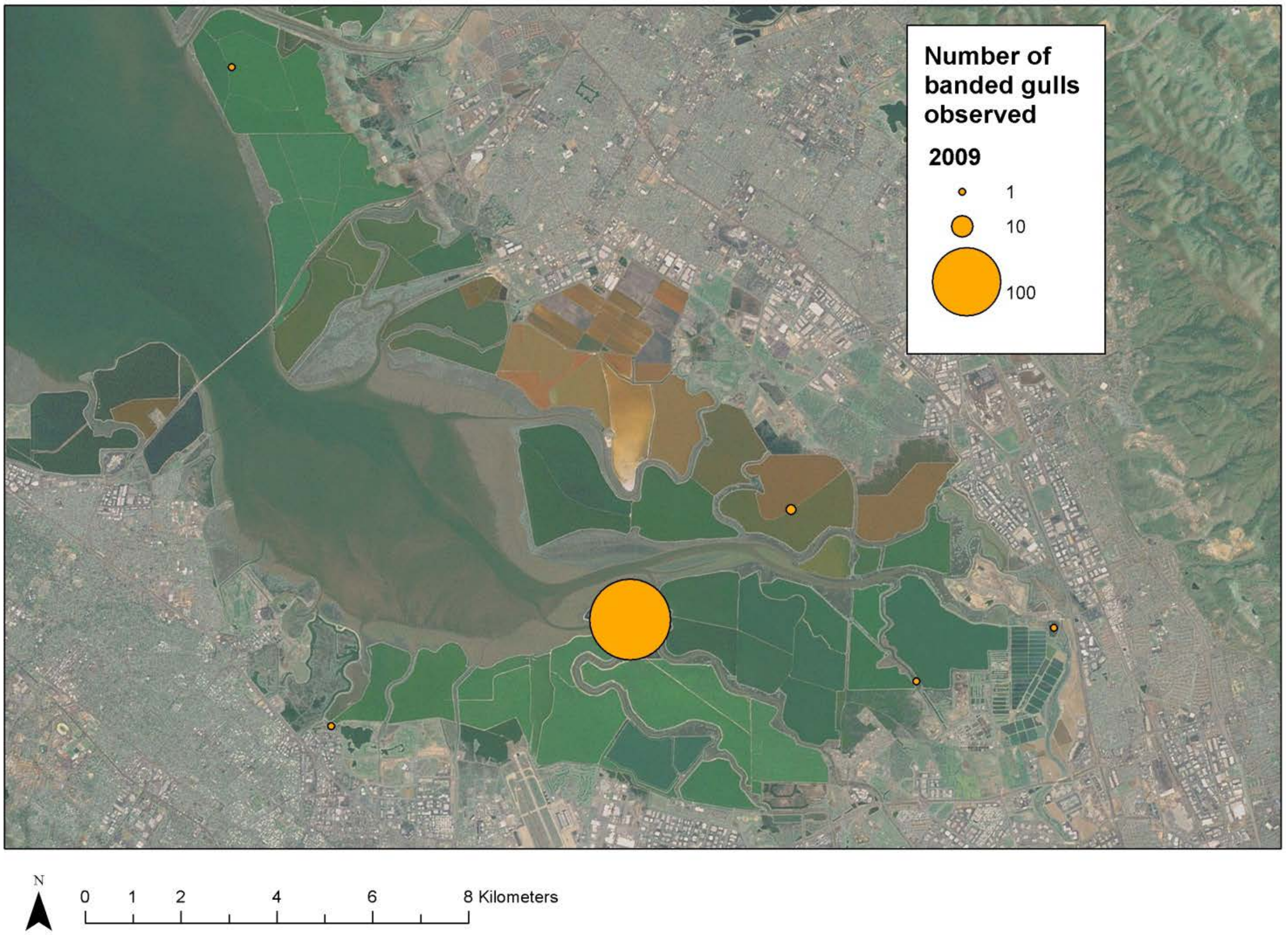


Figure 14. Abundance and location of re-sighted California Gulls in 2009 that were banded with field-readable color bands when they were breeding at the Pond A6 colony, South San Francisco Bay in 2008 (N=276) or 2009 (N=222).

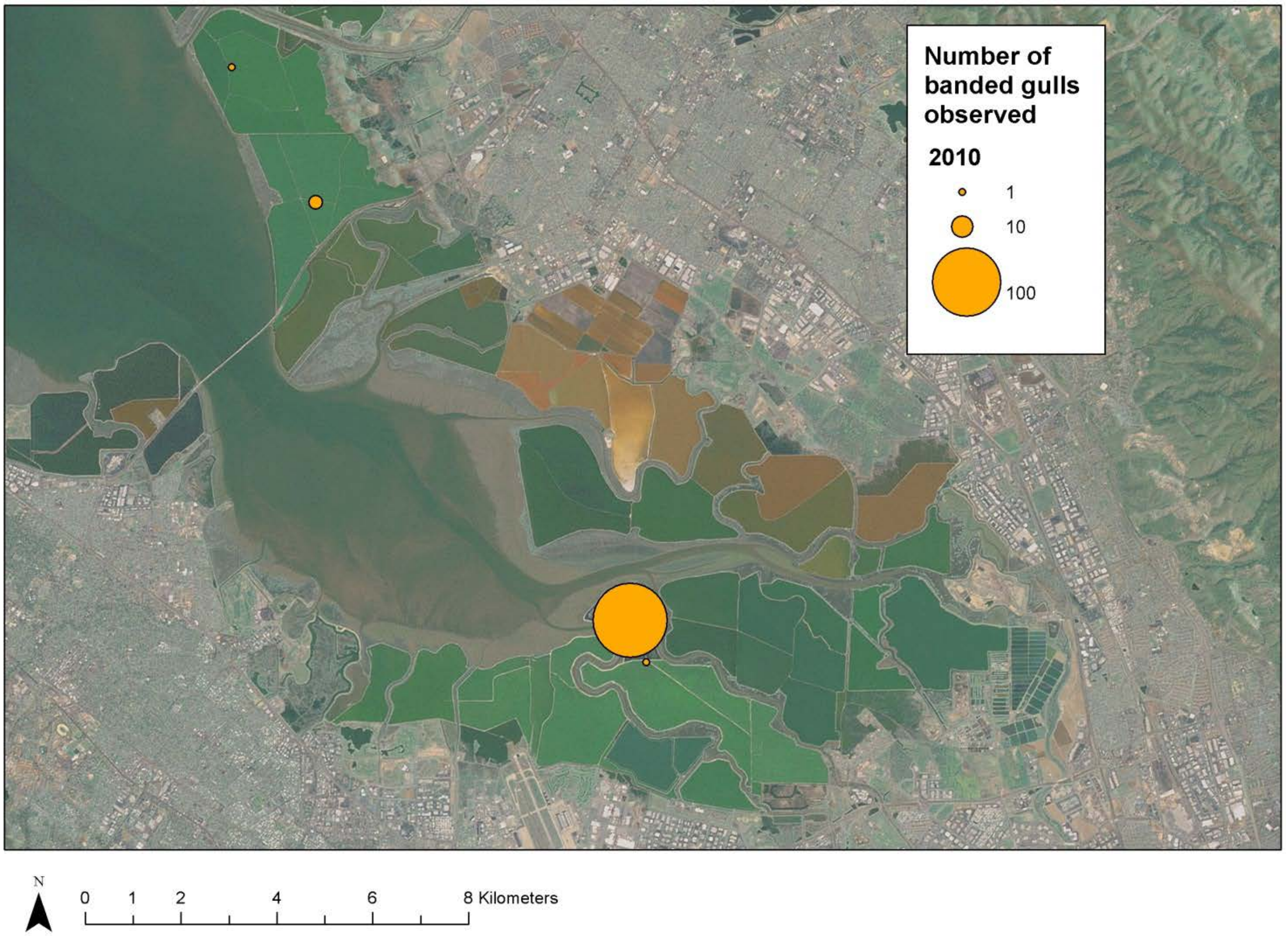


Figure 15. Abundance and location of re-sighted California Gulls in 2010 that were banded with field-readable color bands when they were breeding at the A6 colony, South San Francisco Bay in 2008 (*N*=276), 2009 (*N*=222), or 2010 (*N*=100).

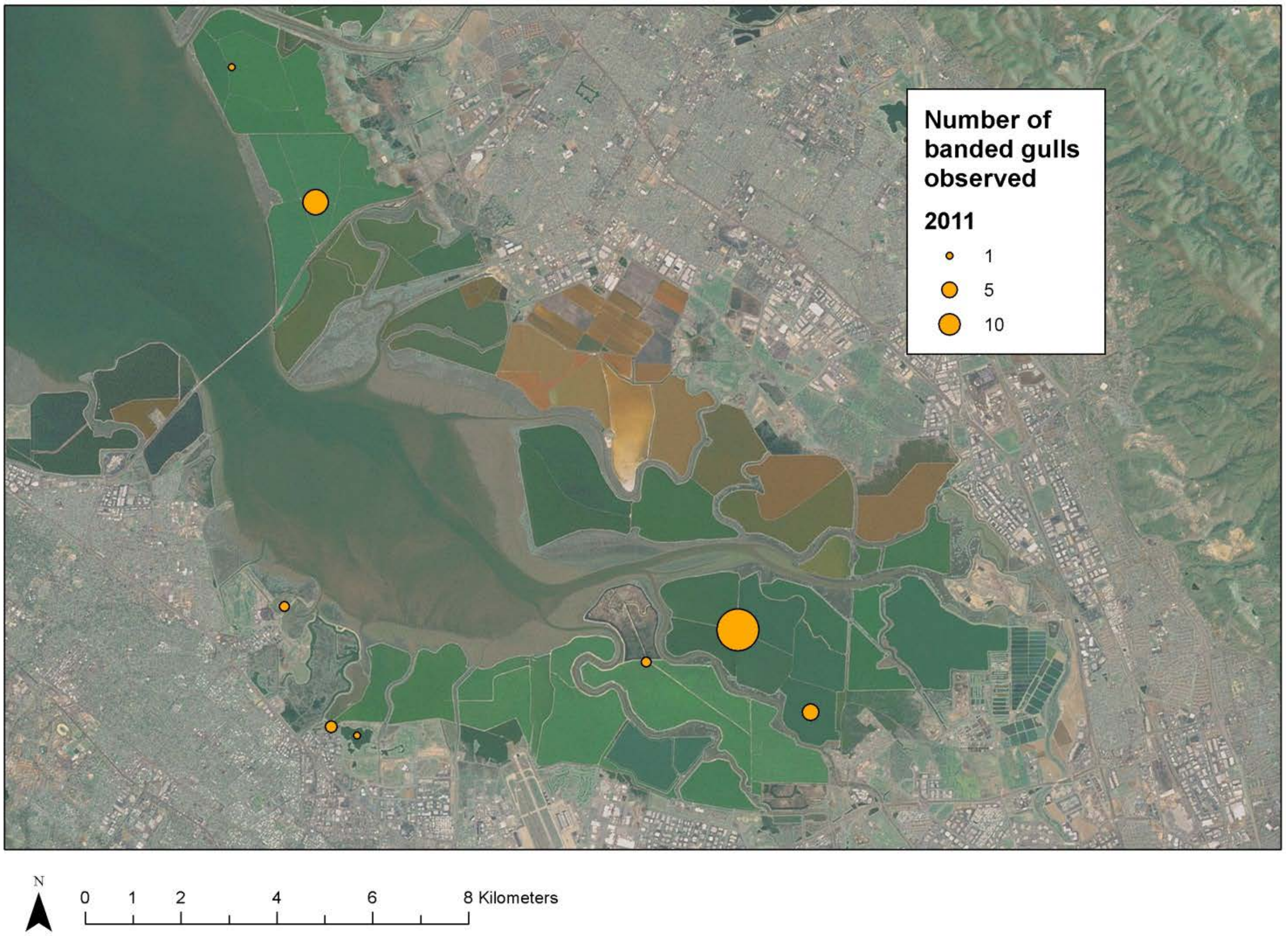


Figure 16. Abundance and location of re-sighted California Gulls in 2011 that were banded with field-readable color bands when they were breeding at the A6 colony, South San Francisco Bay in 2008 (*N*=276), 2009 (*N*=222), or 2010 (*N*=100).

California Gull Chick Growth

For the 633 California Gull chicks captured at Pond A6 in 2010, we also measured their morphology to examine chick growth patterns (**Figures 17 and 18**). We also used morphological data for adults captured in 2007 (*N*=124) and 2008 (*N*=58) from a prior adult telemetry study as comparison (Ackerman et al 2009) and added morphological data from chicks captured in 2007 (*N*=124) and 2008 (*N*=137) to increase our sample size. Morphological size measurements included mass (g), flattened wing length (mm), ninth primary feather length (mm), culmen length (mm), and short tarsus length (mm), all measured on the right side of the body.

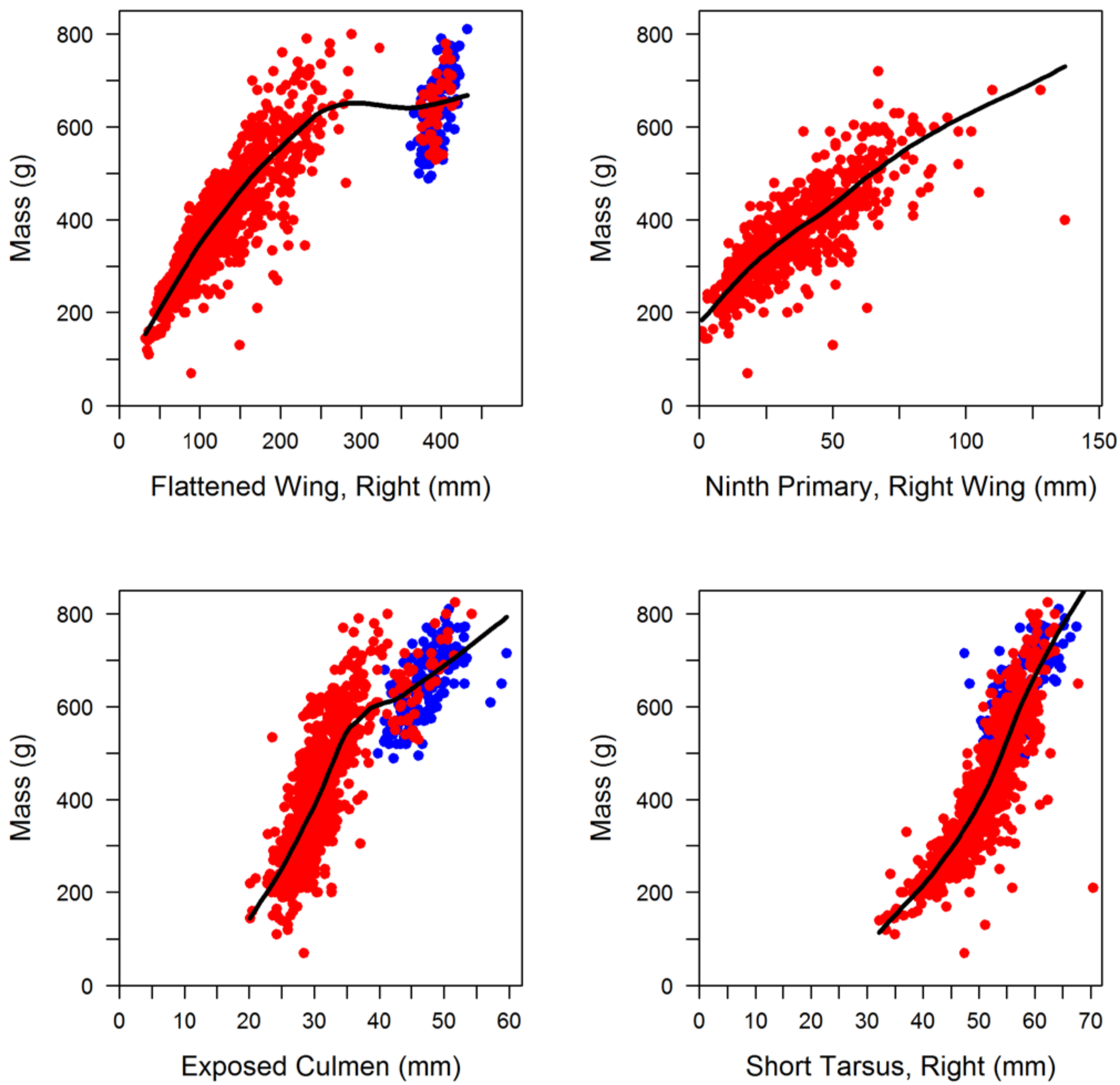


Figure 17. California Gull chick mass as they age, indexed by several structural size morphometrics. Chicks (red symbols) were captured and measured in 2007, 2008, and 2010, and adults (blue symbols) were captured and

measured in 2007 and 2008 at either the Pond A6 or Coyote Hills breeding colonies, South San Francisco Bay. Data from 2007 and 2008 from Ackerman et al. (2009a).

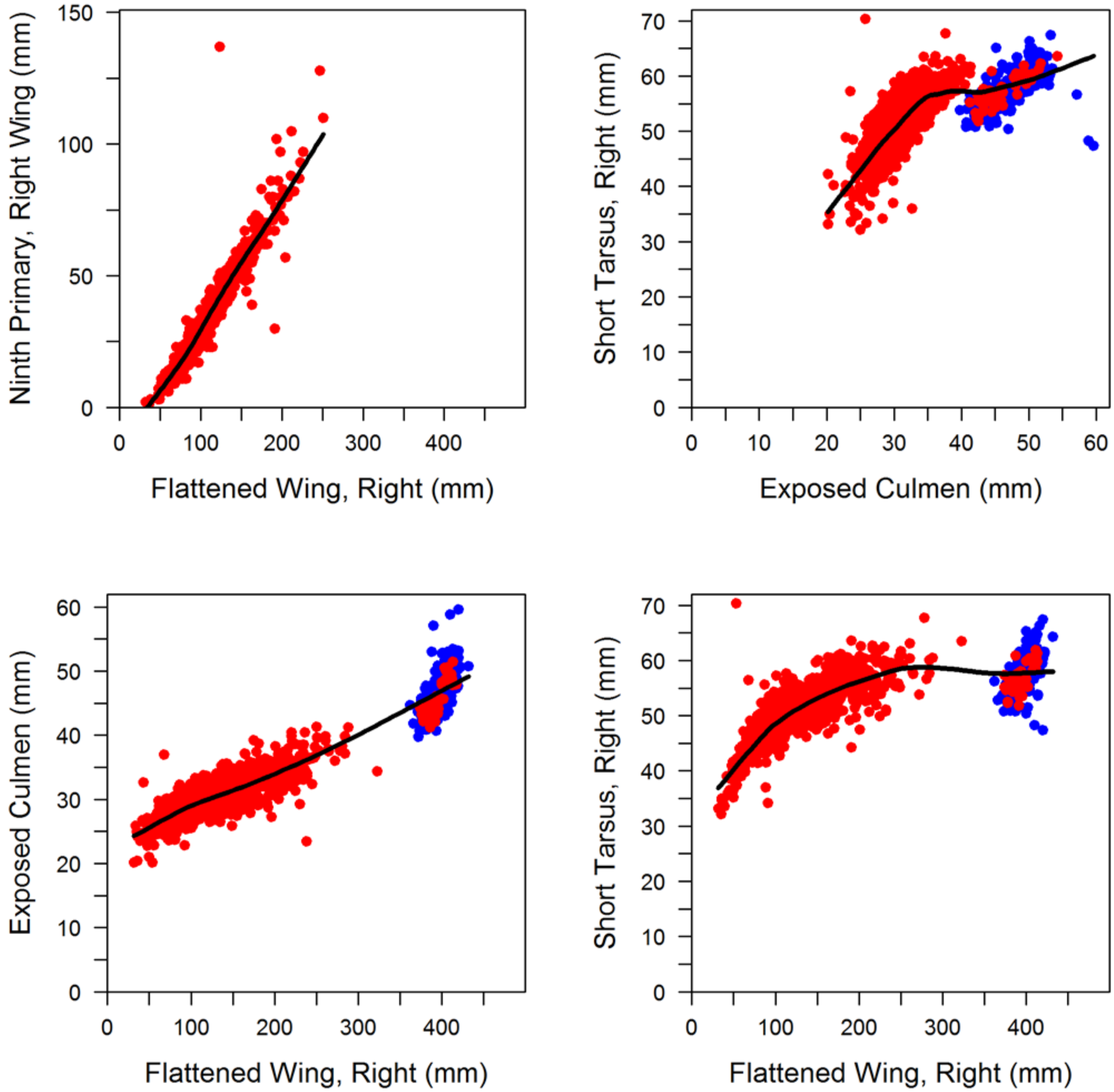


Figure 18. Relationships between several structural size morphometrics for growing California Gull chicks. Chicks (red symbols) were captured and measured in 2007, 2008, and 2010, and adults (blue symbols) were captured

and measured in 2007 and 2008 at either the A6 or Coyote Hills breeding colonies, South San Francisco Bay. Data from 2007 and 2008 from Ackerman et al. (2009a).

Objective 4: California Gull colony surveys in South San Francisco Bay to document current population size and distribution

Methods

SFBBO has conducted colony surveys of all the known California Gull colonies in the South San Francisco Bay since 1982. These surveys consisted of walking through each colony once during the peak of the breeding season and counting all the nests with eggs or chicks. We then multiplied the number of nests by two to estimate the population size for each colony. In 2008, USGS and SFBBO collaborated to divide the Pond A6 nesting area into 14 sections and to begin counting Gull nests in A6 by course habitat feature (levee, panne, raised island, near flooded channel, near dry channel, internal road, or external levee; Ackerman et al 2009). In 2009 and 2010, we continued to count the Gull nests in A6 using these modified methods. After the breach in December 2010, there was no longer a Gull colony at Pond A6, other than 156 nesting Gulls on the A5 island immediately adjacent to Pond A6. At all other colonies, we conducted colony walkthroughs from 2009 to 2011, and we counted all nests by the same course habitat features.

Results and Discussion

In 2009 and 2010, the largest California Gull colony in the South Bay continued to be at Pond A6, with 24,190 and 23,108 nesting Gulls (12,095 and 11,554 nests), respectively. After the A6 levees were breached in December 2010 for tidal restoration, no Gulls bred on A6, as the pond bottom and the islands were submerged at high tide. The largest colony in 2011 became the A14 colony, with 11,956 nesting Gulls (5,978 nests). Other South Bay colonies also increased in size in 2011, including the Palo Alto Flood Control Basin (4,478 Gulls, a 163% increase over the 2010 colony size of 1,704 breeding birds), N6/N7 (4,110 Gulls, a 64% increase over the 2010 colony size of 2,506 breeding birds), and the

M4/M5 colony (6,068 Gulls, a 27% increase over the 2010 colony size of 4,780 breeding birds) (**Figure 3**; San Francisco Bay Bird Observatory, unpublished data).

Figure 19. Abundance, location, and substrate of nesting California Gulls at Pond A6 during 2009 (left panel) and 2010 (right panel). By the 2011 nesting season, A6 had been breached to tidal action and the area was flooded and no longer available for nesting to California Gulls. See Ackerman et al (2009) for the same map for 2008 nesting season.

At the Pond A6 colony, the Gulls nested most densely in blocks 6, 8, 9, and 10 (**Figure 19**). The most dominant habitat types were panne habitat, internal road, near a flooded channel, and on raised islands. The A6 colony contained the most diverse habitat features among all of the South Bay colonies. At the A1, AB2, A5, A14, and M1/2 colonies, California Gulls nested exclusively on bare islands (**Figures 20 and 21**). The Palo Alto Flood Control Basin was in a muted tidal area, and California Gulls nested directly on islands covered with pickleweed (**Figure 22**). All other California Gull colonies in the South Bay are located on pond levees.

Figure 20. Nesting locations of California Gulls at Mowry Ponds 1/2 and 4/5, South San Francisco Bay.

Figure 21. Nesting locations of California Gulls at Alviso Ponds A9/A10/A11/A14 and A5/A7, South San Francisco Bay.

Figure 22. Nesting locations of California Gulls at the Palo Alto Flood Control Basin, South San Francisco Bay.

Management Implications

The relocation of nearly 24,000 breeding California Gulls from the Pond A6 colony site by breaching the Pond A6 levees to tidal flow in December 2010, led to the re-establishment of a nesting colony at Pond A14 in 2011. The breeding population size of California Gulls also decreased from 46,030 Gulls in 2010 to 37,716 Gulls in 2011, but rebounded to 52,172 Gulls in 2012 (SFBBO, unpublished). Therefore, only a 1-year reduction in breeding Gull abundance was observed after the flooding of the largest California Gull colony in San Francisco Bay. If Gull population reduction is a goal, our results suggest that mechanisms other than flooding colony habitat would need to be employed in the future.

California Gulls were confirmed to be the predominant predator of Forster's Tern chicks and Snowy Plover nests, and have been previously documented as the predominant predator of American Avocets and, to a lesser extent, Black-necked Stilts chicks (Ackerman et al. 2006b). Although California Gulls depredated several Snowy Plover nests, Snowy Plover nest survival was still very high (44-67%) for a ground-nesting shorebird. In contrast, Forster's Tern chick survival was low (19%) for a predominantly island-nesting species. Therefore, predation by California Gulls on breeding waterbirds appears to be more focused on colonial island-nesting species, particularly Forster's Terns and American Avocets, which typically are concentrated at high-nesting densities on islands that have very little vegetative cover to conceal eggs and chicks from aerial predators.

The relocation of the Pond A6 California Gull colony caused Forster's Tern chick fledging success at nearby Pond A7 to increase dramatically from 3% to 35%. Additionally, among all Tern colonies in 2010 and 2011, having fewer Gulls at nearby colonies or having Gull colonies further away from Tern colonies improved Tern fledging success. Thus, minimizing Gull numbers at nearby colonies and maximizing Gull colony distance from Tern colonies may enhance Tern, and possibly other waterbirds, chick fledging success. Our results suggest that improving nesting opportunities for breeding waterbirds by creating or enhancing islands suitable for nesting at multiple ponds located throughout the South Bay should enhance waterbird productivity. In addition to providing widespread nesting opportunities for waterbirds, this also would provide waterbirds with greater opportunity to adapt to changing Gull predation pressure by colonizing alternate nesting islands away from Gull colonies. In contrast to the construction of nesting islands in only a few locations, construction of nesting islands in multiple locations would distribute the risk of waterbird breeding colony failures. Currently, the two largest pond enhancement projects by the SBSP Restoration Project have created 30 nesting islands in the same pond at Pond SF2, and 20 nesting islands in the same pond at Pond A16. The islands at Pond SF2, after an initial strong year of nesting attempts by American Avocet, have been used very little by nesting waterbirds in the last two years (193 birds nested in the year [2011] following island creation, but then 68 nested in 2012 and only 24 nested in 2013; Ackerman, unpublished data). This information, combined with our current study's results, suggests that distributing island enhancement projects at a greater number of ponds throughout the three pond complexes in the South Bay may be more effective at increasing nesting opportunities and improving breeding success for waterbirds than creating many islands within a few ponds.

Individual California Gulls appeared to specialize on depredating Forster's Tern chicks. These results indicate that it might be possible to improve waterbird breeding success by focusing management specifically on these specialist Gulls through culling, or other means of control, as other studies on Gulls have documented (Hario 1994, Guillemette and Brousseau 2001, Riensche et al. 2012). In contrast, removing large populations of Gulls had limited success for improving waterbird populations (Harris and Wanless 1997). It is unclear if such practices would be feasible and effective over the long-term. Before such a practice was instituted, additional studies specific to this type of management practice would be warranted. Furthermore, little is known about the breeding success of the California Gull population and whether their continued population increase in South San Francisco Bay is due to local recruitment or immigration, and we suggest direct study of breeding success (nest and chick survival) of California Gulls in order to more effectively inform management options for controlling their population.

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