California Gull Distribution, Abundance, and Predation on Waterbird Eggs and Chicks in South San Francisco Bay

Final Report

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EXECUTIVE SUMMARY

Problem Statement

- California Gull populations have increased by more than 33-fold over the past two decades in the South San Francisco Bay, from less than 1,000 breeding birds in 1982 to over 33,000 in 2006.

- The exponential growth in California Gull populations may have negative effects on ground-nesting birds because they are voracious predators and directly impact native breeding waterbirds by depredating eggs and chicks as well as displacing nesting colonies from preferred breeding sites.

- The South Bay Salt Pond Restoration Project is initiating plans to restore 16,000 acres of salt ponds into tidal marsh. It may cause some of the 33,000 breeding gulls to move to new nesting sites and negatively affect current populations of ground-nesting waterbirds.

Study Objectives

- In this initial study, we examined the distribution and abundance of California Gulls throughout the South Bay salt ponds and associated landfills and determined their impact on the reproductive success of American Avocets and Black-necked Stilts.

Study Results

Objective 1. Determine the current nesting and foraging distributions of California Gulls throughout the South Bay salt ponds and associated landfills, and the proximity of gull colonies to current and historic Caspian Tern and Forster's Tern breeding colonies.

- We surveyed gull distribution and abundance from January 2002 to August 2006 in the South Bay salt ponds and from April 2006 to August 2006 in adjacent landfills. We also mapped the relative abundance and location of current and historic California Gull, Forster's Tern, and Caspian Tern colonies using 25 years of nesting data.

- Gulls were most abundant in the Alviso salt pond complex, followed by Mowry, Newark, Eden Landing, and Ravenswood salt ponds.

- California gulls were the most common gull species, especially during the breeding season, and they are the only gull species that breeds in the South Bay.

- The largest California Gull colony was in the A6 or Knapp salt pond (19,456 adults), followed by the Coyote Hills colony (7,442), Mowry 4&5 colony (5,068), A1 colony (380), Moffet B2 colony (374), A9&10 colony (234), and the new A5 colony (84).

- Other gull species, such as Herring Gulls, Ring-billed Gulls, and Western Gulls, were mostly absent during the breeding season but were relatively abundant within the salt ponds during the winter when California Gulls were less numerous.

- Gulls frequented several local landfills around the South Bay refuge and the average abundance of California Gulls counted during surveys was 3,877 at San Jose's Newby Island landfill, 1,738 at Fremont's Tri-Cities landfill, and 49 at Palo Alto's landfill.

- California Gulls were the most common gull species using landfills from April through August, comprising 98% of the gulls observed, followed by Glaucous-winged Gulls (1%).

- California Gulls' use of landfills declined throughout the breeding season from 8,837 in April to 2,411 in August, indicating decreased reliance on landfills as a food resource and likely increased reliance on more natural prey (like Avocet chicks, see below) as the chick-rearing period progressed (late May through July).

- Whereas California Gull populations (currently 33,038) have rapidly increased over the past two decades, Caspian Tern (157) and Forster's Tern (1,982) populations have declined significantly in the South San Francisco Bay.

Objective 2. Examine the impact of gull predation on nesting success of American Avocets and Black-necked Stilts.

- In 2005 and 2006, we monitored 1,007 Avocet, 552 Stilt, and 1,298 Forster's Tern nests.

- Nest success was highly variable among sites, years, and species. In general, Forster's Terns had higher nest success than Avocets and Stilts in sites where they co-occurred.

- Reduced nest success was primarily caused by egg depredation. In the majority of cases (51% in Avocets, 61% in Stilts, and 71% in Forster's Terns), eggs simply went missing during a depredation event, with no eggshell evidence remaining, indicating potential depredation by gulls and foxes.

- We identified egg predators using remotely triggered infra-red video cameras and fake (plasticine) eggs placed within nests.

- Camera data indicated that 15% of Avocet nests were depredated by California Gulls, but several other predators also depredated eggs including Red-tailed Hawks (23%), Gray Foxes (15%), Rats (15%), Striped Skunks (8%), Raccoons (8%), Opossums (8%), and Common Ravens (8%). Stilt nests were depredated by Striped Skunks (40%), Raccoons (40%), and Gray Foxes (20%).

- Fake egg data indicated a minimum of 14% (2006) to 29% (2005) of Avocet nest depredations were caused by avian predators, but a large proportion of these eggs simply went missing (57% in 2005 and 14% in 2006) indicating likely depredation by gulls or foxes carrying eggs away from nests.

Objective 3. Quantify effects of gull predation on American Avocets and Black-necked Stilts by estimating chick survival with radio telemetry.

- We determined survival and predators of shorebird chicks by radio-marking and tracking

161 Avocet (74 in 2005 and 87 in 2006) and 79 Stilt (33 in 2005 and 46 in 2006) chicks at several sites.

- Stilt chicks had higher survival rates to fledging (32% in 2005 and 56% in 2006) than Avocet chicks (14% in 2005 and 5% in 2006) during each year of the study, due to high rates of aerial predation on Avocet chicks by California Gulls.

- California Gulls depredated at least 61% of Avocet chicks and 23% of Stilt chicks.

- During 2005 and 2006, we found 50 radio transmitters that had been attached to Avocet or Stilt chicks within the A6 California Gull colony (estimated at 19,456 gulls) and 10 Avocet radio transmitters within the Coyote Hills gull colony (estimated at 7,442 gulls). We even found a transmitter within the A6 gull colony that had been attached to an Avocet chick within the Newark ponds – a distance of over 10 km. This indicates that gulls were carrying depredated chicks long-distances back to colonies to feed their young.

Conclusions and Management Implications

- We documented that California Gulls are abundant throughout the South San Francisco Bay salt ponds and adjacent landfills, especially during the breeding season, and are an important predator of shorebird eggs and the major predator of Avocet chicks.

- The South Bay Salt Pond Restoration Project may negatively affect ground-nesting birds by displacing gull colonies from current nesting sites. For example, plans to breach the A6 (Knapp) salt pond in 2008 will displace more than 19,000 gulls currently breeding at this site. It is likely that the majority of these gulls will move to nearby nesting islands, such as in A7, A8, and A16, displacing other breeding waterbirds – a serious concern considering that these sites currently support the largest breeding populations of Avocets and Caspian Terns, and many of the largest breeding colonies of Forster's Terns and Snowy Plovers, in the South San Francisco Bay.

- The planned A6 breach may be used as a learning opportunity to understand how gulls will disperse from former nesting colonies and the consequences for other breeding waterbirds. Documenting gull movement with radio telemetry and altered predation rates on waterbird eggs and chicks would provide insight into potential effects.

CALIFORNIA GULL DISTRIBUTION, ABUNDANCE, AND PREDATION ON WATERBIRD EGGS AND CHICKS IN SOUTH SAN FRANCISCO BAY

Final Report

By Josh T. Ackerman, John Y. Takekawa, Cheryl Strong, Nicole Athearn, and Angela Rex

INTRODUCTION

The San Francisco Bay is the most highly urbanized estuary on the Pacific coast (Nichols et al. 1986). More than 8 million people inhabit the region, yet it still supports highly diverse, natural communities of wildlife. These include large populations of ground-nesting birds consisting of American Avocets, Black-necked Stilts, Forster's Terns, and Caspian Terns, and listed species such as Snowy Plovers, California Clapper Rails, and California Least Terns. Many of these species nest on levees and islands in the South Bay created for commercial salt evaporation ponds, now a habitat feature of the estuary for more than a century. The salt ponds support unique assemblages of invertebrates and fishes, provide refuge and foraging habitat for hundreds of thousands of migrating and wintering shorebirds and waterfowl, and provide nesting habitat for many species (Takekawa 2001a,b). Since the government's acquisition of most of the salt ponds in 2003, a goal for the region under the South Bay Salt Pond Restoration Project has been to provide a diversity of habitats to support and enhance existing populations.

However, another ground-nesting bird, the California Gull, has increased by 33 fold over the past two decades in the San Francisco Bay, from less than 1,000 breeding birds in 1982 to over 33,000 in 2006 (Strong et al. 2004; 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). Their exponential increase in the San Francisco Bay may be

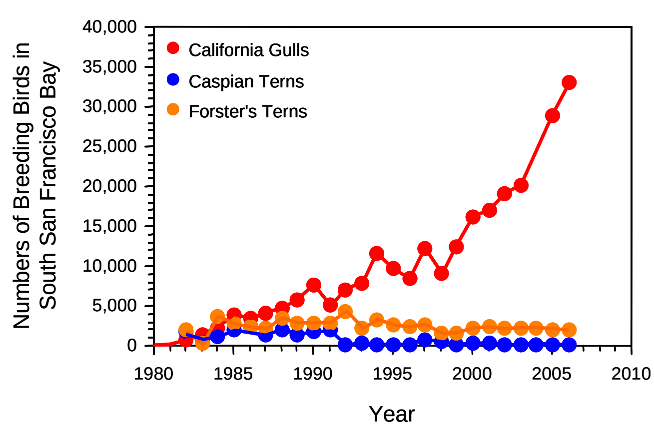

Figure 1. California Gull breeding populations in the South San Francisco Bay have increased rapidly overly the past two decades while Caspian Tern and Forster's Tern populations have declined. Data from Strong et al. 2004 and San Francisco Bay Bird Observatory.

closely related to use of landfills and other anthropogenic sources of food, as there are at least 3 landfills within short flight distance of the main breeding colonies.

The exponential growth in California Gull populations may have negative effects on ground-nesting birds. California Gulls are voracious predators and directly impact native breeding waterbirds by depredating eggs and chicks as well as displacing nesting colonies from preferred sites. The South Bay Salt Pond Restoration Project is initiating plans to restore 16,000 acres of salt ponds into tidal marsh or other habitats, and may cause a portion of the 33,000 breeding gulls to move to new nesting sites, displacing other breeding waterbirds and potentially increasing predation rates.

In the South Bay, the U. S. Fish and Wildlife Service has the responsibility of managing the South Bay Salt Pond Restoration Project, as well as supporting ground-nesting migratory bird species and populations along the Pacific coast, including Caspian Terns relocated under the Caspian Tern Management Plan and Environmental Impact Statement. In San Francisco Bay, Caspian Terns are suspected to be limited by availability of suitable sites for breeding colonies, and their nesting success is adversely influenced via displacement by other waterbirds. However, efforts to support populations of ground-nesting birds may fail if increased predation and displacement by the growing gull population outpaces restoration efforts.

OBJECTIVES

We examined the distribution and abundance of California Gulls throughout the South Bay salt ponds and associated landfills, and determined their impact on breeding American Avocets and Black-necked Stilts. Specifically, our objectives were to:

1. Determine the current nesting and foraging distributions of California Gulls throughout the South Bay salt ponds and associated landfills, and the proximity of gull colonies to current and historic Caspian Tern and Forster's Tern breeding colonies.

2. Examine the impact of gull predation on nesting success of American Avocets and Black-necked Stilts.

3. Quantify effects of gull predation on American Avocets and Black-necked Stilts by estimating chick survival with radio telemetry.

STUDY AREA

The primary intensive study area was the Alviso salt pond complex at the Don Edwards San Francisco Bay National Wildlife Refuge and surrounding landfills (Figure 1). Additional sites south of the Dumbarton Bridge also were surveyed for gull presence. Primary sites for American Avocet and Black-necked Stilt nesting and chick studies were ponds A8, A16, New Chicago Marsh, and Newark 4&5. Gull surveys occurred throughout the Alviso salt pond complex, including primary nesting sites in ponds A6, Coyote Hills, Mowry, A1, B2, A9&10, and A5, and landfill foraging sites at San Jose's Newby Island, Fremont's Tri-Cities, and the City of Palo Alto.

METHODS

Objective 1. Determine the current nesting and foraging distributions of California Gulls throughout the South Bay salt ponds and associated land fills, and determine proximity of gull colonies to current and historic Caspian Tern and Forster's Tern breeding colonies.

Salt Pond Surveys for Gulls

We surveyed gull distribution and abundance once monthly throughout the year at several salt pond complexes (Figure 2). We conducted surveys from October 2002 to August 2006 in the Alviso and Eden Landing salt pond complexes, from November 2002 to August 2006 in the Ravenswood salt pond complex, and from September 2005 to August 2006 in the Newark and Mowry salt pond complexes. Salt pond surveys were conducted following existing protocols (Takekawa et al. 2001a,b). To facilitate spatial analysis of gull distribution and abundance, each salt pond was divided into 250 m x 250 m grids based on Universal Transverse Mercator (UTM) coordinates. Using spotting scopes and binoculars, we identified gulls to species, enumerated gulls with behavioral activity (feeding, roosting, or nesting), and assigned gulls to the geographic grid in which they were observed using natural landmarks. In most cases, gulls were identified to species but in some cases we pooled gulls into an unidentified gull category. Gull distribution and densities were mapped using ArcView GIS (ESRI 1996).

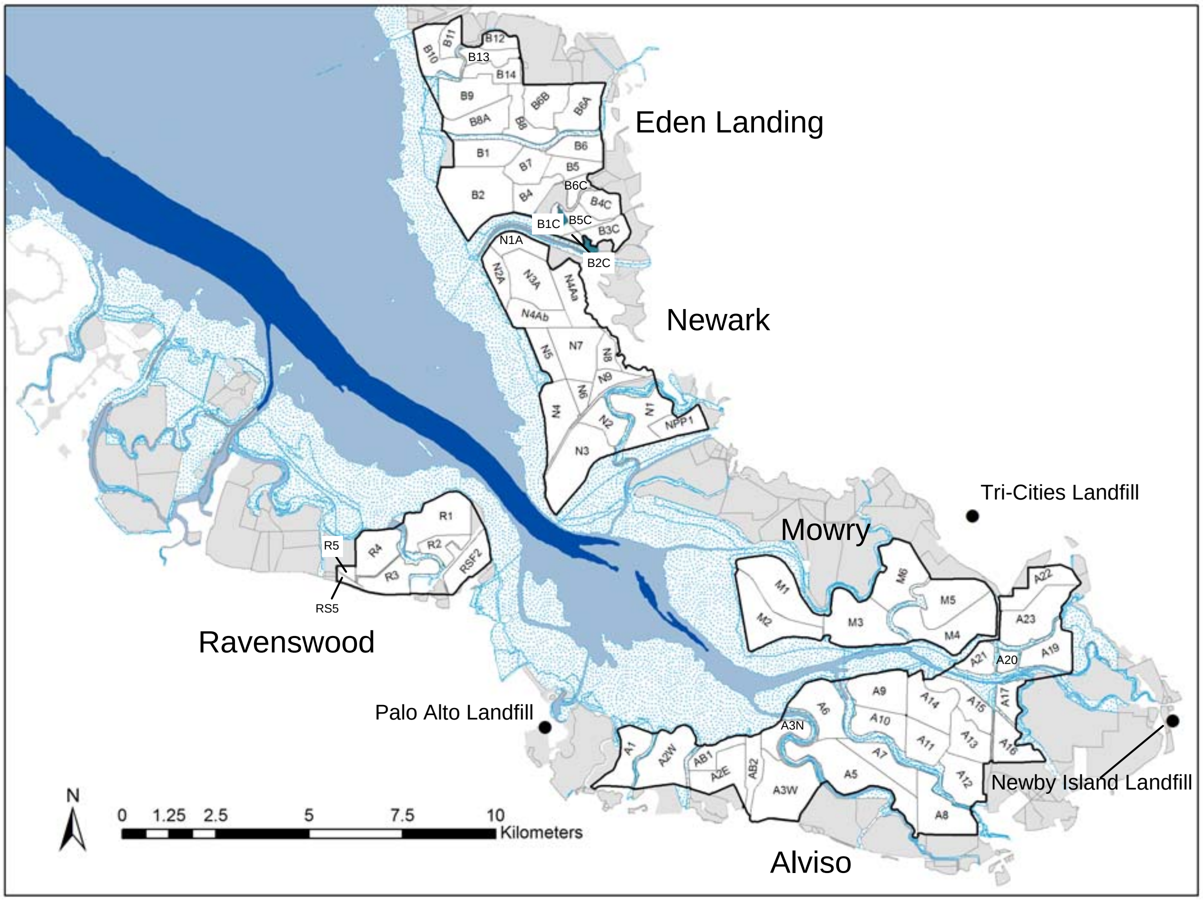

Figure 2. Study area map of the South San Francisco Bay depicting salt pond complex names, pond numbers, and landfill locations.

Landfill Surveys for Gulls

We surveyed landfills adjacent to the Don Edwards San Francisco Bay National Wildlife Refuge for California Gulls, including San Jose's Newby Island landfill, Fremont's Tri-Cities landfill, and the City of Palo Alto's landfill. We used spotting scopes and binoculars to identify and count gulls. Landfill surveys occurred while either overlooking the landfill (Newby Island) or directly adjacent to the active face (Tri-Cities and Palo Alto). Surveys were performed monthly from April to August 2006. Observations were conducted by one or two individuals each month on randomly selected days. Gulls were counted in 3 categories: 1) exposed refuse, 2) partially covered refuse, and 3) non-refuse areas. Gull counts were conducted twice each survey day at one hour intervals and then averaged.

At the beginning of each hour, we used binoculars to identify a group of known size. We estimated the total number of gulls and the number of gulls in each of the 3 categories by counting the number of groups of the known size and multiplying by the group's size. This method was employed at landfills with large numbers of gulls (Newby Island and Tri-Cities). We included only those gulls within 30 m of the ground in counts, therefore counts are minimum estimates.

Breeding Colony Surveys for Gulls

The San Francisco Bay Bird Observatory has surveyed most of the known Forster's Tern, Caspian Tern, and California Gull colonies in the Bay since 1982. A colony was defined as a location used by pairs of nesting larids. Colony censuses were conducted during five four-day periods each year. Survey periods coincided roughly with courtship, egg laying, incubation, chick rearing, and fledging. In addition, we quantified the number of birds nesting at some colonies by entering the colony and counting all nests with eggs or chicks. Although this method provides an accurate count, it was employed infrequently to avoid disturbance. For estimates of colony size, we multiplied nest counts by two, rounded adult counts to the next even number, and used either the adult count or twice the nest count, whichever number was greater, as the colony size estimate.

Objective2. Examine the impact of gull predation on nesting success of American Avocet and Black-necked Stilts.

Waterbird Nest Success

We conducted weekly searches at several salt ponds and marshes for Avocet, Stilts, and Forster's Tern nests. We initiated nest searches in late March and continued through July to ensure finding both early-nesting and late-nesting birds. We marked each nest with a 30 cm colored and numbered pin flag stake that was placed 2-m north of the nest bowl and we also marked the nest with a metal tag placed at the nest bowl. We revisited each nest once every seven days, the stage of embryo development was determined by floating (modified from Hays and LeCroy 1971), and clutch size and nest fate (hatched, destroyed, or abandoned) was recorded. We considered a nest to be successful if at least one egg hatched (as determined from eggshell remains; Ackerman

2002). We calculated nest success for each pond and species using Mayfield (1961, 1975) techniques.

Egg Predator Identification

We identified predators of nests by using fake eggs made of plasticine (clay) and remote infra-red video cameras. We randomly removed one real egg during early incubation (<7 days old) and replaced it with a fake egg. Fake eggs were shaped to resemble either an Avocet or Stilt egg, were dyed with tea to a dull brown color, and were spotted with permanent markers to resemble real eggs (Ackerman et al. 2004a). During each subsequent visit, we determined whether the nest was depredated and, if so, we removed the fake egg and examined it for tooth or beak marks and classified the predator as either mammalian or avian.

As a more refined method for identifying actual predators of eggs, we also placed remotely triggered infra-red video cameras on a smaller number of nests in salt ponds A8, A16, and New Chicago Marsh. Remote cameras (Bushnell Trail Scout 3.0, Bushnell, Overland Park, Kansas, USA) were placed near Avocet and Stilt nests early in incubation (<7 days old) and were checked twice each week to replace batteries and download images. We identified the predator responsible for the destroyed eggs at each nest where we placed a camera by reviewing the video footage. We documented predator species and quantified predation events to determine the main predators of shorebird eggs.

Objective 3. Quantify effects of gull predation on American Avocets and Black-necked Stilts by estimating chick survival with radio telemetry.

Radio-marking Chicks

We hand-captured Avocet and Stilt chicks within a few days of hatching at nests under observation at A8, A16, New Chicago Marsh, Coyote Creek Lagoon, Newark 4A and 8&9, AB1, and A7 salt ponds in the South San Francisco Bay. We randomly selected chicks for radio-marking if there were >1 hatched chick or >1 chick in a clutch. We weighed chicks with a spring scale (±1.0 g with a 100-g Pesola® spring scale, Pesola Ag, Baar, Switzerland), and we measured exposed culmen length, culmen tip to nares length, and short tarsus length with digital calipers (±0.01 mm with Fowler® electronic digital calipers, Newton, Massachusetts, USA) and flattened wing chord length with a wing board (±1.0 mm). We collected UTM coordinates for each capture location (Garmin® GPS 72, Garmin International Inc., Olathe, Kansas, USA).

We attached small radio transmitters containing thermistor switches (Model BD-2T, Holohil Systems Ltd., Carp, Ontario, Canada) to the dorsal midline of chicks with sutures (Ethicon® Vicryl FS-2, 3-0, Ethicon Inc., Piscataway, New Jersey, USA) through front and rear channels and a third suture was tied in the middle and over the top of the transmitter. We left the front and rear sutures loose (about a pea-sized loop) so that the chick could grow without pulling the suture material out of their skin. We tied the third suture over the top of the transmitter and pulled it tight to hold the transmitter in place while the chick was still young. We tied each suture with 2–3 knots and secured it with super-glue (Loctite 422, Henkel Corp., Rocky Hill, Connecticut, USA). We used very small transmitters to reduce the potential for transmitter effects on behavior or survival (Ackerman et al. 2004b). Transmitters weighed 1.1 g for Avocets and 0.8 g for Stilts (<6% of chick body mass), were 19 mm long × 7 mm wide for Avocets and 16 mm long × 6 mm wide for Stilts, operated at 163–168 MHz, and had a 12-cm external whip antenna. Transmitters with thermistor switches improved our ability to determine chick mortality because an increase or decrease in temperature given off by the chick resulted in a corresponding increase or decrease in pulse rate; the pulse rate changed from about 30 pulses per minute at 0°C to about 45 pulses per minute at 40°C. Immediately after attaching transmitters, we returned radio-marked chicks and their siblings to their nest sites or to the site of capture. On average, it took 13±4 min in 2005 and 28±11 min in 2006 to radio-mark a chick.

Radio-tracking Chicks

We tracked radio-marked chicks from trucks equipped with dual 4-element Yagi antenna systems with null-peak systems to accurately determine bearings (Takekawa et al. 2002, Ackerman et al. 2006). We located chicks daily from the time of radio attachment until their fate (depredated, dead, dropped transmitter) was determined. We searched for chicks daily that went missing until we found them (e.g., carried away by gulls to colonies) or until the transmitter was estimated to have quit working (about 32 days for Stilts and 40 days for Avocets). For each location by truck, we obtained 2 bearings within several minutes to minimize movement error.

Warnock and Takekawa (1995) reported average error rates of 1.5 degrees for bearings, 58 ± 35 (SE) m for distances between true and calculated locations, and 1.1 ha for error-polygon size with similar truck systems and location distances (e.g. <3 km). We used triangulation program software (Location of a Signal, version 3.0.1, Ecological Software Solutions, Schwägalpstrasse 2, 9107 Urnäsch, Switzerland) to calculate UTM coordinates for each location. We verified chick locations with visual observations (44% in 2005 and 23% in 2006) whenever possible without disturbing the chick. We tracked chicks during the cool morning and evening hours of the day to help differentiate the chick's temperature from the ambient temperature and determine chick mortality. If we thought the chick had died, we used hand-held Yagi antenna systems and receivers to find the transmitter and chick within 24 hours. Once found, we conservatively identified the type of predator by using retrieval location (e.g., in a gull colony, under a raptor roost) and predator remains (e.g., tooth marks, footprints, scat).

Statistical Analysis of Chick Survival

We analyzed chick survival rates using PROC LIFETEST and PROC PHREG tests with SAS software (SAS Institute 1990). Some chicks had unknown fates due to poor retention of radio transmitters in 2005; therefore, we assessed survival to 21 days post-hatch using the non-parametric Kaplan-Meier estimator (Kaplan and Meier 1958) so that we could include censored observations in statistical analyses. We censored observations if radio transmitters were recovered without evidence of depredation or if transmitter signals disappeared without evidence of impending transmitter failure. We treated censored observations in the analysis as surviving until the censoring date and having unknown fates after censoring. Due to limitations in radio transmitter lifespan for Stilts, we considered Stilt chicks to have fledged if they survived to 21 days post-hatch. We radio-tracked Avocets through fledging at approximately 35 days, however, in order to statistically compare survival rates of Stilts with Avocets, we also considered Avocet chicks to have fledged if they survived to 21 days post-hatch. We defined the time origin as hatching (i.e., age=0), not calendar date, so there were no staggered entries of birds. We qualitatively assessed log-survival and log-log-survival plots to determine if distributions were exponential or Weibull (Lee 1980, Allison 1995) and if Cox's regression model (i.e., proportional hazards model) was appropriate to examine the relationship between initial capture date and mass at initial capture (after adjusting for structural size, see below), and Avocet and

Stilt chick survival.

Survival estimates may be biased if the assumption of independence between censoring and subsequent survival is violated; for example, if missing chicks or recovered transmitters actually represent depredated chicks (Pollock et al. 1989, Bunck and Pollock 1993). Unfortunately, it is not possible to test whether censoring is informative (i.e., non-random) or non-informative (Lagakos 1979). When censoring mechanisms are potentially informative, upper and lower bounds of survival can be estimated by assuming censored observations represent either all survivors or all deaths (Heisey and Fuller 1985, Pollock et al. 1989). Censoring observations during the first week after hatch may actually represent mortality due to depredation, while in older, rapidly growing chicks, transmitter and signal loss may have been random, reflecting poor suture retention or, in the case of Stilts, transmitter failure. Therefore, we conducted an additional sensitivity analysis (see Allison 1995, p. 249) where we classified all transmitter and signal losses (i.e., missing chicks) that occurred ≤7 days post-hatching as depredated. This analysis assumed that predators were responsible for early (≤7 days) transmitter and signal losses, but that losses >7 days post-hatch were due to transmitter failure or poor suture retention (i.e., censoring after 7 days was random).

To control for the influence of transmitter attachment date and relative body mass at hatching, we included Julian hatch date and a body mass condition index as covariates in the above analyses. We controlled for the effects of structural body size (also an index of age) on body mass by calculating the residuals from a regression of chick body mass on the first principal component of 3 structural measurements (i.e., exposed culmen, short tarsus, and flattened wing chord). In 2005, PC 1 accounted for 83%, 74%, and 82% of the variance in culmen, tarsus, and wing chord, respectively, for Avocets and 91%, 94%, and 58% of the variance in these measurements, respectively, for Stilts. In 2006, PC 1 accounted for 83%, 73%, and 71% of the variance in culmen, tarsus, and wing chord, respectively, for Avocets and 86%, 87%, and 67% of the variance in these measurements, respectively, for Stilts.

Chick locations were plotted using ArcView 3.2 (ESRI 1996). We report means ± SD, unless otherwise indicated.

RESULTS AND DISCUSSION

Objective 1. Determine the current nesting and foraging distributions of California Gulls throughout the South Bay salt ponds and associated land fills, and determine proximity of gull colonies to current and historic Caspian Tern and Forster's Tern breeding colonies.

Salt Pond Surveys for Gulls

We surveyed gull distribution and abundance from January 2002 to August 2006 (e.g., Figure 3). Surveys in Alviso and Eden Landing salt pond complexes were conducted monthly starting in October 2002. Surveys in Ravenswood salt pond complex were conducted monthly starting in November 2002. Surveys in Newark and Mowry salt pond complexes were conducted monthly starting in September 2005.

Figure 3. Gulls foraging within salt pond A16 during a low dissolved oxygen event and subsequent fish kill in August 2005.

In general, gull abundance differed among salt pond complexes (ANOVA: $F_{4,1877}$=62.2, P<0.0001), species ($F_{11,1877}$=50.0, P<0.0001), and year ($F_{4,1877}$=3.1, P=0.02), but did not vary among months ($F_{11,1877}$=1.1, P=0.34).

Gulls were most abundant in the Alviso salt pond complex, followed by Mowry, Newark, Eden Landing and Ravenswood salt ponds (Figure 4). California Gulls were the most common gull species (Figure 5), especially in March through October near the time of the breeding season (Figure 6). When we analyzed California Gull data separately, we found that California Gull abundance differed among months (ANOVA: $F_{11,139}$=1.8, P=0.06), salt pond complexes ($F_{4,139}$=40.6, P<0.0001), and years ($F_{4,139}$=3.9, P=0.01). California Gulls are the only gulls which breed locally and have increased densities during the breeding season. Conversely, other gull species, such as Herring gulls, Ring-billed Gulls, and Western Gulls, are mostly absent during the breeding season but are relatively abundant during the winter when California Gull populations are reduced.

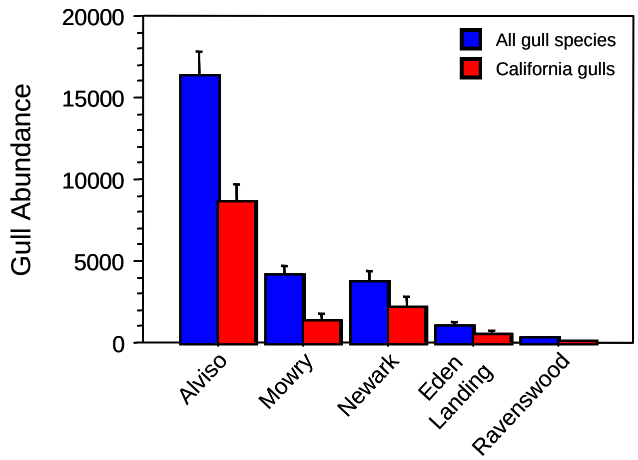

Figure 4. Mean±SE of California Gulls and all gull species counted at each salt pond complex from Jan 2002 to Aug 2006.

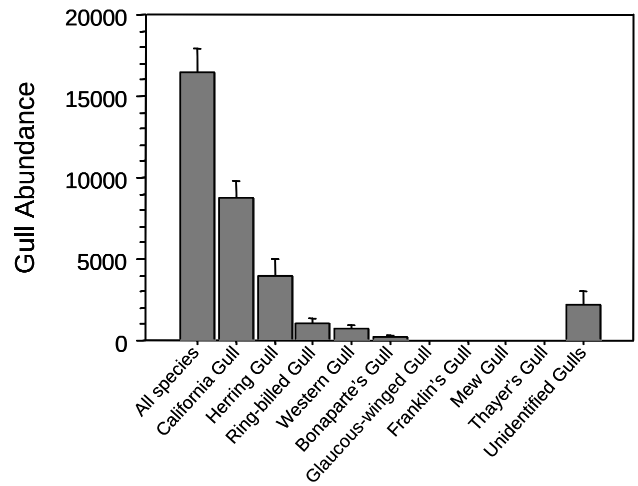

Figure 5. Mean±SE of gulls counted in the Alviso salt pond complex from Jan 2002 to Aug 2006.

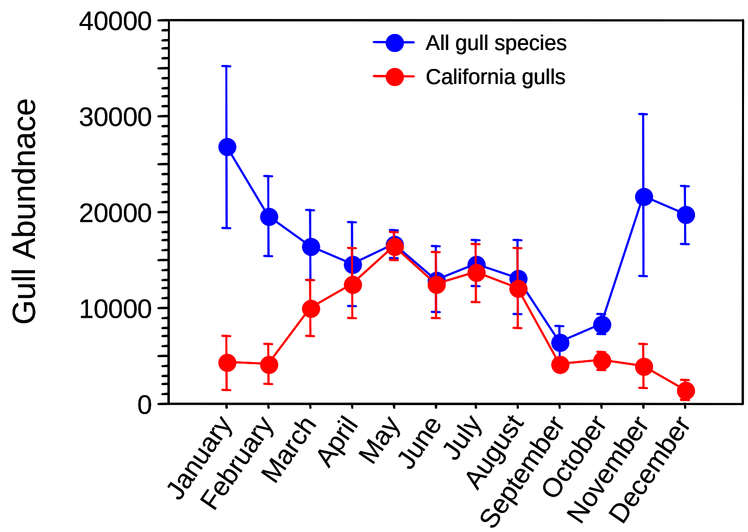

Figure 6. Monthly mean±SE abundance of California Gulls and all gull species counted at the Alviso salt pond complex from Jan 2002 to Aug 2006.

Maximum numbers of gulls within salt ponds occurred during winter surveys and reached more than 53,000 gulls in the Alviso complex alone in January 2006 (Figure 7). California Gull numbers peaked during the breeding season (spring and summer) and reached more than 23,000 in the Alviso complex in June 2006.

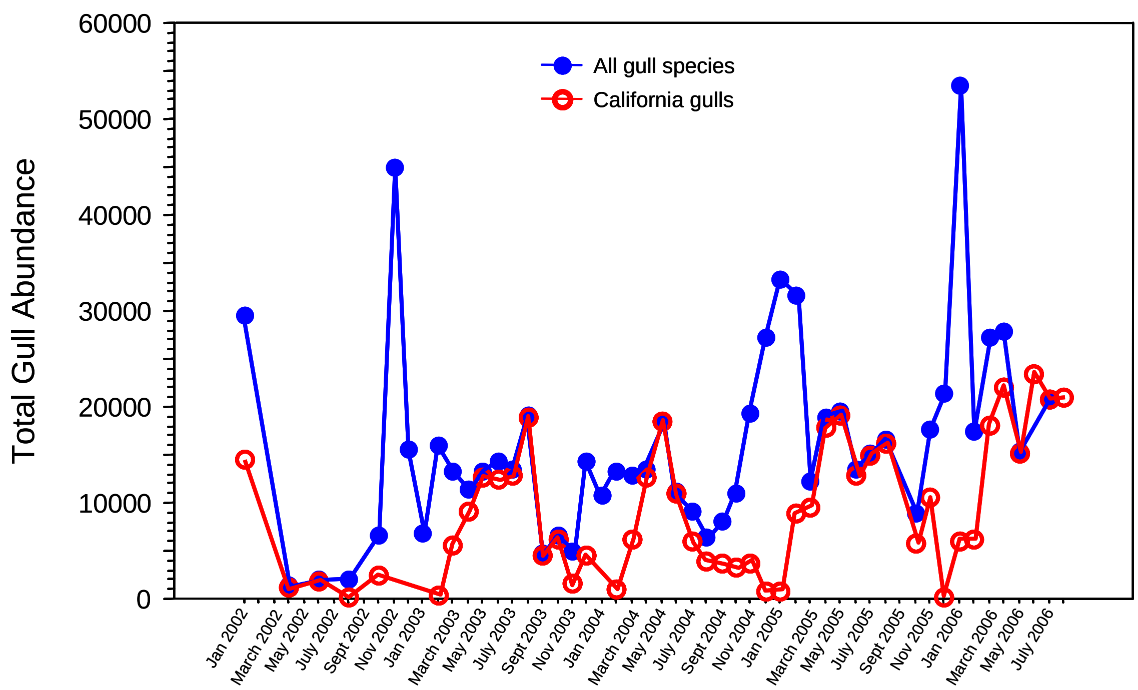

Figure 7. Total counts for California Gulls and all gull species combined at the Alviso salt pond complex from Jan 2002 to Aug 2006.

The distribution and abundance of California Gulls within South Bay salt ponds are shown by month (Figures 8-19). Monthly abundances in each grid cell are averages of all years surveyed from January 2002 to August 2006 for Alviso and Eden Landing salt pond complexes, from November 2002 to August 2006 for Ravenswood, and from September 2005 to August 2006 for the Newark and Mowry salt pond complexes. The intensity of the grid cell color indicates increasing densities of California Gulls.

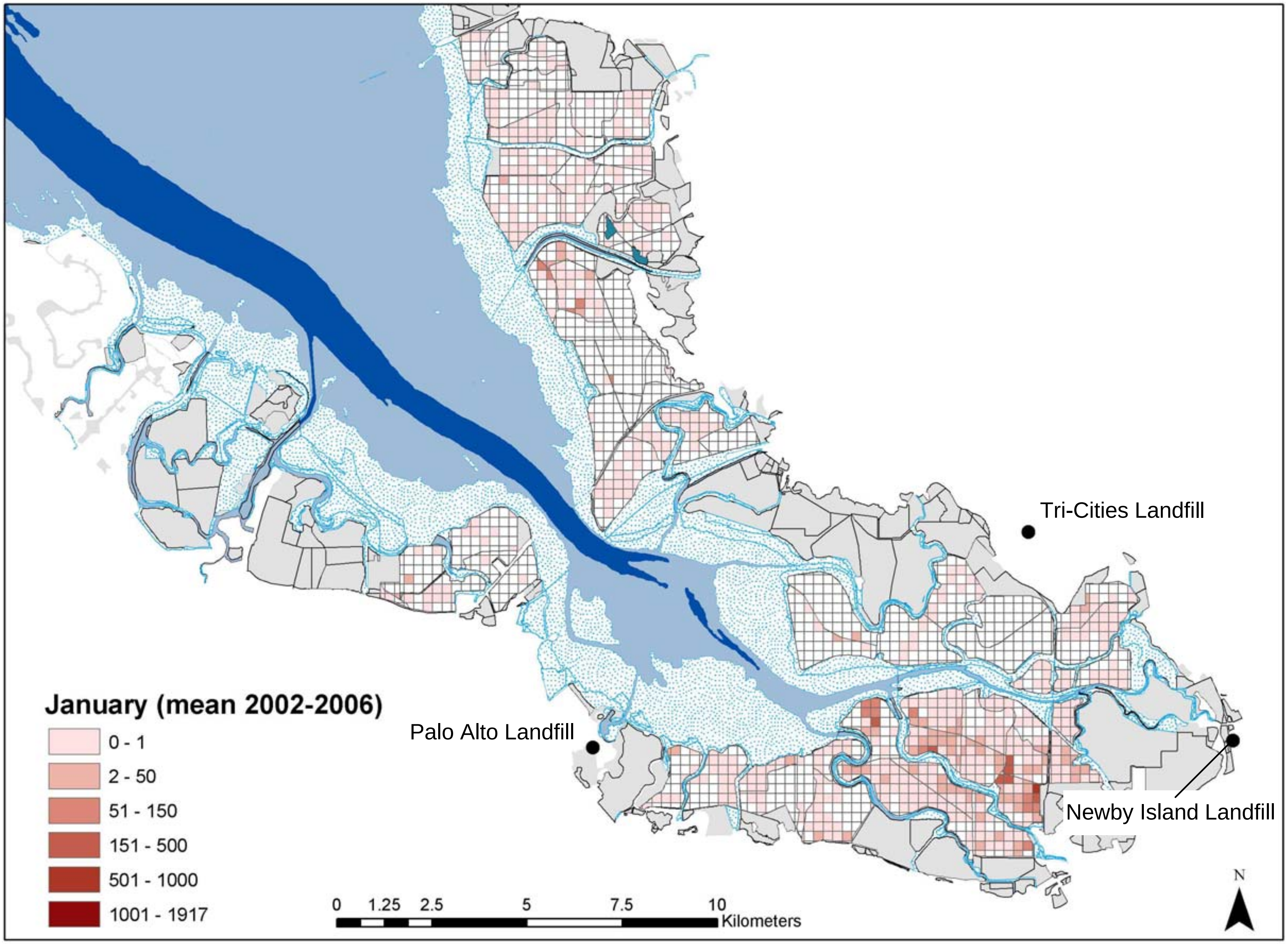

Figure 8. Distribution and mean abundance (2002-2006) of California Gulls in South San Francisco Bay salt ponds during January.

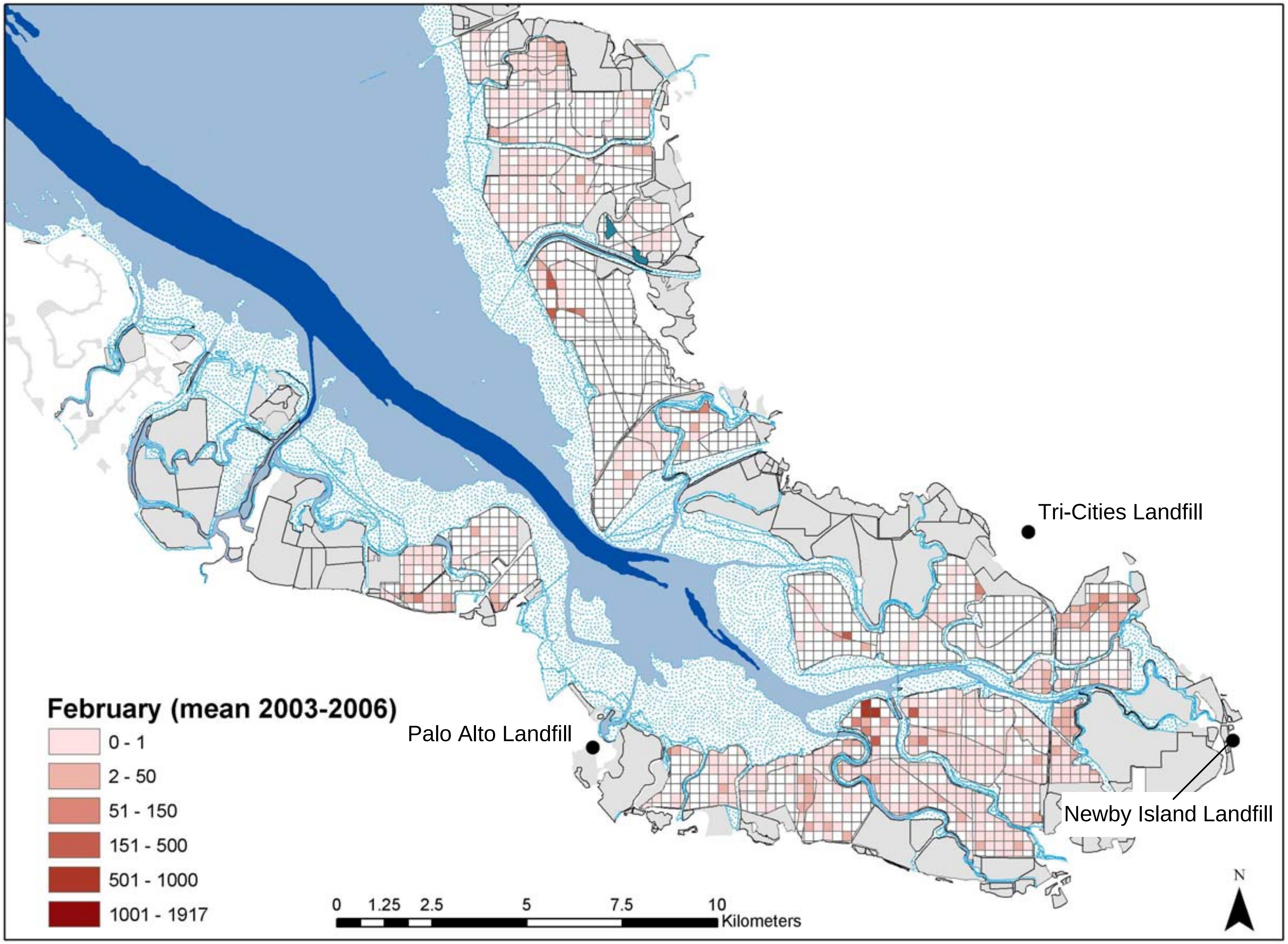

Figure 9. Distribution and mean abundance (2003-2006) of California Gulls in South San Francisco Bay salt ponds during February.

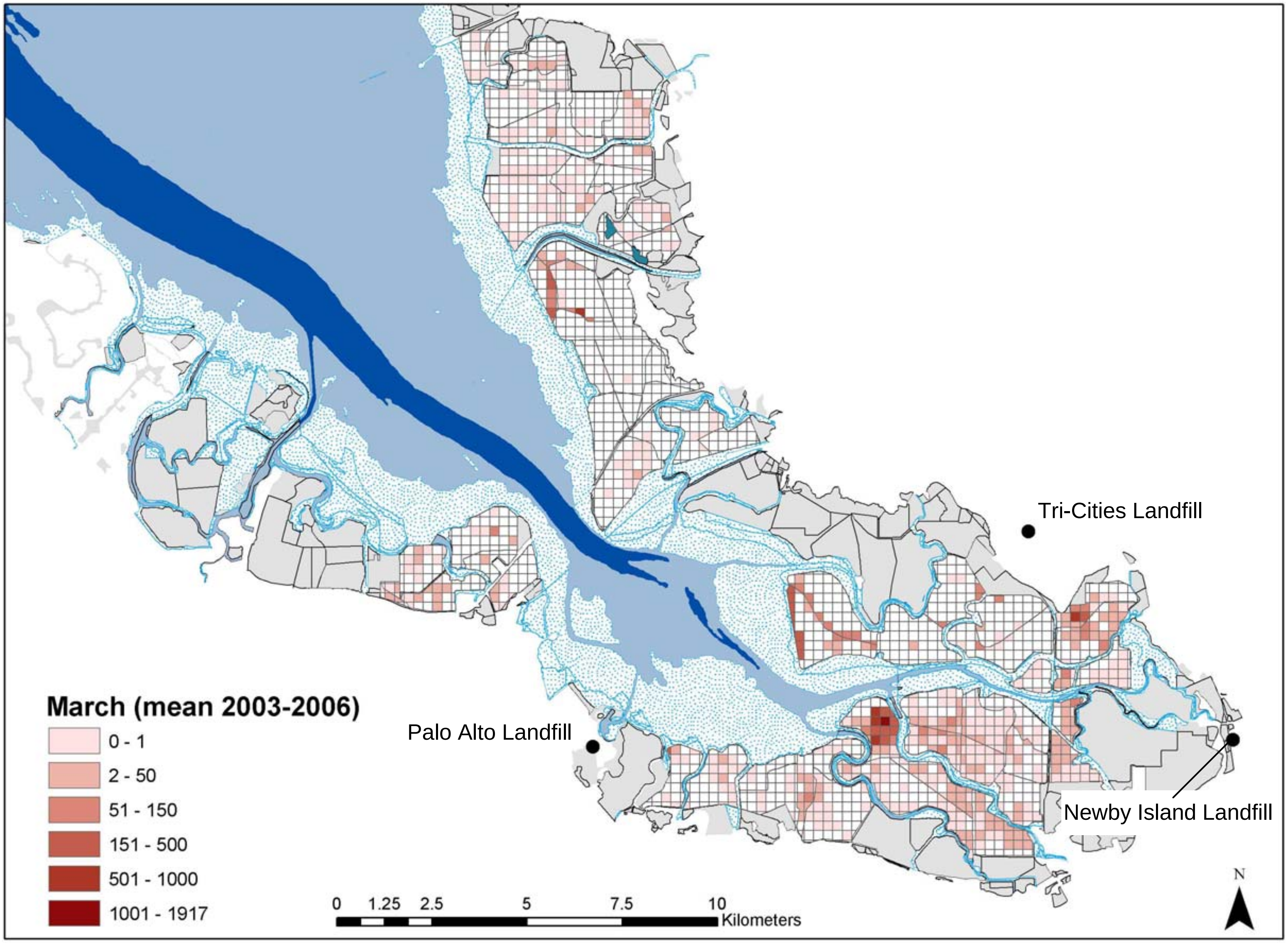

Figure 10. Distribution and mean abundance (2003-2006) of California Gulls in South San Francisco Bay salt ponds during March.

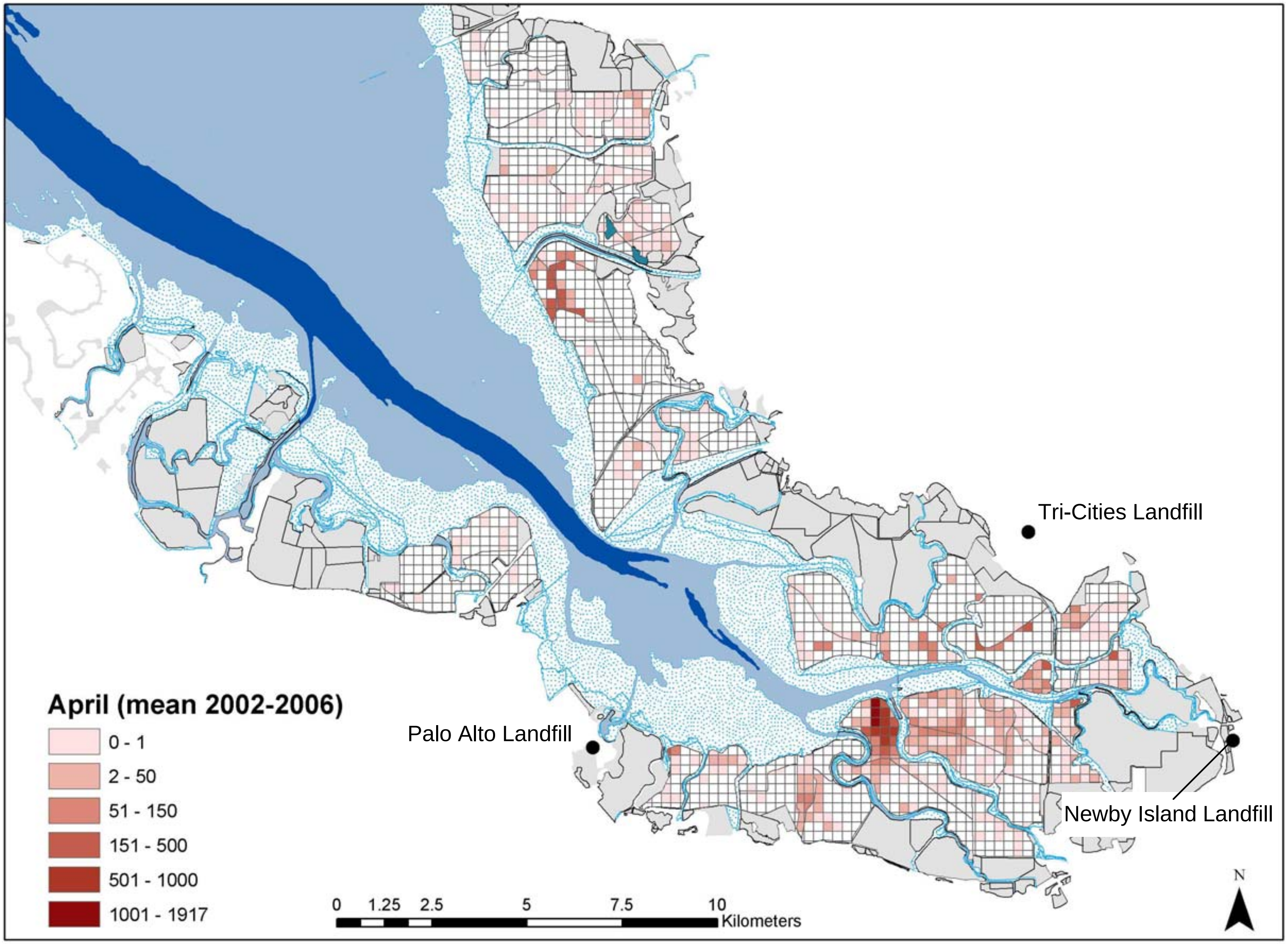

Figure 11. Distribution and mean abundance (2002-2006) of California Gulls in South San Francisco Bay salt ponds during April.

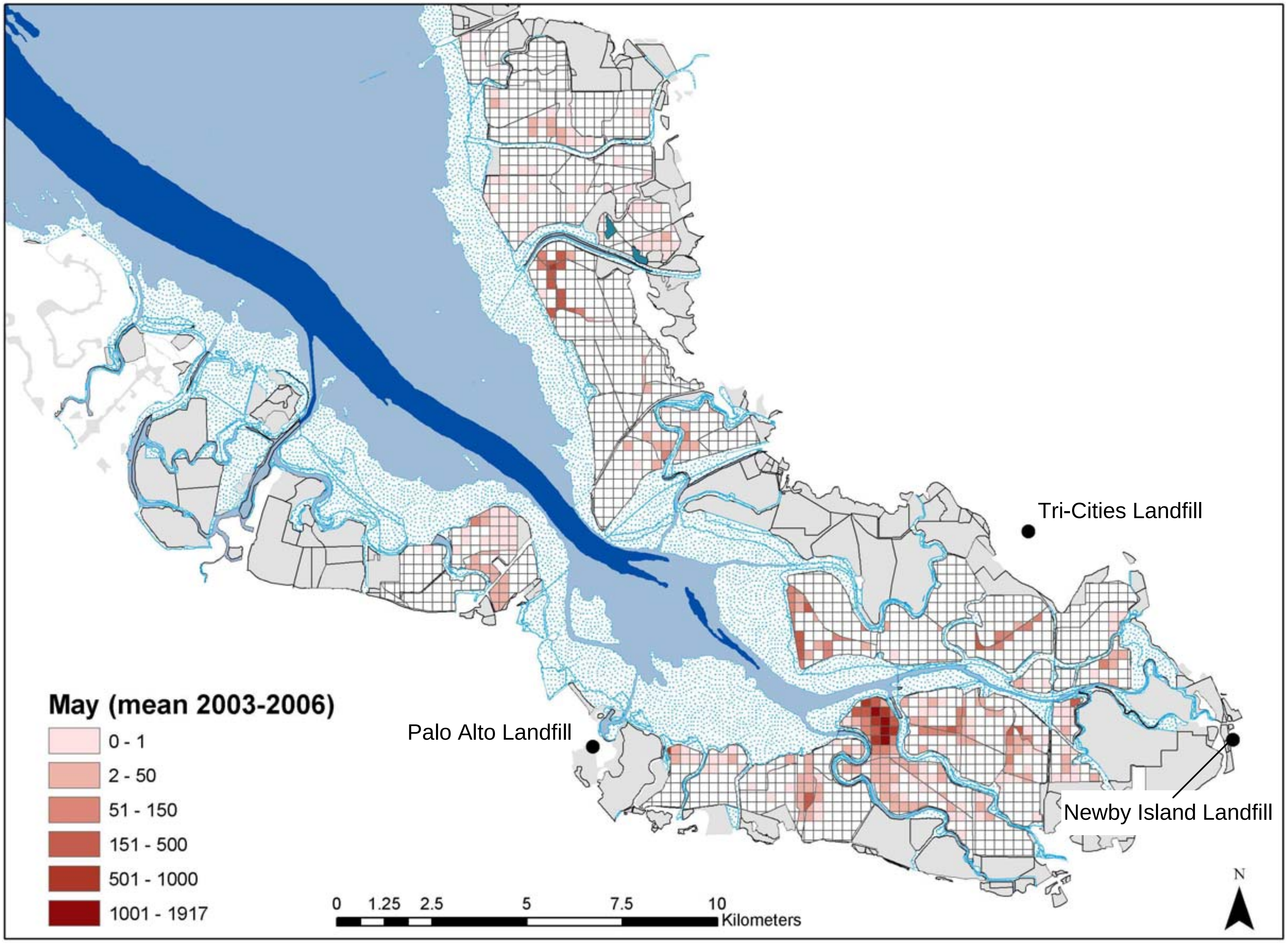

Figure 12. Distribution and mean abundance (2003-2006) of California Gulls in South San Francisco Bay salt ponds during May.

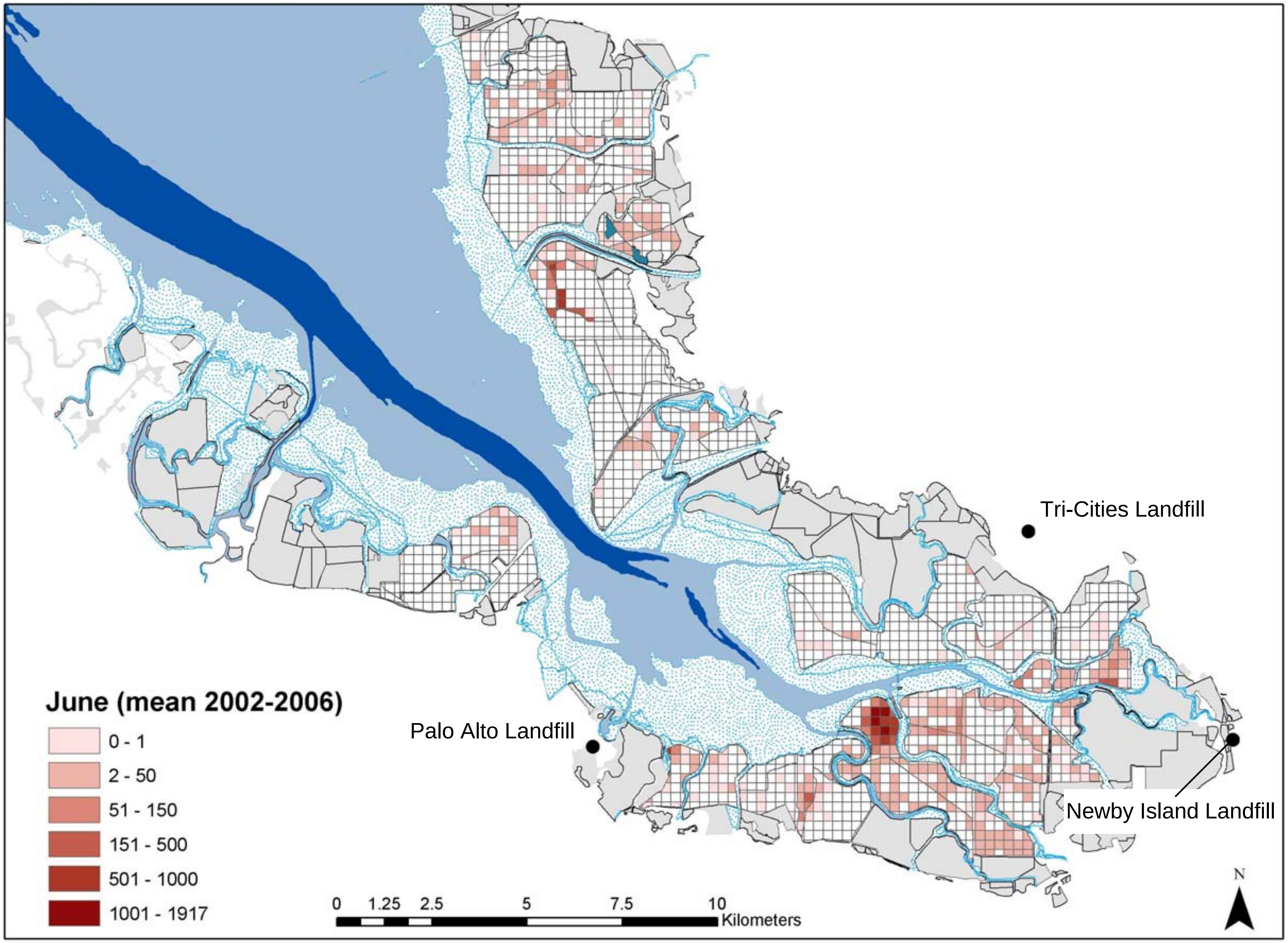

Figure 13. Distribution and mean abundance (2002-2006) of California Gulls in South San Francisco Bay salt ponds during June.

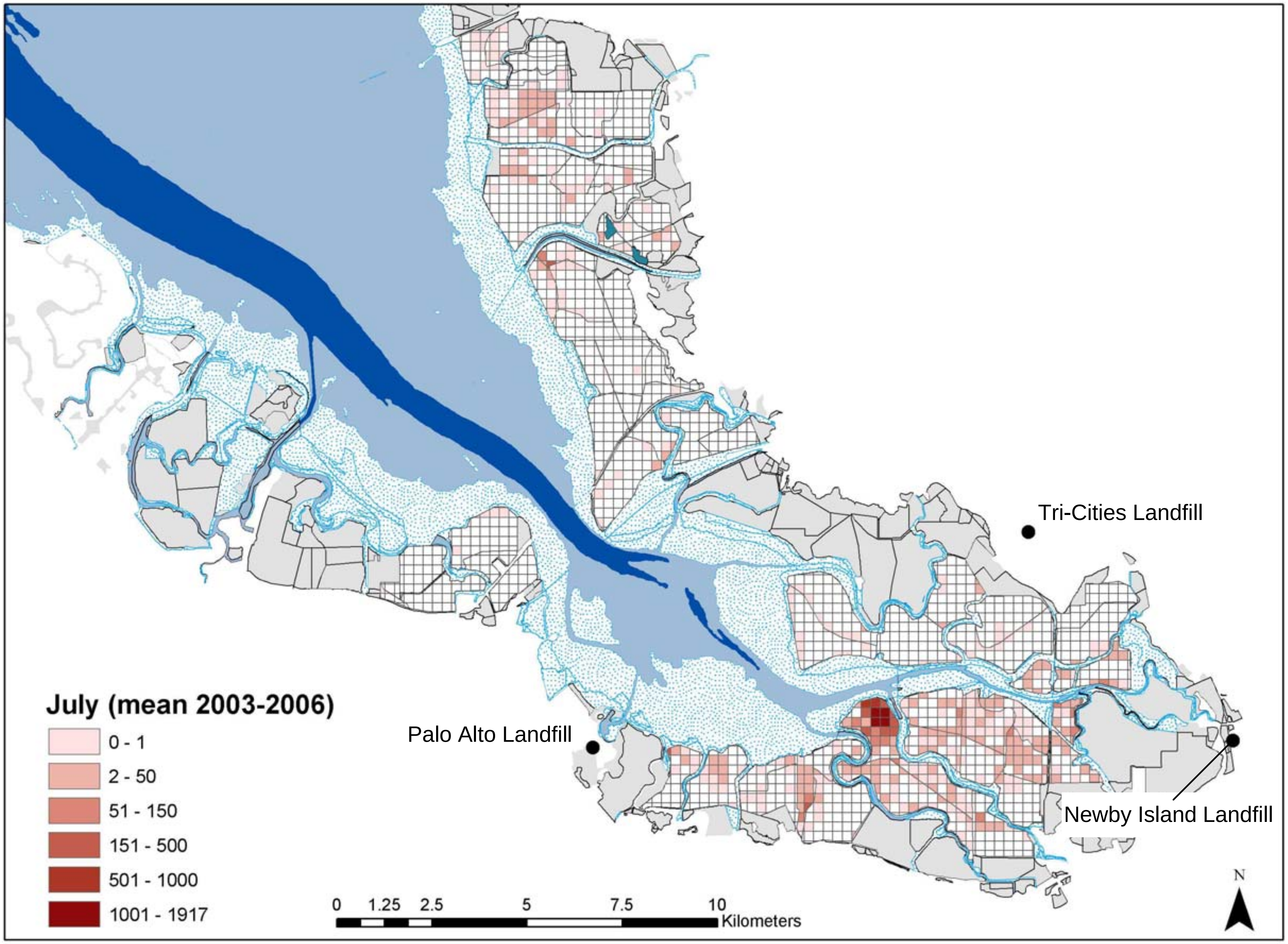

Figure 14. Distribution and mean abundance (2003-2006) of California Gulls in South San Francisco Bay salt ponds during July.

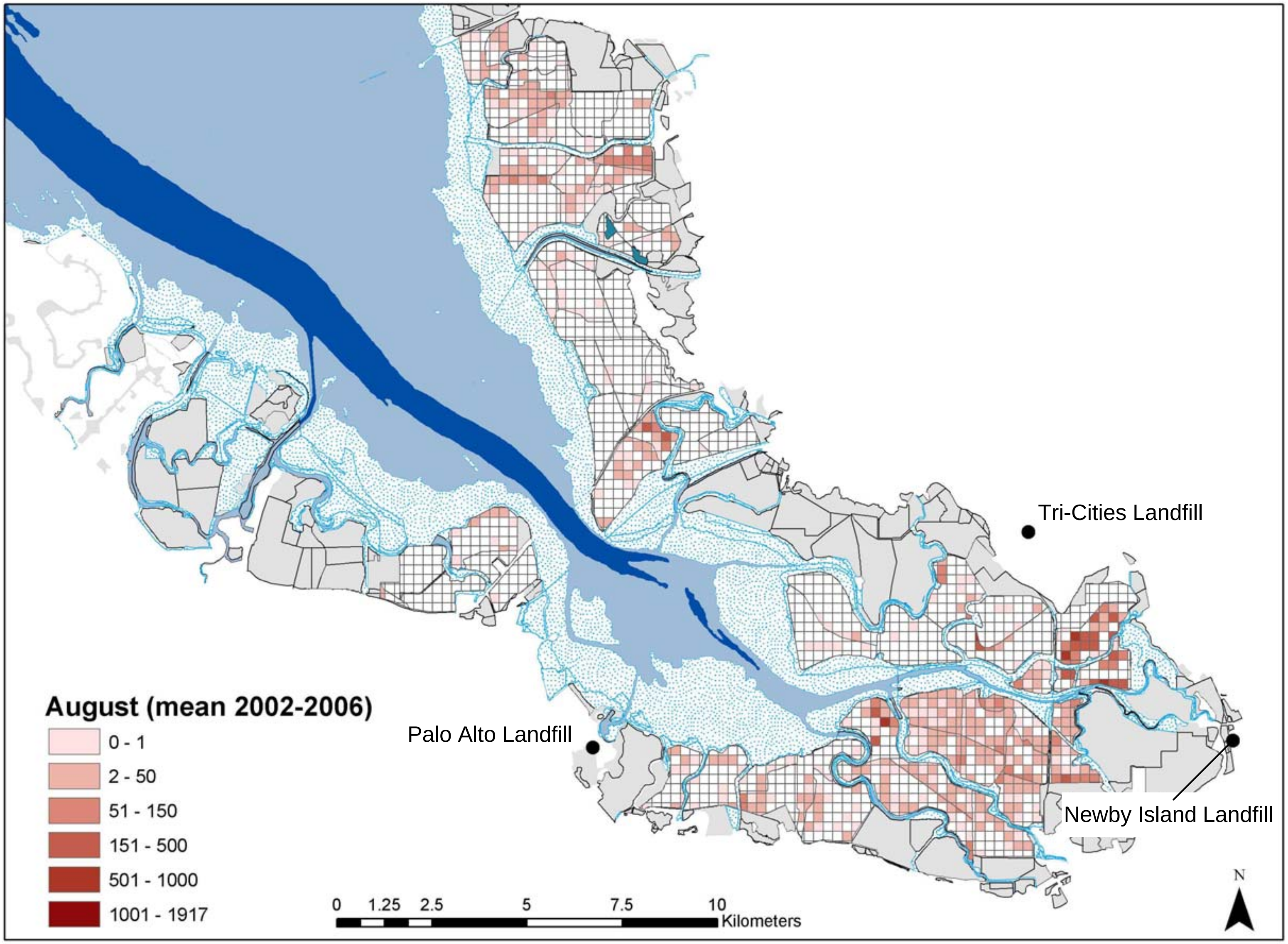

Figure 15. Distribution and mean abundance (2002-2006) of California Gulls in South San Francisco Bay salt ponds during August.

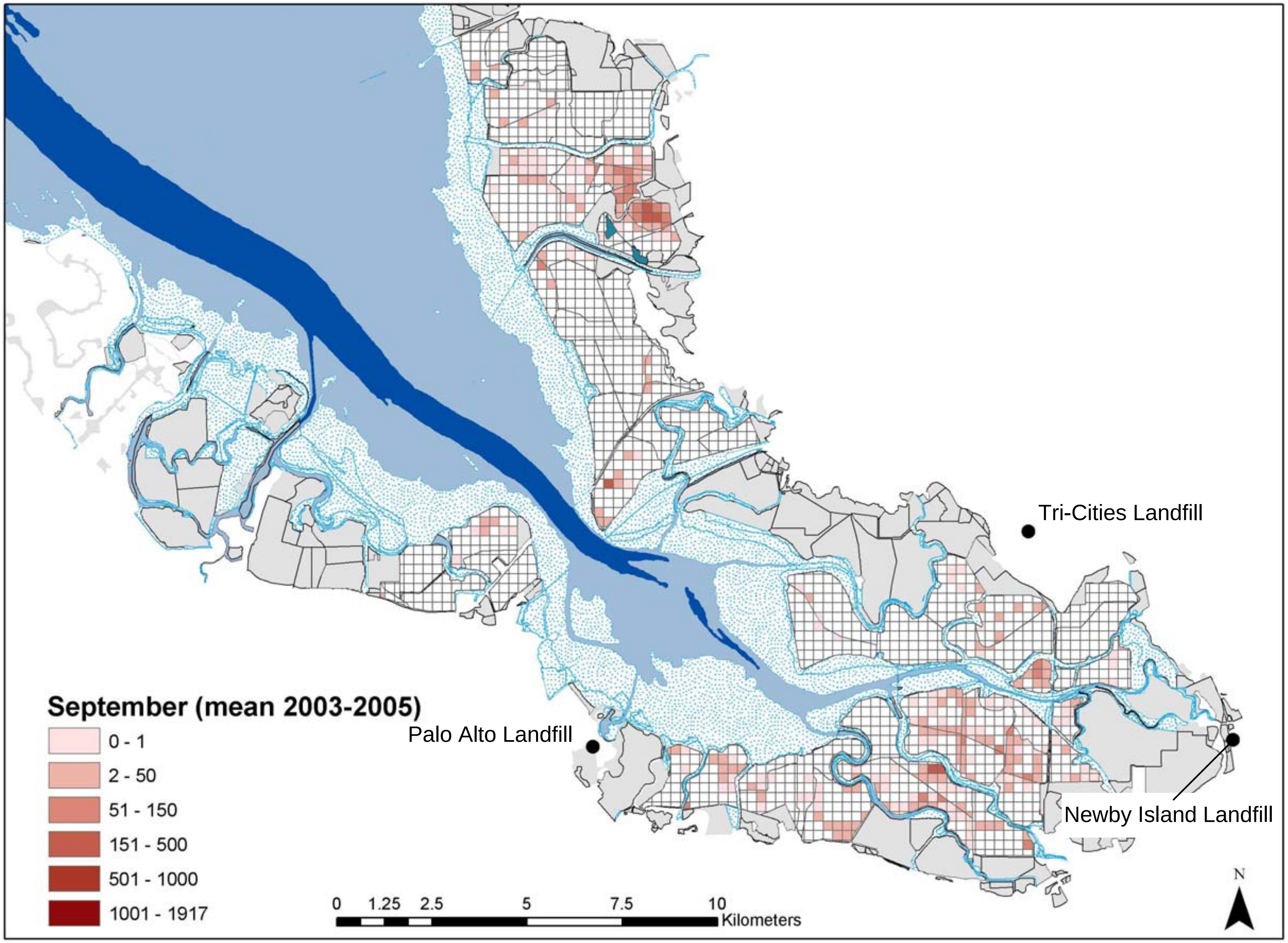

Figure 16. Distribution and mean abundance (2003-2005) of California Gulls in South San Francisco Bay salt ponds during September.

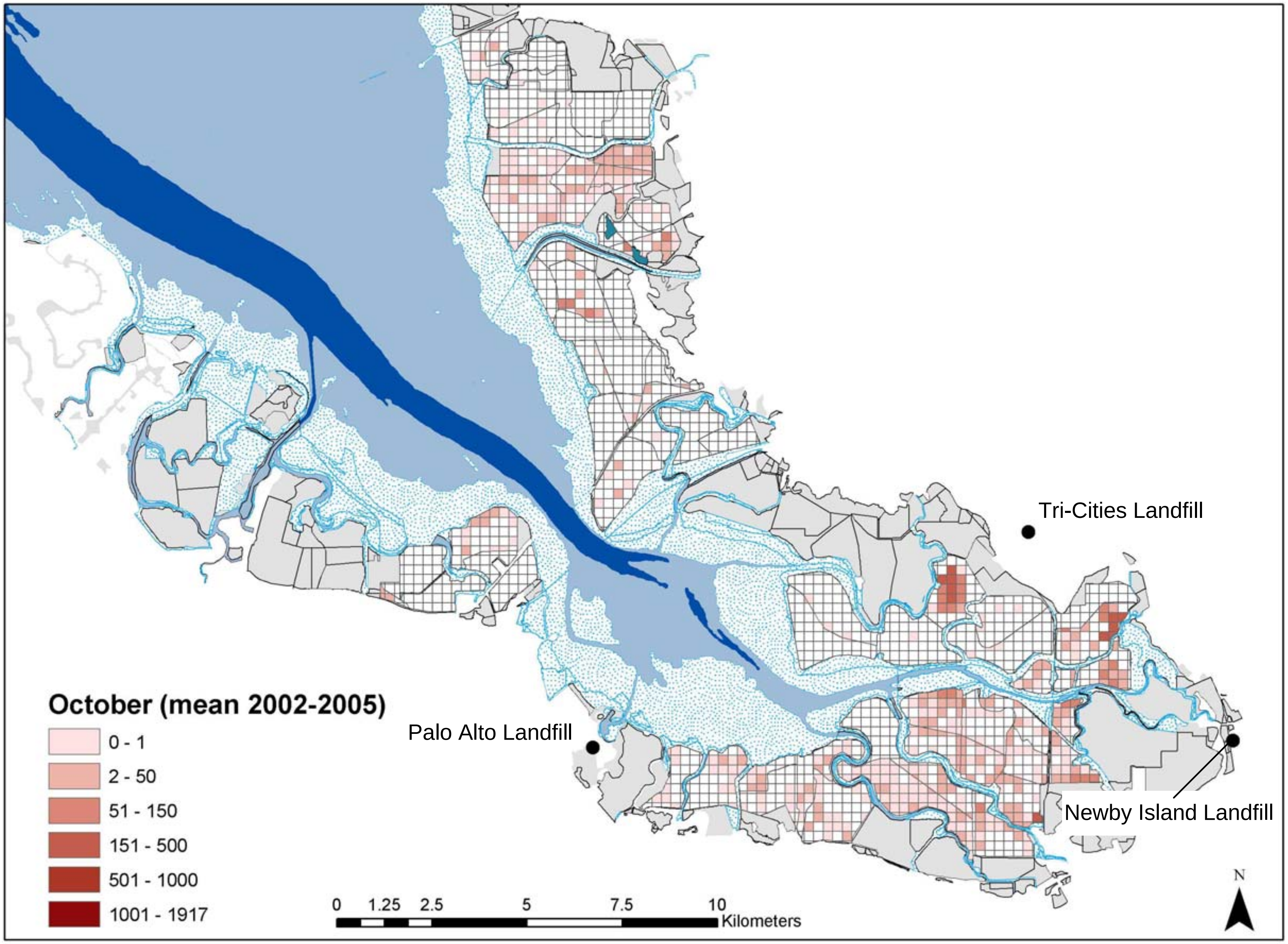

Figure 17. Distribution and mean abundance (2002-2005) of California Gulls in South San Francisco Bay salt ponds during October.

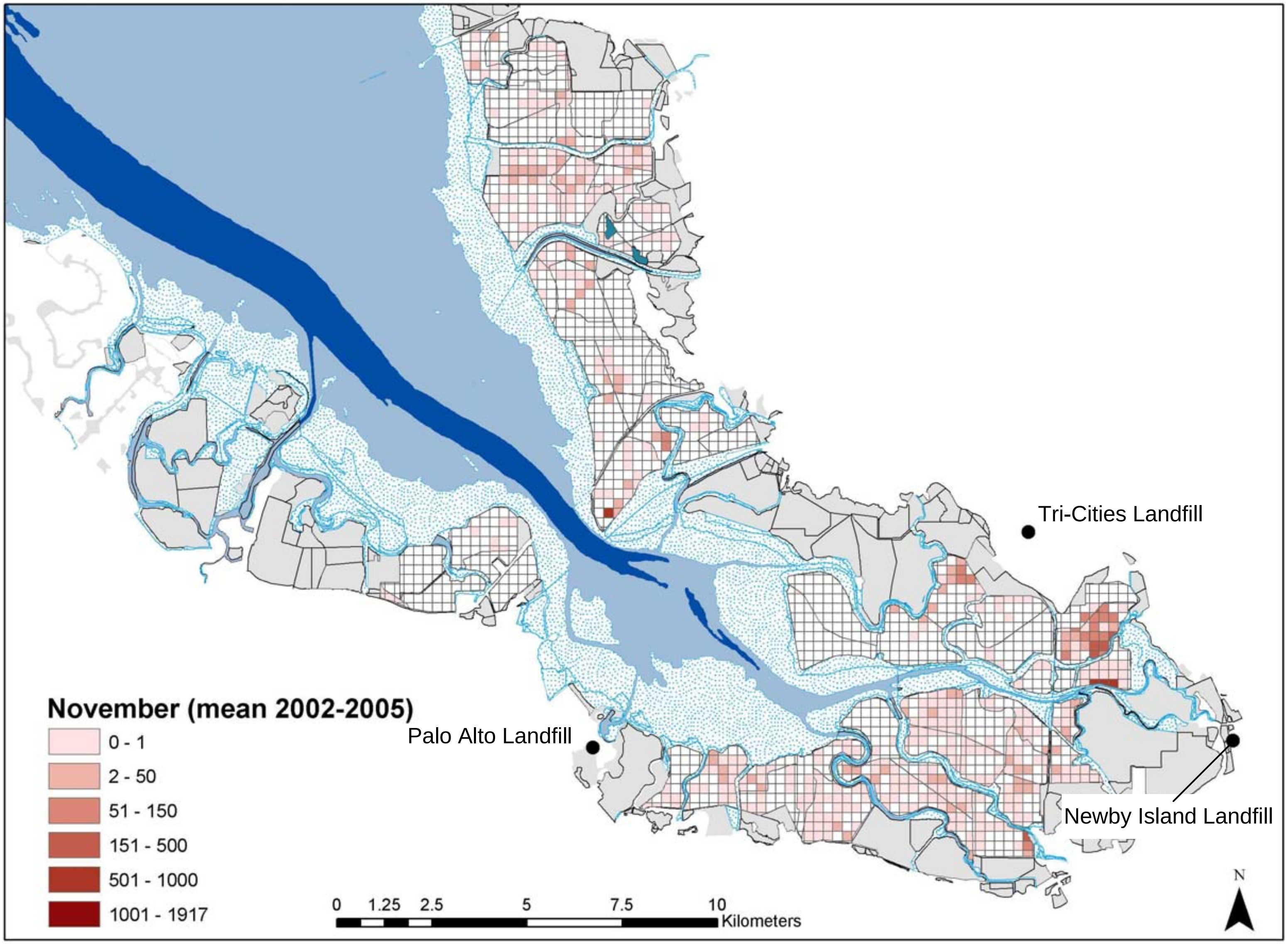

Figure 18. Distribution and mean abundance (2002-2005) of California Gulls in South San Francisco Bay salt ponds during November.

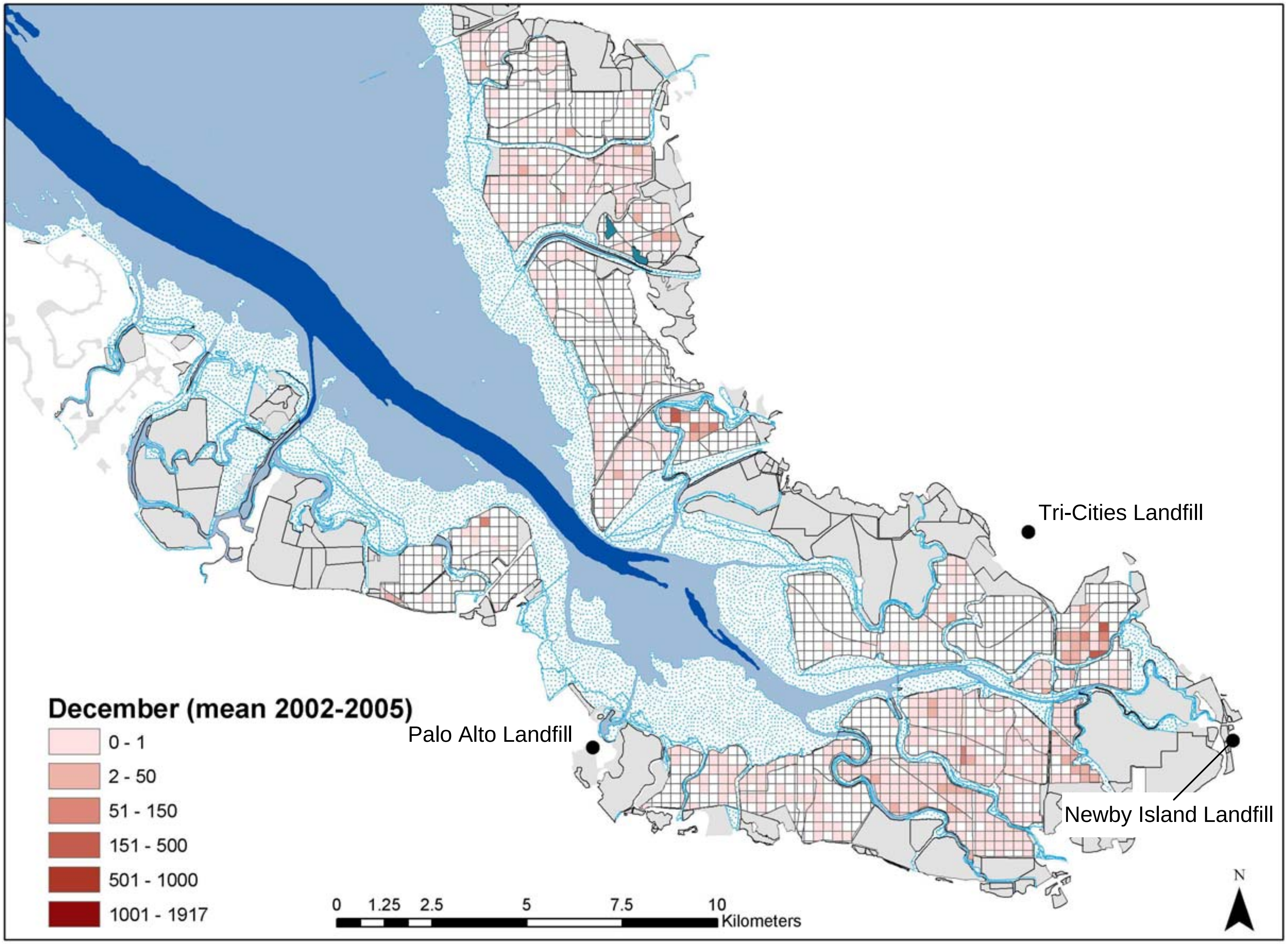

Figure 19. Distribution and mean abundance (2002-2005) of California Gulls in South San Francisco Bay salt ponds during December.

Landfill Surveys for Gulls

Gulls frequented several local landfills around the South Bay refuge and total numbers of California Gulls counted during five monthly surveys were 19,386 at San Jose's Newby Island landfill, 8,691 at Fremont's Tri-Cities landfill, and 245 at the City of Palo Alto's landfill. Nearly 98% of the gulls observed at landfills were California Gulls. Six other species were observed at landfills, including Glaucous-winged Gulls (1%), Western Gulls (<1%), Herring Gulls (<1%), Ring-billed Gulls (<1%), Thayer's Gulls (<1%), and Glaucous Gulls (<1%). Gulls other than California Gulls were almost completely absent after April surveys, during the main breeding season (May-July), with an increase in Thayer's Gulls and Western Gulls in August. Counts of all other gulls combined ranged from 494 in April to 8 in July and then to 96 in August when gulls began moving back into the area for the winter (similar to the salt pond survey data). These data indicate that landfill use by gulls is likely greater in the winter than during the breeding season, but we did not survey landfills in winter.

Interestingly, California Gull use of landfills declined over the course of the breeding season from 8,837 in April to 2,411 in August (Figure 20). These data indicate that California Gulls likely decreased their reliance on landfills as a food resource and instead switched to foraging on more natural prey (including Avocet chicks, see below) as the chick-rearing period progressed (late May through July). A similar decline in use of landfills by Yellow-legged Gulls was observed during the chick rearing period in France (Duhem et al. 2005), presumably as a way to increase the quality of their chicks' diets.

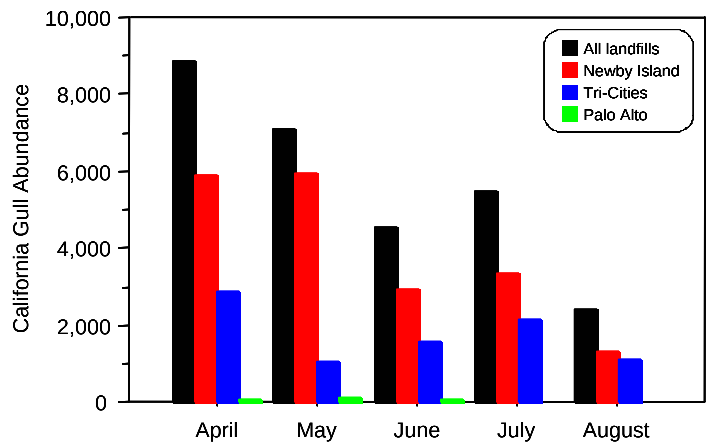

Figure 20. Use of landfills by California Gulls declined throughout the breeding season.

The Newby Island landfill is the largest active landfill in the South San Francisco Bay. It receives waste from San Jose, Milpitas, and the surrounding cities. This site covers more than 270 acres and is still at least 30 feet from its permitted height of 120 feet. It is not scheduled to close for the next several decades. In addition to providing refuse for foraging gulls and other birds, this landfill is located adjacent to salt ponds and levees that are used extensively by roosting gulls. The active face of this landfill was used by thousands of California Gulls, and there was active exchange between the gulls on the landfill and those roosting on salt ponds A18 and A19. We also counted California Gulls in salt ponds A18 and A19 each month and total counts averaged 6,199 gulls in addition to those present within the Newby Island landfill. Therefore, our estimates of gull use of the Newby Island landfill are likely biased low due to its close proximity to available roosting sites in salt ponds between meals.

The Tri-Cities landfill is scheduled to close in the near future. It has received municipal solid waste from Fremont, Newark, and Union City since the 1960s. This landfill currently provides forage for gulls and is located next to salt ponds and levees used by roosting and nesting gulls. This landfill was the only site counted in March of 2006; at this time it had very few gulls using the active face. The pattern of California Gulls using this site was somewhat different to that of Newby Island - gulls peaked in April with a decline in May, then a more gradual increase from June to July and a drop in numbers again in August. Because of the proximity of Tri-Cities landfill to the Newby Island landfill, there was likely some turnover between the two landfills which may account for some of the variation in monthly counts.

The Palo Alto landfill was used very little by gulls. This is due to the fact that this landfill is limited to residents bringing waste materials from their homes, whereas the City's solid waste is taken to a transfer station and disposed of elsewhere. Thus, this landfill apparently has only a limited amount of foraging opportunities for gulls. During our surveys, total abundance never exceeded 88 gulls at this landfill.

Breeding Colony Surveys for Gulls

We counted 16,475 California Gull nests in the South San Francisco Bay in 2006. California Gull nesting abundance continued to increase significantly in the South Bay (N=27 years, $P<0.0001$, $R^2=0.82$; Figure 21). The largest colony is still located within A6 (Knapp property; 19,456 adults; Figure 22), a dry salt pond located in Alviso next to A7 (nesting site for the largest colony of Caspian Terns in the South Bay) and A8 (nesting site for the largest population of

Avocets and one of the largest sites for Forster's Terns and Snowy Plovers in the South Bay). Areas of the A6 colony flooded this breeding season forcing more gulls to nest along pond levees and on small islands in the adjacent salt pond (A5).

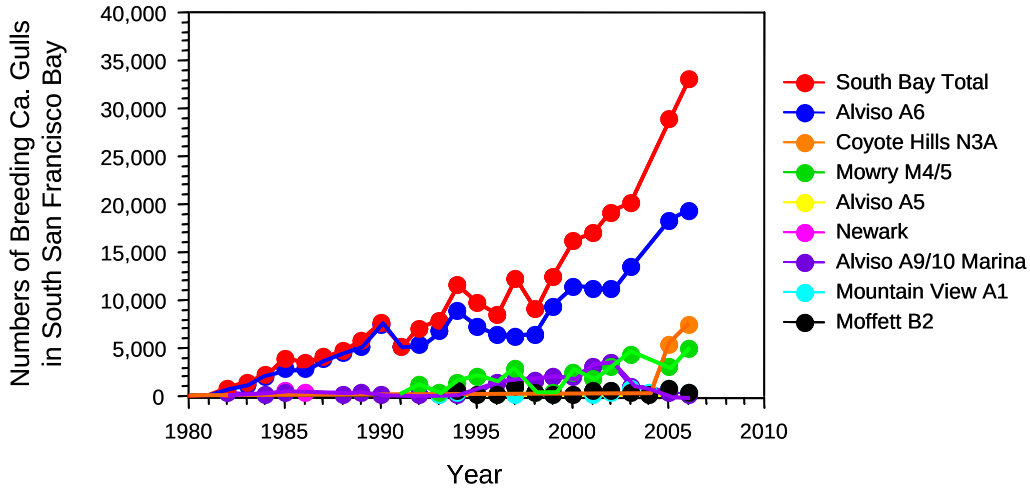

Figure 21. Growth of several California Gull colonies in the South San Francisco Bay since 1982.

California gulls continued to nest at several other colonies as well, including Coyote Hills (7,442), Mowry 4&5 (5,068), A1 (380), Moffet B2 (374), A9&10 (234), and A5 (84). High water levels were evident at the California Gull colony in pond A1. As such, the A1 nesting island was separated into three parts with nests on the southernmost section built up over water. New dredge spoil islands in Mowry pond 2 were used by nesting gulls; as these islands dry out, gulls will likely increase their use of the new islands.

Figure 22. Biologists conduct nesting surveys within the A6 California Gull colony.

Proximity of Gull Colonies to Tern Colonies

Using San Francisco Bay Bird Observatory's long-term dataset of colony counts for gulls and terns, we determined the proximity of gull colonies to current and historic tern colonies. In increments of 4 years, we mapped the relative abundance and location of California Gull, Forster's Tern, and Caspian Tern colonies over the past two decades since 1982 (Figures 23-29).

As shown in the following seven figures, California Gull colonies first formed in the San Francisco Bay at the A6 site, shortly followed by the A9&10 site in 1982. As the years progressed, additional California Gull colonies appeared, mostly in the extreme South Bay, while the main colony at A6 grew rapidly. The third largest California Gull colony at Mowry appeared in 1992, and the second largest California Gull colony at Coyote Hills newly appeared in 2005.

Although we cannot infer a causal relationship, tern nesting populations have declined in the South Bay while California Gull abundance has increased. For example, Caspian Tern abundance has declined significantly in the South Bay (N=25 years, $P<0.0001$, $R^2=0.55$) from roughly 2,000 birds in the 1980s to about 150 today (average population size was 882). The main colony sites in the 1980s at Bair-Redwood, Turk, Mowry, and Baumberg are not present today. Instead, the few Caspian Tern colonies that remain are located at A7 and Coyote Hills. Unfortunately, the A7 Caspian Tern colony is very close to the A6 California Gull colony (~1 km) and few tern chicks fledge successfully. Moreover, the Coyote Hills Caspian Tern colony is literally surrounded on all sides by nesting California Gulls (within 10 m) and few, if any, tern chicks have fledged in the past few years.

Forster's Tern populations have also declined in the South Bay (N=24 years, $P=0.03$, $R^2=0.20$); we had to exclude data from 1983 because several large colonies were not counted in that year. The average abundance of Forster's Terns in the South Bay has been 2,621 birds and was 1,982 in 2006. No clear pattern has emerged from the distribution or abundance of Forster's Terns, but colonies at A1, Baumberg 8A, Belmont, and Turk generally have increased whereas colonies at A5-8, Bair-Redwood, Baumberg 10-11, Dumbarton, Moffet B2, and Ravenswood generally have decreased.

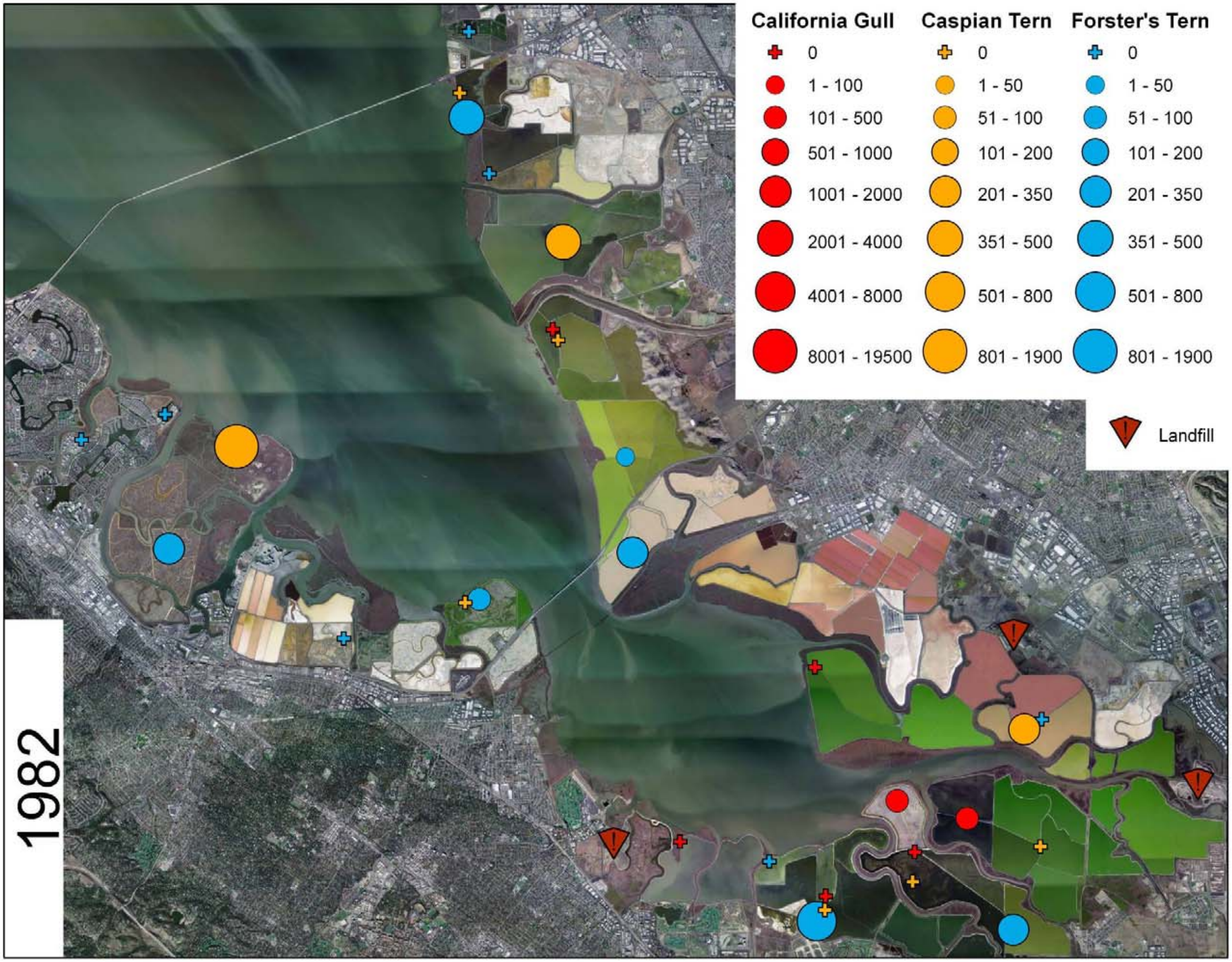

Figure 23. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 1982.

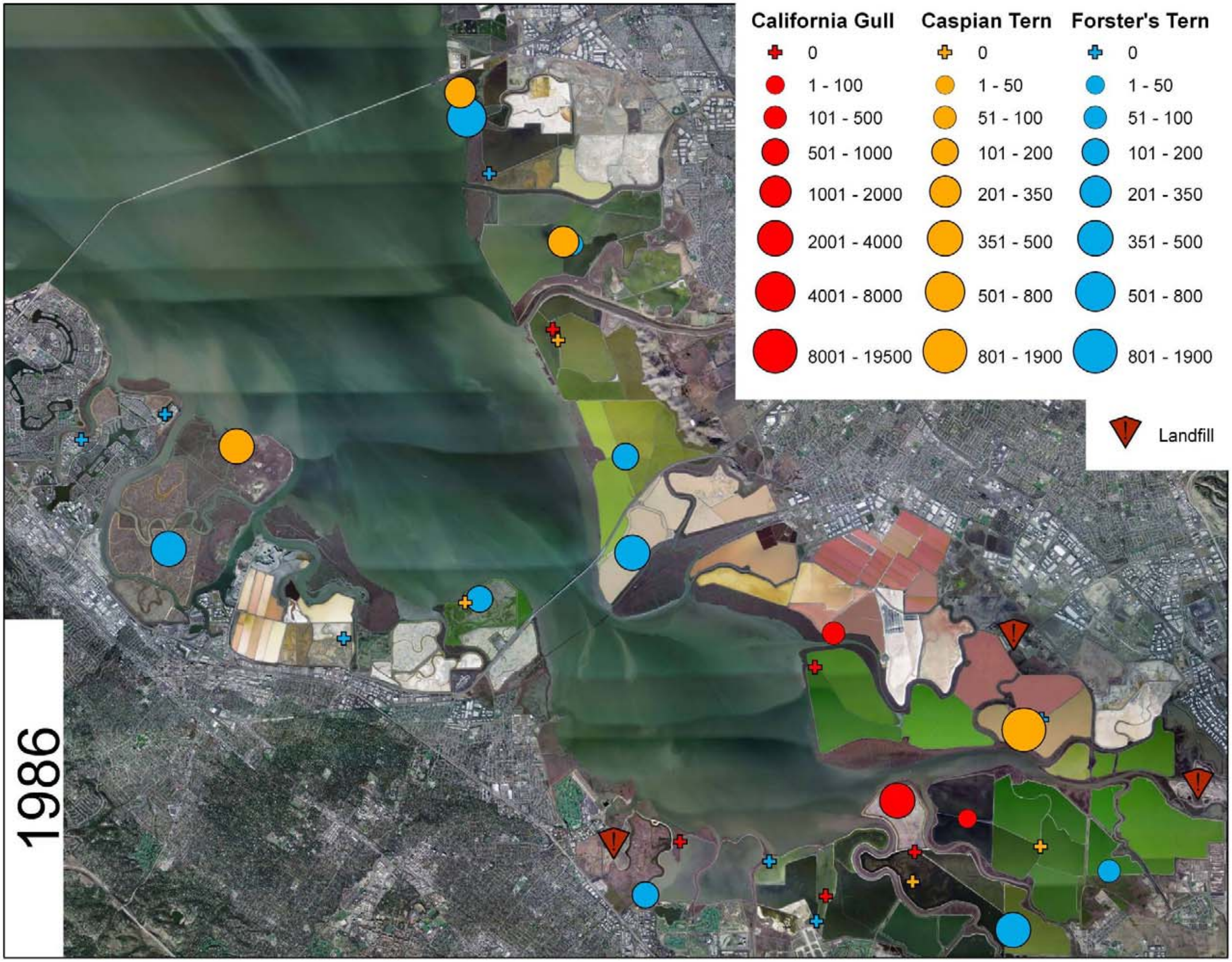

Figure 24. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 1986.

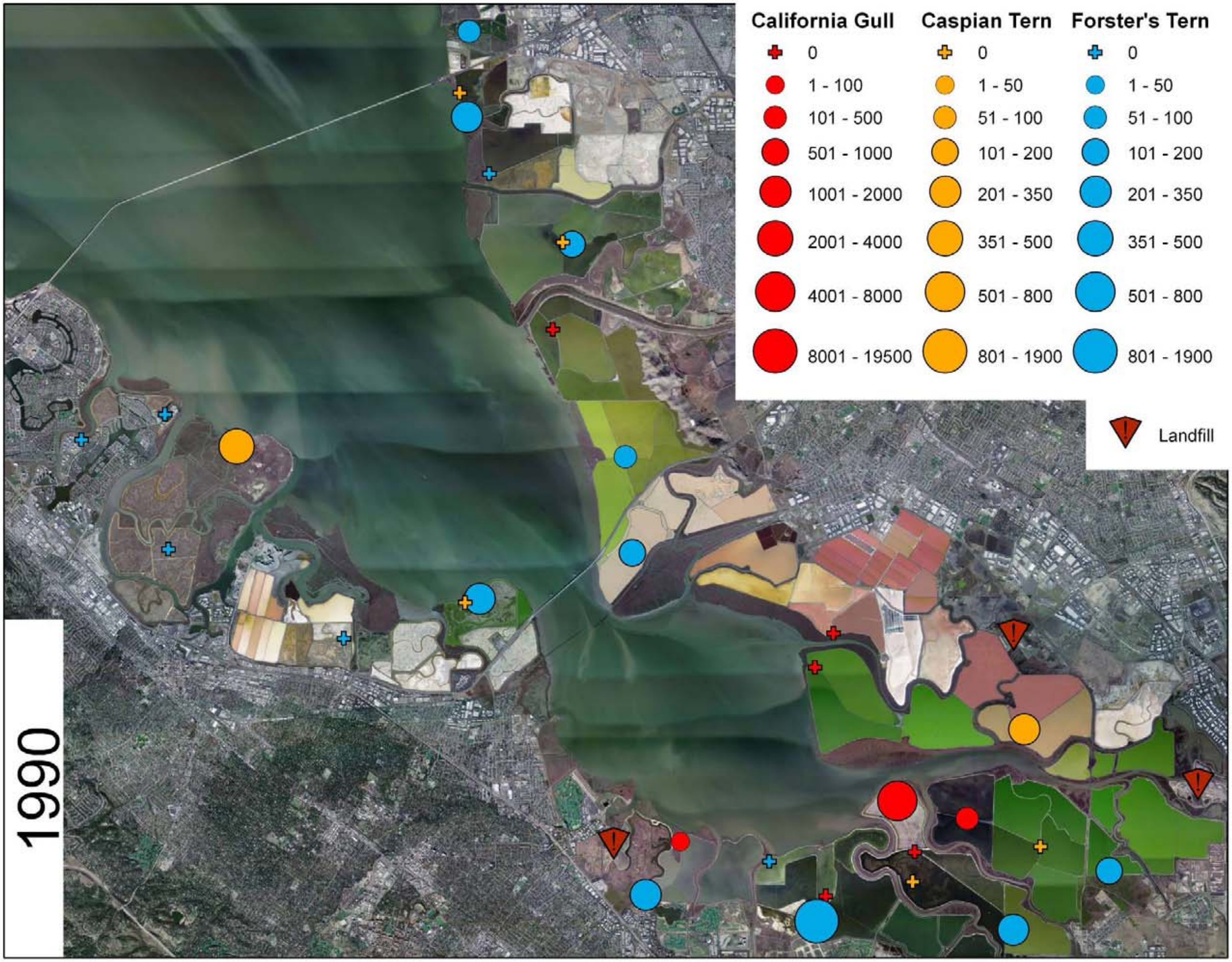

Figure 25. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 1990.

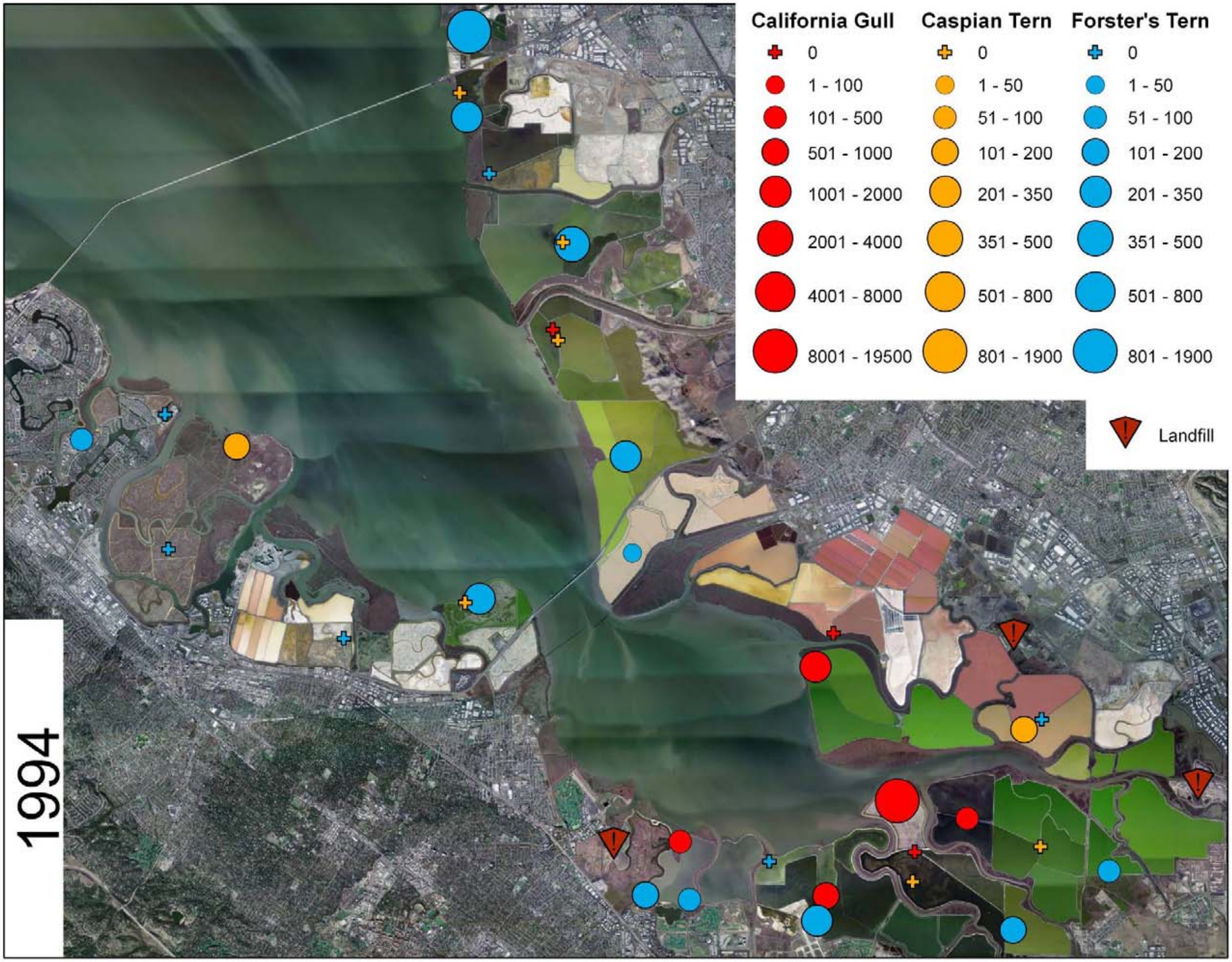

Figure 26. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 1994.

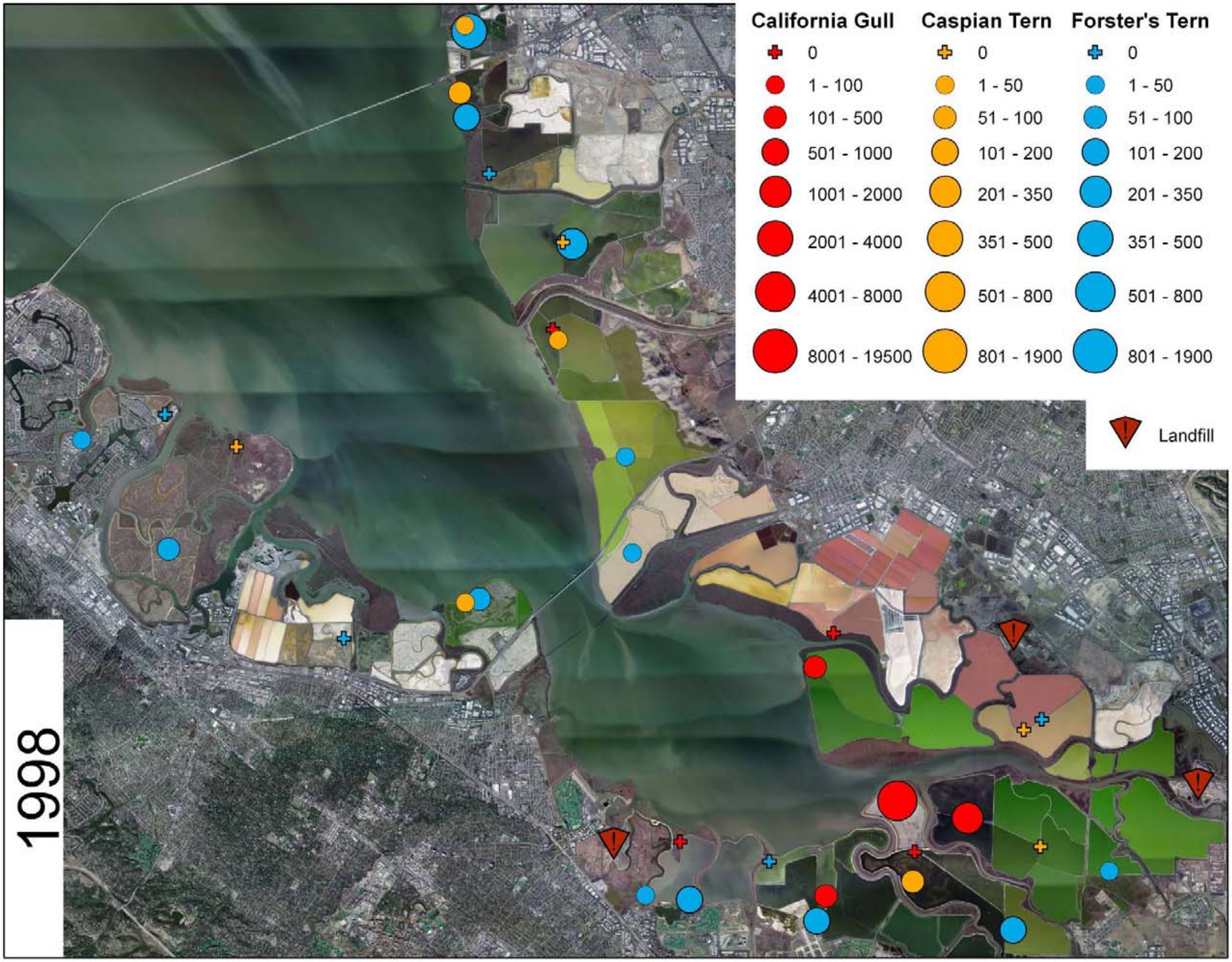

Figure 27. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 1998.

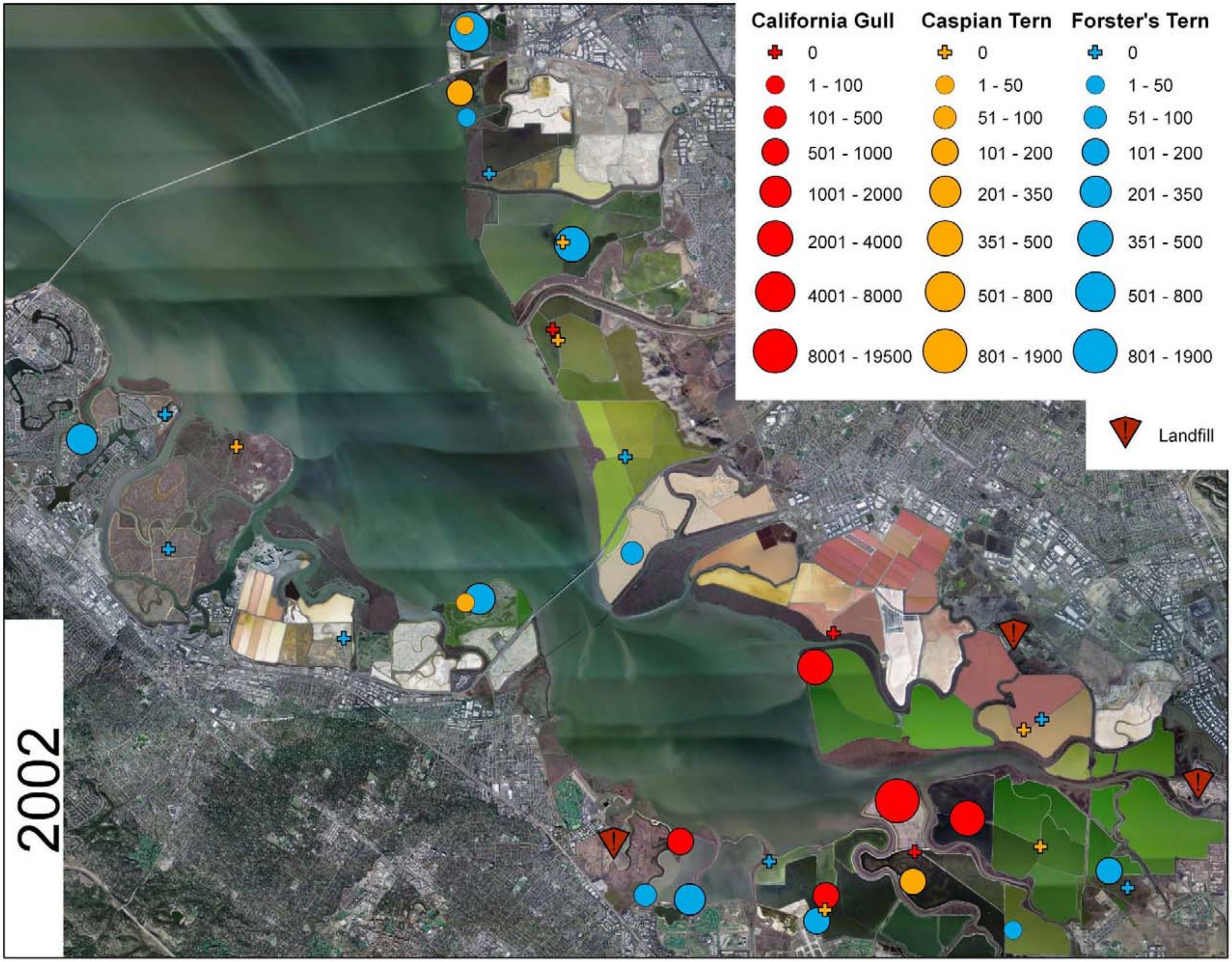

Figure 28. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 2002.

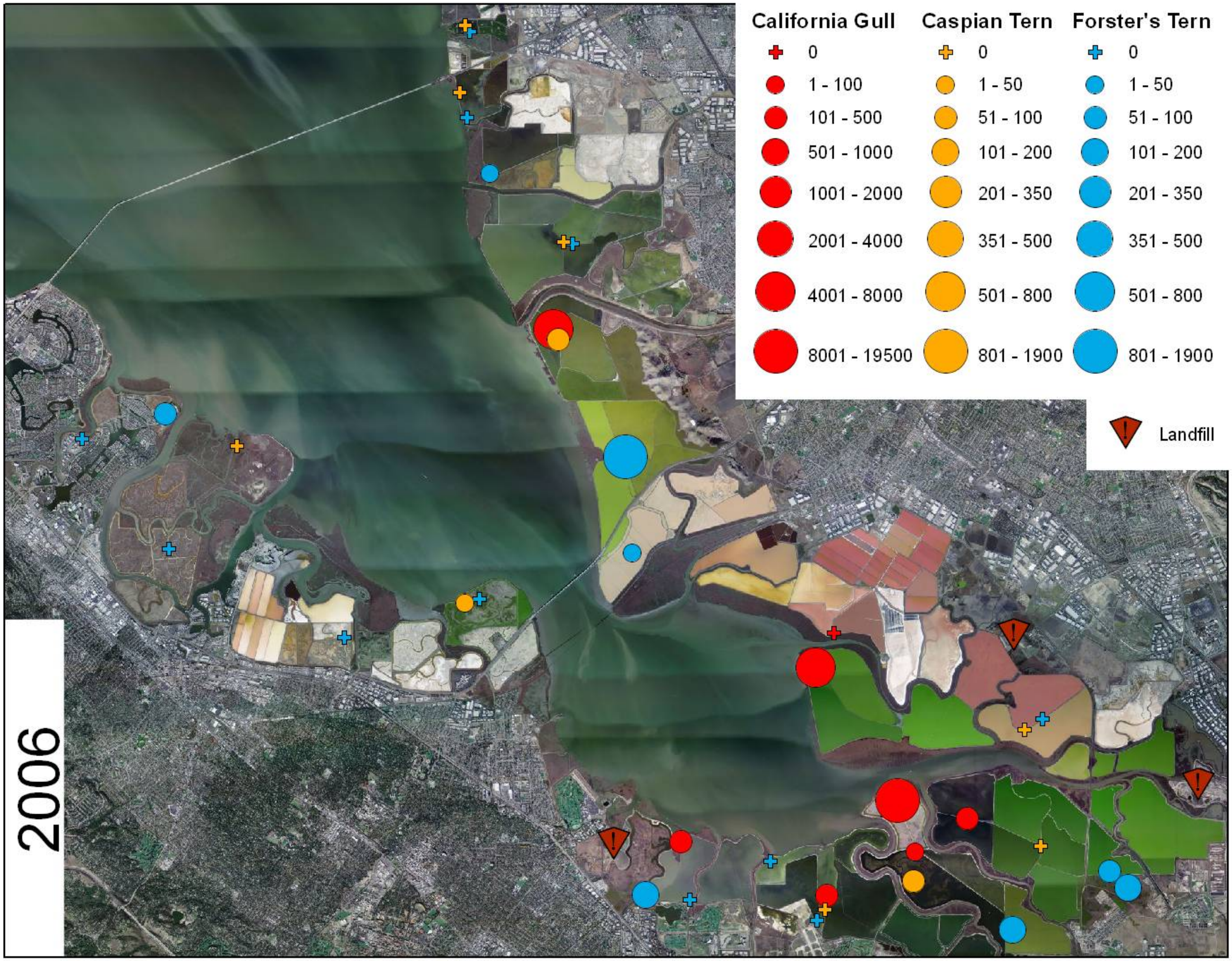

Figure 29. Size and location of California Gull, Forster's Tern, and Caspian Tern colonies in South San Francisco Bay, 2006.

Objective 2. *Examine the impact of gull predation on nesting success of American Avocet and Black-necked Stilts.*

Waterbird Nest Success

In 2005 and 2006, we monitored 1,007 Avocet, 552 Stilt, and 1,298 Forster's Tern nests (Table 1). Nest success was highly variable among sites, years, and species. In general, Forster's Terns had higher nest success than Avocets and Stilts at sites where they co-occurred, likely due to their habit of nesting colonially on islands. This provides increased refuge from terrestrial predators as well as colonial mobbing of aerial predators to deter predation.

Table 1. The number of Avocet, Stilt, and Forster's Tern nests monitored and their nest success during 2005 and 2006 breeding seasons in the San Francisco Bay.

	Avocet				Stilt				Forster's Tern			
	2005		2006		2005		2006		2005		2006	
Site	*N*	Nest Success	*N*	Nest Success	*N*	Nest Success	*N*	Nest Success	*N*	Nest Success	*N*	Nest Success
South Bay												
A16	164	86%	20	11%	3	*na*	6	19%	168	94%	131	23%
A8	188	35%	211	40%	0	*na*	2	*na*	115	73%	63	59%
New Chicago	28	33%	77	30%	98	48%	302	22%	17	63%	91	26%
Moffett	11	60%	55	28%	0	*na*	0	*na*	124	94%	3	41%
A7	---	---	4	23%	---	---	0	---	---	---	198	65%
Coyote Creek	---	---	37	16%	---	---	8	3%	---	---	0	*na*
Rect. Marsh	---	---	18	15%	---	---	9	80%	---	---	0	*na*
Newark	---	---	83	53%	---	---	35	50%	---	---	231	80%
Eden Landing	24	33%	72	22%	32	44%	22	51%	21	62%	0	*na*
North Bay												
Rush Creek	2	*na*	---	---	24	3%	---	---	0	*na*	---	---
Pond 4	13	5%	---	---	0	*na*	---	---	0	*na*	---	---
Figeras Tract	0	*na*	---	---	11	67%	---	---	0	*na*	---	---
Pond 2	0	*na*	---	---	0	*na*	---	---	136	57%	---	---
Total	**391**		**505**		**101**		**362**		**424**		**717**	

--- indicates that we did not search the area for nests

NA indicates that birds did not nest in high enough densities to sufficiently calculate nest success

Reduced nest success was almost entirely due to predation (91%, 94%, and 94% of destroyed nests), but flooding of eggs (6%, 5%, and 4%) and foaming of eggs (<1%, <1%, and 3%) also caused some nest destruction in Avocets, Stilts, and Forster's Terns, respectively, in 2006. Of those nests destroyed by predators, we used eggshell remains to help identify the type of predator responsible for the nest depredation event. In 51%, 61%, and 71% of nest depredations on Avocets, Stilts, and Forster's Terns, respectively, eggs simply went missing with no other signs of predation. Conversely, eggshell fragments remained at 29%, 36%, and 24% of nest depredations on Avocets, Stilts, and Forster's Terns, respectively. Only yolk was present at the remaining 20%, 4%, and 4% of nest depredations on Avocets, Stilts, and Forster's Terns, respectively. It is difficult to assign predators based on nest remains, but it is likely that gulls and foxes were responsible for many of the nest depredations where eggs simply went missing. Using remote video cameras (described below), gulls and foxes were the main predators that removed entire eggs from nests, but we did document other predators, like raccoons and gopher snakes, that removed eggs. Another possibility is that parents removed eggshells from nests after partial clutch depredation events (Ackerman et al. 2003) to reduce the likelihood of further nest depredation. For example, Avocets and Stilts commonly remove eggshells after chicks hatch, and we documented eggshell removal on our video footage. However, eggshell removal is only likely to occur following a partial clutch depredation event and not after complete clutch loss, which occurred in the majority of cases. We caution that evidence remaining at the nest after a depredation event is difficult to interpret (Larivière 1999).

Predator Identification

We added fake eggs (Figure 30) to 42 Avocet and 33 Stilt nests in 2006 and 9 Avocet nests in 2005. Of these, 33% of Avocet and 64% of Stilt nests were depredated by predators in 2006 and 78% of Avocet nests were depredated in 2005. For Avocets in 2006, 36% of egg depredations were caused by mammalian predators, 14% by avian predators, 14% of eggs were simply missing, 14% of fake eggs had unidentifiable marks, and 21% had no marks in the eggs despite the other eggs in the nest being depredated. For Avocets in 2005, 29% of depredations were caused by avian predators, 57% of eggs were simply missing, and

Figure 30. Beak marks in plasticine eggs that were added to natural nests to determine predator type.

14% of fake eggs had unidentifiable marks. For Stilts in 2006, 10% of depredations were caused by mammalian predators, 5% by avian predators, 5% of eggs were simply missing, 48% of fake eggs had unidentifiable marks, and 29% had no marks in the eggs despite the other eggs in the nest being depredated.

In summary of the fake egg study, a minimum of 14% (2006) to 29% (2005) of Avocet nest depredations were caused by avian predators, but we could not differentiate the actual bird type from the beak marks. Anecdotal evidence from our field observations indicate that gulls were probably causing these depredations, but Common Ravens and Red-Tailed Hawks were also present and are known to depredate bird eggs. Additionally, a large proportion of the fake eggs simply went missing (57% in 2005 and 14% in 2006) indicating likely depredation by avian predators carrying eggs away from nests, but foxes are also known to carry eggs away from nests. Therefore, predator type could not be readily assigned in these cases.

We improved our ability to accurately distinguish predators of eggs using remotely triggered infra-red video cameras (Figure 31). These cameras are expensive, so we were able to document predation at a smaller number of nests. We placed cameras near 54 Avocet nests and 21 Stilt nests in ponds A8, New Chicago Marsh, and Coyote Creek Lagoon. Overall, 54% of Avocet nests and 48% of Stilt nests were depredated. We documented 43 depredation events and identified 8 different predators of nests, including California Gulls, Red-tailed Hawks, Common Ravens, Striped Skunks, Gray Fox, Raccoons, Opossums, and Rats. Avocet nests were mainly depredated by Red-tailed Hawks (23%), California Gulls (15%), Gray Foxes (15%), Rats (15%), Striped Skunks (8%), Raccoons (8%), Opossums (8%), and Common Ravens (8%). Stilt nests were depredated by Striped Skunks (40%), Raccoons (40%), and Gray Foxes (20%). All gull depredation events occurred in A8.

Figure 31. Remote infra-red video cameras were used to identify predators of eggs, such as this Stilt nest in New Chicago Marsh.

Objective 3. Quantify effects of gull predation on American Avocets and Black-necked Stilts by estimating chick survival with radio telemetry.

Radio-marking

We radio-marked 161 Avocet (74 in 2005 and 87 in 2006) and 79 Stilt (33 in 2005 and 46 in 2006) chicks within a few days of hatching (Figure 32). All Stilt chicks were radio-marked within New Chicago Marsh in 2005 (33) and in New Chicago Marsh (N=45) and A8 (N=1) in 2006. Avocet chicks were radio-marked at several sites in 2005 (N=46 in A16, N=17 in A8, N=8 in New Chicago Marsh, N=2 in Coyote Creek Lagoon, and N=1 in A1) and 2006 (N=35 in A8, N=23 in New Chicago Marsh, N=13 in Newark 8&9, N=6 in Newark 4A, N=4 in AB1&2, N=2 in Newark 7, N=2 in Coyote Creek Lagoon, N=1 in A16, and N=1 in A7).

Figure 32. Avocet (shown here) and Stilt chicks were radio-marked at hatching and subsequently tracked until they fledged to determine survival and identify predators of chicks.

Chick Survival

Avocet and Stilt chicks commonly fledge around 27 days of age (Robinson et al. 1997, 1999). We estimated survival to 21 days of age because Stilt radio transmitters were extremely small and did not have enough battery life to last the full period until fledging. Kaplan-Meier product-limit survival estimates to 21 days after hatching were 22.3% (±6.2% SE) in 2005 and 7.1% (±3.3% SE) in 2006 for Avocet chicks and 39.2% (±11.9% SE) in 2005 and 64.7% (±7.4% SE) in 2006 for Stilt chicks. The odds of mortality were 2.43 (95% CL: 1.30–4.56) times greater in

2005 and 5.38 (95% CL: 2.95–9.80) times greater in 2006 for Avocet chicks than for Stilt chicks (Cox's Proportional Hazards Model: 2005: N=107, χ^2=7.65, P=0.006; 2006: N=133, χ^2=30.26, P<0.0001).

In 2005, the likelihood of mortality decreased with residual chick mass in each species (Cox's Proportional Hazards Model: N=107, χ^2=9.72, P=0.002); chicks were 1.25 (95% CL: 1.09–1.43) times more likely to survive with each 1-g increase in residual body mass at hatching. However, Julian hatching date did not influence the likelihood of survival for either species in 2005 (Cox's Proportional Hazards Model: N=107, χ^2=1.33, P=0.25).

In contrast, in 2006, Julian hatching date significantly influenced the likelihood of survival for both species (Cox's Proportional Hazards Model: N=133, χ^2=5.86, P=0.02); chicks were 1.02 (95% CL: 1.00–1.03) times more likely to die with each additional day later in the nesting season that they were hatched. Residual body mass at hatching did not influence mortality rates in 2006 (Cox's Proportional Hazards Model: N=133, χ^2=1.54, P=0.21) as they did in 2005.

The above analyses assumed that all Avocet (23% in 2005 and 14% in 2006) and Stilt (42% in 2005 and 15% in 2006) chicks that went missing were not depredated. This assumption likely caused our mortality rates to be underestimated since most chicks that go missing are actually depredated and the transmitters are simply carried to locations where we cannot hear them or they are destroyed when chicks are eaten. The majority of missing chicks occurred within 7 days of attachment when transmitters should still have been functioning properly and, hence, the chicks probably were depredated.

Therefore, we re-ran the above analyses and assumed that all chicks that went missing in ≤7 days were dead. In the revised analysis, survival estimates to 21 days after hatching were reduced to 13.9% (±4.2% SE) in 2005 and 5.1% (±2.4% SE) in 2006 for Avocet chicks and 31.7% (±10.1% SE) and 56.2% (±7.4% SE) in 2006 for Stilt chicks (Figure 33).

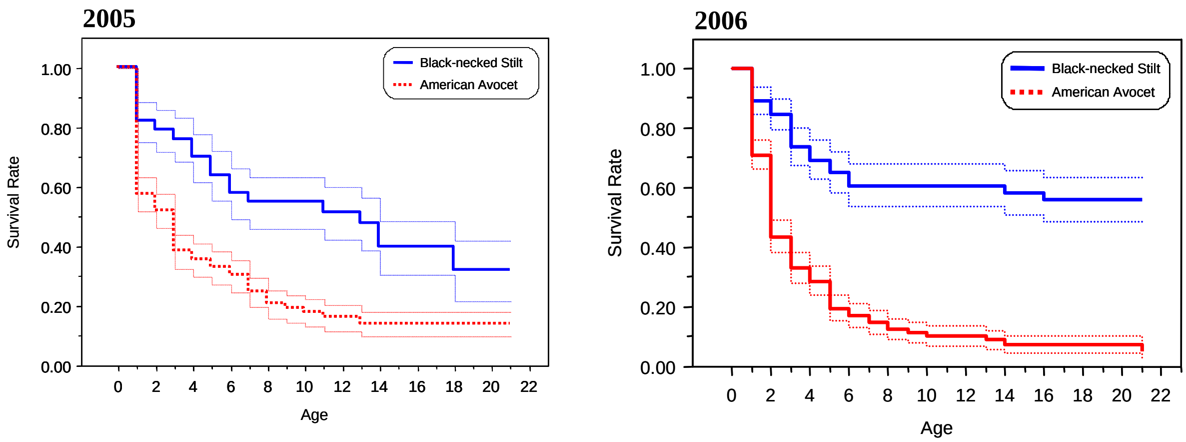

Figure 33. Survival rates±SE of Black-necked Stilt (blue line) and American Avocet chicks (red line) to 21 days post-hatching determined using Kaplan-Meier product-limit survival estimates in 2005 and 2006. Analysis assumes chicks that went missing ≤7 days had died.

Using this revised analysis, the odds of mortality were 2.52 (1.45–4.39) times greater in 2005 and 4.65 (2.72–7.93) times greater in 2006 for Avocet chicks than for Stilt chicks (Cox's Proportional Hazards Model: 2005: N=107, χ^2=10.67, P=0.001; 2006: N=133, χ^2=31.71, P<0.0001). In 2005, the likelihood of mortality decreased with residual chick mass (Cox's Proportional Hazards Model: N=107, χ^2=6.18, P=0.01) but not in 2006 (Cox's Proportional Hazards Model: N=133, χ^2=1.67, P=0.20). Instead, Julian hatching date significantly influenced the likelihood of survival for both species in 2006 (Cox's Proportional Hazards Model: N=133, χ^2=7.13, P=0.01), but not in 2005 (Cox's Proportional Hazards Model: N=107, χ^2=1.81, P=0.18).

Predators of Avocet Chicks

Of the 87 radio-marked avocet chicks in 2006, 66% (57) were depredated, 14% (12) went missing, 10% (9) were found dead with no signs of depredation, 6% (5) died due to water or foam exposure, 3% (3) were considered to have fledged, and 1% (1) had a transmitter fail. Of the 57 confirmed depredated avocet chicks, 91% (52) were depredated by avian predators, 7% (4) were depredated by small mammals (skunks, raccoons, weasels, squirrels, etc.), and we were not able to determine the predator type in one case.

Large proportions (83%) of the avian depredations were caused by California Gulls. In fact, 32 radio transmitters that were attached to chicks were subsequently found within the A6 California

Gull colony (estimated at 19,456 breeding adults plus their chicks) and 10 radio transmitters were found within the Coyote Hills gull colony (estimated at 7,442 breeding adults plus their chicks). This indicates that depredated chicks were carried back to gull colonies to feed their young. The remaining 9 avian depredations were caused by Red-tailed Hawks (4), Northern Harriers (1), Herons and Egrets (2), and unidentified avian predators (2).

We documented extensive predation by California Gulls on Avocet chicks in several ponds located both near to and far from the gull colonies. For example, of the 32 radio transmitters we found within the A6 gull colony, 66% (21) of the Avocet chicks had hatched and were radio-marked in A8 (~4.6 km), 25% (8) were hatched in New Chicago Marsh (~6.0 km), 1 was hatched in A7 (~2.0 km), 1 was hatched in A16 (~5.5 km), and 1 was even hatched in Newark 8&9 (~12.5 km). Similarly, for the 10 radio transmitters we found within the Coyote Hills gull colony, half of the Avocet chicks were hatched in Newark 8&9 (~2.4 km) and half were hatched in Newark 4A (~4.0 km). Examining gull depredation by pond, 75% of the 28 depredated Avocet chicks in A8, 85% of the 13 depredated Avocet chicks in Newark 8&9 and 4A, and 67% of the 12 depredated Avocet chicks in New Chicago Marsh were caused by gulls.

We also documented high rates of gull predation on Avocet chicks in 2005. Of the 74 radio-marked Avocet chicks in 2005, 51% (38) were depredated, 23% (17) went missing, 10% (8) were found dead with no signs of depredation, 7% (5) had dropped their transmitters, 5% (4) had an unknown fate (chicks either had dropped their transmitter or were depredated), and 3% (2) were considered to have fledged. Only 4 of the 17 Avocet chicks that went missing had been tracked for ≥7 days, indicating that many of these chicks may have been depredated and potentially carried away by avian predators. Of the 38 confirmed depredated Avocet chicks, 74% (28) were depredated by avian predators, 16% (6) were depredated by mammalian predators (foxes, skunks, weasels, etc.), 5% (2) were depredated by snakes, and 5% (2) were found down burrows, indicating depredation by either weasels, snakes, or scavenged by ground squirrels.

More than 54% of the avian depredations were caused by gulls in 2005; we found 15 radio transmitters within the A6 California Gull colony (estimated at 18,418 breeding gulls plus their chicks) indicating that depredated chicks had been carried there by gulls. The remaining 13 avian depredations were caused by Herons and Egrets (4), Hawks (2), Burrowing Owls (1), and undetermined avian predators (6). Examining gull depredation by pond, 36% of the 28 depredated Avocet chicks in A16, 80% of the 5 depredated Avocet chicks in A8, and none of the 4 depredated Avocet chicks in New Chicago Marsh were caused by gulls.

Our estimates of gull predation on Avocet chicks (40% in 2005 and 74% of all depredations in 2006) are minimum estimates. It is likely that many more chicks were actually depredated by gulls but that we were not able to identify predators in these circumstances. For example, 23% (2005) and 14% (2006) of the radio-marked Avocet chicks simply disappeared. These chicks were likely depredated and carried away by predators to areas we were not able to receive radio transmitter signals.

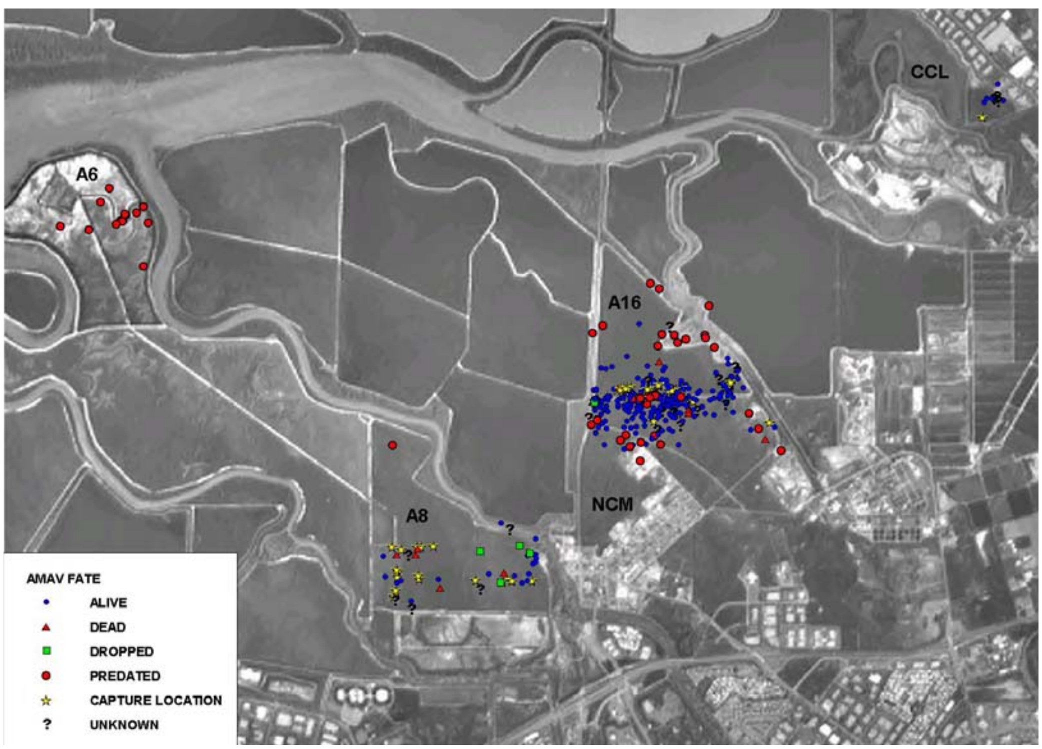

Figure 34. Locations and fates of radio-marked Avocet chicks in Alviso, 2005.

Figure 35. Locations and fates of radio-marked Avocet chicks in Alviso, 2006.

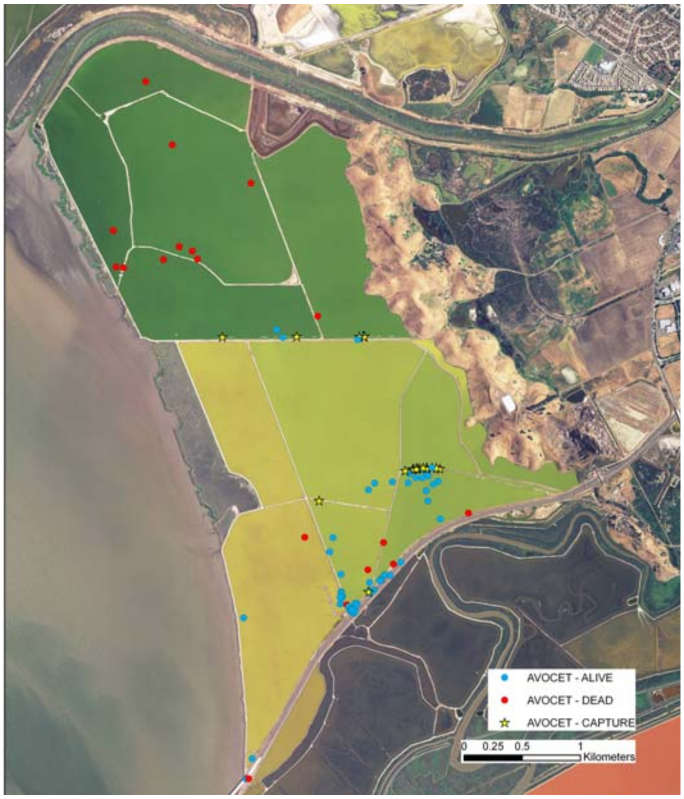

Figure 36. Locations and fates of radio-marked Avocet chicks in Newark, 2006.

Predators of Stilt Chicks

Stilt chicks had much higher survival than Avocet chicks in 2006 and we therefore documented a smaller number of predations from which to identify predators. Of the 46 radio-marked Stilt chicks in 2006, 15% (7) went missing, 13% (6) were depredated, 11% (5) were found dead with no signs of depredation, 9% (4) died due to water or foam exposure, and 52% (24) were considered to have fledged. Of the 6 confirmed depredated Stilt chicks, 50% (3) were depredated by California Gulls and found within the A6 colony, 1 was depredated by an unidentified avian predator, and we were not able to identify the predator in 2 additional cases.

Stilt chicks also had higher survival than Avocet chicks in 2005. Of the 33 radio-marked stilt chicks in 2005, 42% (14) went missing, 24% (8) were found dead with no signs of depredation, 21% (7) were depredated, 6% (2) had dropped their transmitters, and 6% (2) were considered to have fledged. Eight of the 14 Stilt chicks that went missing had been tracked for ≥15 days, indicating that many of these chicks probably survived but that the transmitters may have stopped functioning (expected transmitter life was >21 days but some radios were fading after 15 days). Of the 7 confirmed depredated Stilt chicks, 43% (3) were depredated by avian predators (1 Burrowing Owl, 1 Corvid, 1 Heron and Egret), 29% (2) were depredated by mammals, and 29% (2) were found down burrows, indicating depredation by either weasels, snakes, or scavenged by ground squirrels. No Stilt chicks were confirmed to be depredated by gulls in 2005, in contrast to our 2006 data.

In summary, we estimated that California Gulls were responsible for 61% of all depredations of Avocet chicks, and for 23% of depredated Stilt chicks in 2005 and 2006.

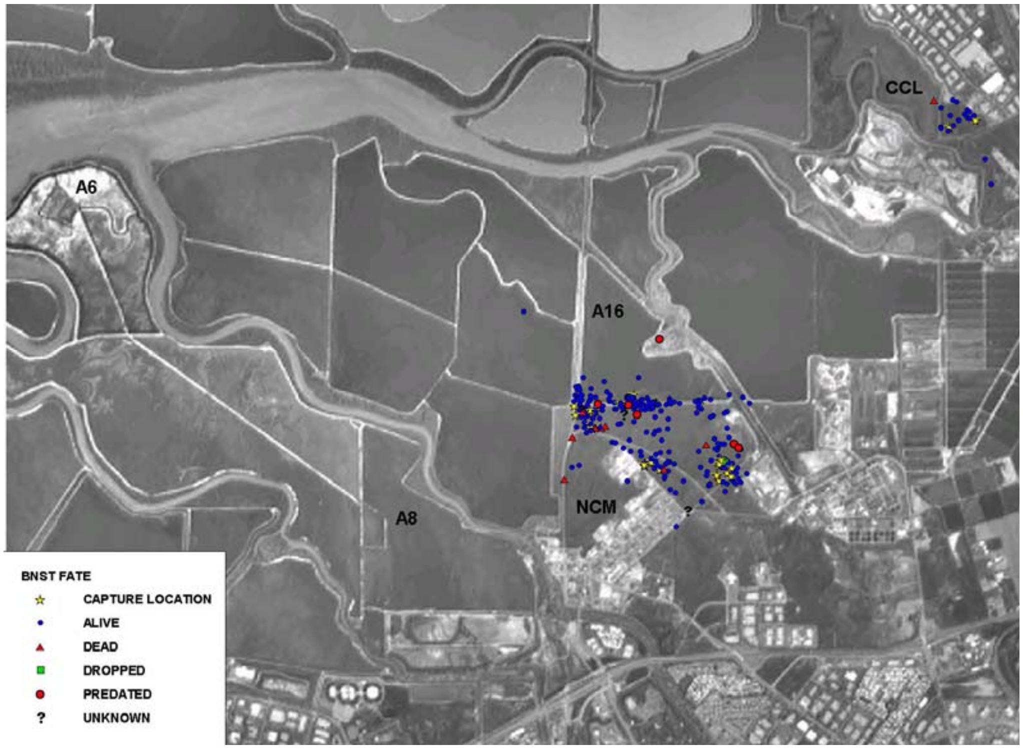

Figure 37. Locations and fates of radio-marked Stilt chicks in Alviso, 2005.

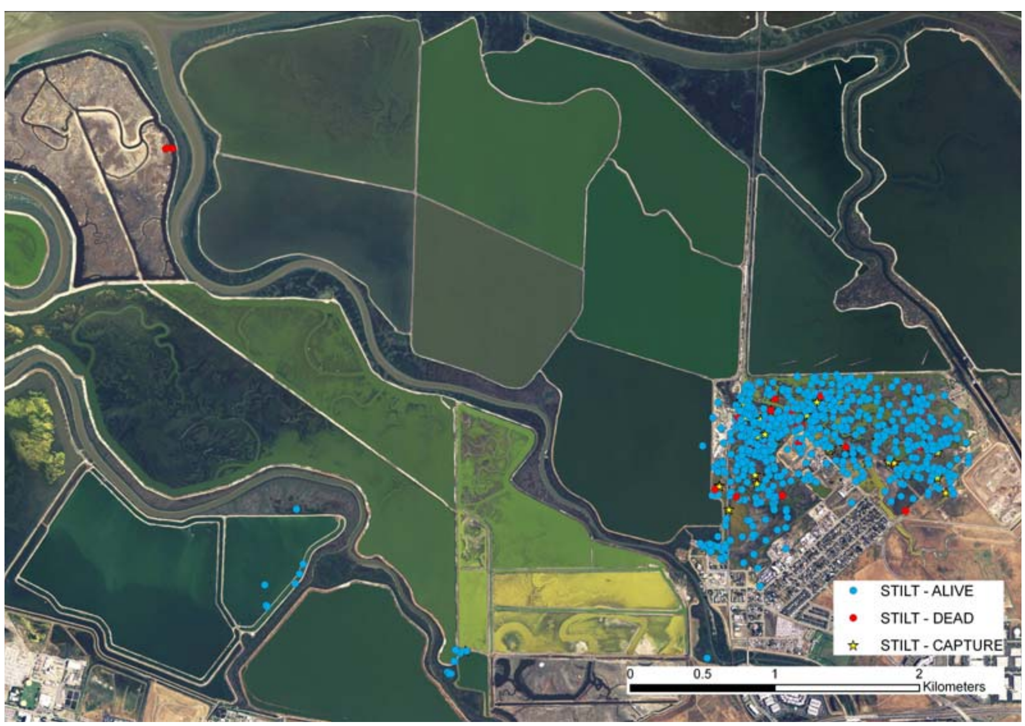

Figure 38. Locations and fates of radio-marked Stilt chicks in Alviso, 2006.

Chick Movements

One way to assess effects of predation pressure on shorebird chicks is to examine their movements and habitat use. Avocet and Stilt chicks almost always stayed within the pond where they were hatched during the chick rearing period (Figures 34-38). However, there was one exception to this; Avocet chicks radio-marked in A16 often moved into the adjacent New Chicago Marsh after hatching in 2005. In 2006, we were not able to assess these movement patterns because Avocets did not nest in high enough densities in A16 to radio-mark chicks. The lack of Avocet nesting on A16 in 2006 (Table 1) may have been due to the fact that large aggregations of California Gulls were roosting on the four nesting islands well into the typical nest initiation dates for Avocets (18 April). Forster's Terns, on the other hand, were able to nest at higher densities on A16 (Table 1) because they initiate nests later in the breeding season (17 May) and few gulls remained roosting on the islands at this time.

In 2005, radio-marked Avocet chicks in A16 were predominantly located around the A16 and New Chicago Marsh levee, the southern A16 islands, and the northwestern portion of New Chicago Marsh (Figure 34). Depredated chicks were found mainly within the A6 gull colony and along levees and canals surrounding A16 and New Chicago Marsh (Figure 34). Avocet chicks that were found dead, with no obvious signs of depredation, were located primarily along islands and levees within 20 cm of the water, indicating possible death caused by physical exertion or thermoregulatory stress during swimming.

Avocets that survived longer moved from A16 into New Chicago Marsh, where they were able to find emergent vegetation cover to help escape aerial predation by gulls. For Avocet chicks radio-marked in A16 (2005) and that we had ≥10 locations, 26 out of 30 (87%) movement vectors from the site of capture to the last known alive location traveled south into New Chicago Marsh for an average movement of 265±202 m (Figure 39). Maximum known distances traveled from the site of capture were 423±267 m for Avocet chicks (N=40, includes only chicks with a known alive location).

In contrast, Stilt chicks stayed within New Chicago Marsh during the chick rearing period with occasional movements into the southern edge of A16 to feed on the abundant aquatic invertebrates along the A16 and New Chicago Marsh shoreline (Figure 37). Stilt chicks moved an average of 254±299 m (chicks with ≥10 locations; N=22) from the capture site to the last known alive location (Figure 39). Maximum known distances traveled from the site of capture were 540±280 m for Stilts (N=26, includes only chicks with a known alive location). No Stilt chicks were confirmed to be depredated by gulls in 2005, in contrast to Avocet chicks. Stilt chicks probably avoided gull predation by using habitats with more emergent vegetation cover that is characteristic of New Chicago Marsh (Figures 37 and 38). As an indication of this, mean vegetation height within 1-m around Stilt nests was 18 cm in New Chicago Marsh compared to 0 cm for Avocet nests in A16.

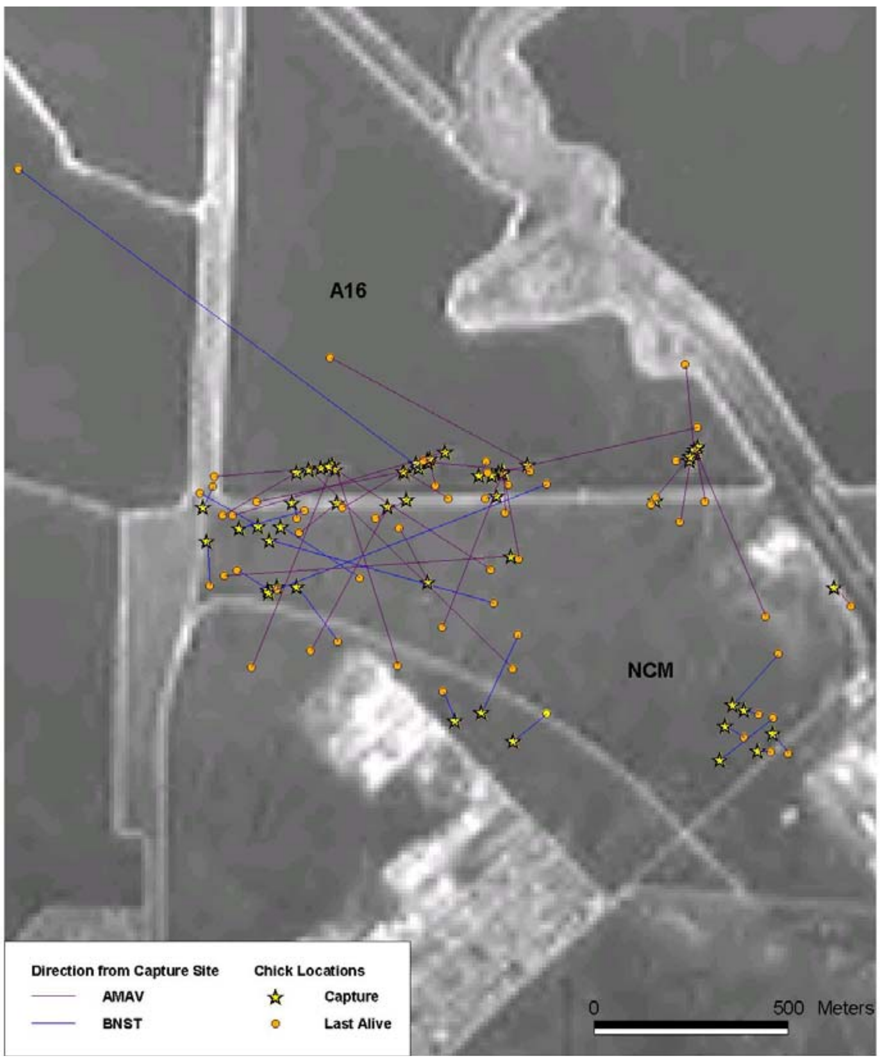

Figure 39. Movements of radio-marked Avocet (red lines) and Stilt chicks (blue lines) from capture site (stars) to the last location where the chick was known to still be alive (circles) in ponds A16 and New Chicago Marsh (NCM) in 2005. Only chicks with ≥10 locations were used in this analysis.

MANAGEMENT IMPLICATIONS AND RECOMENDATIONS

The California Gull breeding population in the South San Francisco Bay continues to increase exponentially with no sign of slowing. The A6 gull colony is still the largest and continues to grow at a rapid pace, but the Coyote Hills and Mowry gull colonies have increased most rapidly in the past couple of years. Similarly, California Gull predation on Avocet chicks increased from 40% to 74% of all depredations and on Stilt chicks from 0% to 50% in 2005 and 2006, respectively. These limited data indicate a potential increasing trend in predation rates, although we have only a limited time series of two years of data. We also documented that California Gull predation on shorebird chicks was not limited to a single site, but instead was prevalent throughout the main nesting areas for Avocets (A7, A8, A16, New Chicago Marsh, Coyote Creek Lagoon, and Newark ponds 4, 5, 8, and 9), Stilts (New Chicago Marsh), Forster's Terns (A7, A8, A16, New Chicago Marsh, and Newark), Caspian Terns (A7), and Snowy Plovers (A8). Although California Gulls breeding in A6 were responsible for the majority of shorebird chick depredations (83%), we also found many depredated chicks within the Coyote Hills gull colony (17%). These data indicate that gull predation on native breeding waterbirds is widespread throughout the South Bay and may be increasing.

The South Bay Salt Pond Restoration Project may displace gull colonies from current nesting sites and result in higher predation rates on breeding waterbirds. For example, plans to breach the A6 (Knapp) salt pond in 2008 will displace the >19,000 gulls currently breeding at this site (Figure 40). It is likely that the majority of these gulls will move to nearby nesting islands, such as in A7, A8, and A16, and displace breeding waterbirds. This is disconcerting because these sites currently support the largest breeding populations of Avocets (A8 and A16) and Caspian Terns (A7), and many of the largest breeding colonies of Forster's Terns (A7, A8, and A16) and Snowy Plovers (A8), in the South San Francisco Bay. In addition, New Chicago Marsh contains the largest breeding population of Stilts in the entire San Francisco Bay Estuary. Gull predation on Stilt eggs and chicks is likely to become a more significant problem to Stilt populations if gulls relocate their breeding colonies to nesting islands in A16, which is directly adjacent to New Chicago Marsh.

In 2006, we observed a small number of gulls establish a new nesting site because of limited breeding areas in A6 due to flooding. This may be our first glimpse into how gulls will relocate once A6 is breached. Gulls moved their nesting sites closer to levee roads and some gulls even nested in A5 (84 nests) for the first time in over two decades. A5 has several small islands but they are not nearly large enough to support the A6 gull colony, and therefore we are likely to see nearby salt ponds with larger islands (such as A7, A8, and A16) become colonized by gulls.

Our results suggest that managers and the South Bay Salt Pond Restoration Project Management Team may want to reduce the impacts of gulls to other breeding waterbirds and determine where displaced gulls will relocate. The planned A6 breach could be used as a learning opportunity to understand how displaced gulls will relocate from former nesting colonies and the consequences for other breeding waterbirds. Recommendations for priority gull research include an understanding of gull movement using telemetry, the importance of landfills to sustaining gull populations and diet, and continued monitoring of Avocet, Stilt, and Forster's Tern egg and chick survival as indicators for predation on other breeding waterbirds, including threatened Snowy Plovers. Currently, an opportunity exists to supplement the ongoing California Gull study assessing the contribution of landfills to gull diet using stable isotopes (Ackerman et al., USGS-FWS Science Support Funds). This study could be greatly improved with more direct studies of gull diet using regurgitates, collections, and prey deliveries to chicks as isotope studies can only provide a rough understanding of marine versus terrestrial input to diet. In addition, the data contained within this report provides some of the baseline data for comparison to future surveys collected during and after management activities to document the effects of displacing gulls via breaching nesting sites, hazing, active removal, or egg control for future adaptive management.

Figure 40. California Gulls nesting within the A6 (Knapp) colony.

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