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Trends in Caspian Tern Nesting and Diet in San Francisco Bay: Management Implications

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ABSTRACT Caspian terns (*Hydroprogne caspia*) nesting in the Columbia River estuary between Oregon and Washington, USA, are known to inflict significant losses to threatened juvenile salmonids (*Oncorhynchus* spp.), but the impact of Caspian terns nesting in San Francisco Bay on survival of juvenile salmonids out-migrating through the Bay are unknown. We investigated breeding population size, nesting ecology, and diet of

Caspian terns in the San Francisco Bay area during 2003-2009 to help assess the potential for (1) tern nesting habitat enhancement and/or restoration but also (2) possible negative effects of terns on threatened salmonids. The number of breeding Caspian terns declined 36% from 2003 to 2009 and productivity declined 69%, in part due to the decline of the Brooks Island colony, the largest in the Bay Area. Marine forage fishes (silverside [Atheridae], surfperch [Embiotocidae], anchovy [Engraulidae], and others) were the predominant prey types in Caspian tern diets from San Francisco Bay; however, diet composition varied among colonies, suggesting that fish assemblages near colonies differed and nesting terns tended to forage near their colony. Juvenile salmonids comprised 22.9% of the diet of terns nesting at Knight Island in the North Bay, 5.3% of the diet of terns nesting on Brooks Island in the Central Bay, and 0.1% of the diet of terns nesting at Eden Landing in the South Bay. Our results suggest that construction of suitable tern nesting islands in the South Bay will help maintain and restore the breeding population of Caspian terns in the region without significantly enhancing mortality of salmonid stocks of conservation concern in the San Francisco Bay area.

KEYWORDS California, Caspian tern, colony restoration, colony size, diet composition, *Hydroprogne caspia,* limiting factors, nesting success, *Oncorhynchus*, salmonids, San Francisco Bay.

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The history of Caspian tern breeding colonies in the San Francisco Bay area has been dynamic, with frequent changes in both the location and size of colonies. The first nesting record for Caspian terns in this region was in 1916, when Caspian tern eggs were collected from a site in the South Bay (Grinnell and Miller 1944). Prior to 1916, Caspian terns were only known as a nesting species in California at interior lakes and marshes. In 1922, a Caspian tern colony (7 nests) was discovered in the South Bay on a salt pond levee near the east end of the Dumbarton Bridge in an area now called Coyote Hills (DeGroot 1931). In 1924, this colony relocated approximately 2.5 km further south and was active until 1966, having grown to 299 nesting pairs (Gill 1972). From the late 1960s until the onset of this study, nesting by Caspian terns in the South Bay has been reported at nine different locations, with between one and five different colonies active during any particular year (Gill 1972, Strong et al. 2004). Caspian terns first nested in the North Bay in the Napa River marsh in the 1970s and in the Central Bay at Brooks Island in 1985. Since the mid 1980s, only three sites have been used by nesting Caspian terns in the Central Bay (i.e., Alameda, Brooks Island, and Agua Vista Park), and only one site has been used by nesting Caspian terns in the North Bay (i.e., Knight Island; Strong et al. 2004). Bay-wide estimates of the number of breeding pairs of Caspian terns appeared to be in decline from 1981, when a total of about 1,500 breeding pairs nested at five different colonies (Gill and Mewaldt 1983), to 2001, when about 828 breeding pairs nested on six different colonies (Shuford and Craig 2002).

For at least the past decade, Brooks Island has been the site of the largest Caspian tern colony in the San Francisco Bay area. Brooks Island is a natural island in central San Francisco Bay near the City of Richmond, and is owned by the City and managed under a long-term lease by the East Bay Regional Parks District. The tern colony is located on a low-lying sandy spit that extends to the northwest of the main part of the island, consisting of dredged material from the Port of Richmond shipping channel. The size of the Brooks Island Caspian tern colony in 2001 was estimated at 512 breeding pairs, or about 62% of the estimated total number of breeding pairs in the Bay Area during that year (Shuford and Craig 2002). The terns nested in close proximity to gull colonies that also occupied the spit: a colony of western gulls (*Larus occidentalis*) that has traditionally used Brooks Island, and a newly-formed colony of California gulls (*L. californicus*) that has expanded since 2001. Brooks Island is a popular destination for recreational boaters, and is located beneath the flight path of recreational and commercial aircraft. Rats (*Rattus* sp.) have been inadvertently introduced to Brooks Island and other mammalian predators, such as raccoons (*Procyon lotor*) and red foxes (*Vulpes vulpes*), have threatened the waterbird colonies in the past (S. Bobzien, East Bay Regional Parks District, personal communication). Consequently, expanding gull colonies, nest predation, and human disturbance may all limit the size of the Caspian tern colony on Brooks Island. Published literature is lacking, however, on many aspects of the nesting ecology of Caspian terns on Brooks Island and at other colonies in the San Francisco Bay area.

Further north along the Pacific Coast, the Columbia River estuary supports the largest known concentration of nesting Caspian terns ever documented (Wires and Cuthbert 2000, Suryan et al. 2004). Currently, these birds are nesting at one colony on East Sand Island (ca. 10,700 breeding pairs in 2008), where millions of salmonid smolts, some listed as threatened or endangered under the U.S. Endangered Species Act (ESA), are consumed annually (BRNW 2009). In 2008, the U.S. Army Corps of Engineers (USACE) began implementing management actions for Caspian terns that were described in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* (USFWS 2005, 2006). This management plan, which was developed jointly by the USACE, the U.S. Fish and Wildlife Service (USFWS), and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island to alternative colony sites in interior Oregon, Northeastern California, and the San Francisco Bay area by 2015. The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin, while at the same time ensuring the protection and conservation of Caspian terns in the Pacific Coast region.

As part of this plan, nesting habitat would be created for Caspian terns at three locations in the San Francisco Bay area. Two islands would be constructed as Caspian tern nesting habitat in the South Bay, one at Don Edwards National Wildlife Refuge and one at Hayward Regional Shoreline, and nesting habitat would be improved and expanded at the existing colony site on Brooks Island in the Central Bay. Social attraction techniques (decoys, audio playback systems; Kress 1983, 1998) would then be used to attract Caspian terns displaced from the Columbia River estuary to the newly created or enhanced nesting sites in the Bay Area. Some fisheries managers in the Bay Area, however, have raised concern over the prospect of relocating thousands of pairs of Caspian terns to an area where efforts are underway to restore several ESA-listed stocks of salmonids. In particular, several ESA-listed stocks of Chinook salmon (*O. tshawytscha*) from the Sacramento-San Joaquin Basin out-migrate through San Francisco Bay, and are potentially susceptible to Caspian tern predation.

In the present study, our objective was to assess breeding population size, nesting ecology, and diet of Caspian terns in the San Francisco Bay area to help evaluate the suitability of proposed management initiatives for enhancing the breeding population of Caspian terns in this region. The specific objectives of this study were to determine the diet composition, colony size, nesting success, and factors limiting colony size and nesting success for Caspian terns nesting at colonies in the San Francisco Bay area during 2003-2009. These data will help assess the suitability of sites chosen for future tern colony restoration in the San Francisco Bay area. In particular, we sought to assess how diet composition of nesting Caspian terns varies by colony location within the various sectors of the Bay (i.e., North, Central, and South Bay), and which local stocks of forage fishes, particularly salmonids, are likely to be affected by increases in numbers of nesting Caspian terns. This study was also designed to investigate whether food availability, nest predation, nest site competition, human disturbance, or other extrinsic factors may strongly limit some tern colonies in the Bay Area and potentially render them population sinks (Penland 1982). Finally, data collected as part of this study will determine current trends in colony size, nesting distribution, and habitat use of Caspian terns in San Francisco Bay for comparison with published trends in Caspian tern nesting ecology in the Bay Area prior to 2003 (Gill and Mewaldt 1983, Wires and Cuthbert 2000, Strong et al. 2004, Suryan et al. 2004).

STUDY AREA

This study was conducted at Caspian tern colonies located in the San Francisco Bay area, California during 2003-2009 (Figure 1, Table 1). For the purposes of this study, the San Francisco Bay area was divided into three discrete sectors: the North Bay (San Pablo Bay, the area north of the Richmond-San Rafael Bridge to Carquinez Strait), the Central Bay (the area south of the Richmond-San Rafael Bridge to Hunters Point on the west bank and San Leandro Channel on the east bank), and the South Bay (the area south of Hunters Point and San Leandro Channel; Figure 1). Caspian tern breeding colonies were located in the North Bay at Knight Island (active during 2003-2005); in the Central Bay at Brooks Island (active during 2003-2009) and Agua Vista Park (active during 2003-2009); and in the South Bay at Alviso Ponds A-7 (active during 2003-2006), Eden Landing E-10 (formerly Baumberg Pond; active during 2003-2004 and 2008-2009), Coyote Hills (active during 2005-2006), Ravenswood (active during 2006-2007), Stevens Creek B-2 (active during 2007-2009), and Redwood Shores (active during 2009; see Table 1, Shuford and Craig 2002, and BRNW 2009 for site descriptions). Our primary study sites were Knight Island in the North Bay, Brooks Island in the Central Bay, and Eden Landing E-10 in the South Bay, with limited data collection at the other colonies. Our project personnel collected all data presented for 2003-2005 and 2008-2009, while the data on colony status and approximate colony size during 2006-2007 were provided by the San Francisco Bay Bird Observatory (C. Strong, San Francisco Bay Bird Observatory, personal communication) for the Agua Vista colony and all South Bay tern colonies, and by U.S. Fish and Wildlife Service (G. McChesney, U.S. Fish and Wildlife Service, personal communication) and Humboldt State University (P. Capitolo, Humboldt State University, personal communication) for the Brooks Island and Knight Island colonies (see Capitolo et al. 2009).

METHODS

Colony monitoring was conducted during the Caspian tern breeding season, which occurred from late March through late July/early August. We constructed observation blinds at the periphery of some colonies (Brooks Island, Knight Island, Eden Landing E-10, and Stevens Creek B-2) to facilitate colony observations without disturbing nesting terns; otherwise, colonies were observed from a vehicle or mainland vantage point that was sufficiently distant from the colony to avoid disturbance. Data on number of terns on the colony, diet composition, and causes of tern nesting failure were collected by observers regularly (2-7 days per week) at the primary study sites (i.e., Brooks Island, Eden Landing E-10, and Knight Island). Other colonies were visited on a less frequent basis (1-2 days per week), primarily to determine colony status.

With the exception of the large Caspian tern colony on Brooks Island, the number of Caspian terns nesting at colonies in the San Francisco Bay area was estimated from ground counts of incubating adult terns near the end of the incubation period, when maximum colony attendance was assumed (Bullock and Gomersal 1981, Gaston and Smith 1984). At Brooks Island, colony size was estimated by counting the total number of Caspian terns using low-altitude, high-resolution aerial photography of the colony taken near the end of the incubation period. The average of three independent counts of adult terns in aerial photography was then adjusted to reflect the total number of breeding pairs using the ratio of sitting terns to total terns on plots visible from an observation blind adjacent to the tern colony.

Nesting success was determined by counting the total number of chicks on colony about one week prior to the median fledging date (~ one week after the first chick fledged) and dividing by the estimated number of breeding pairs at the time of the aerial photography. We assumed that at this stage of the fledging period the number of young that had already fledged and left the colony would approximate the number of chicks counted on-colony that would not survive to fledging (Roby et al. 2002, Roby et al. 2003).

Diet composition was determined for Caspian terns nesting at Brooks Island in the Central Bay during 2003-2005 and 2008-2009; at Knight Island in the North Bay during 2003-2005; and at Eden Landing E-10 in the South Bay during 2003 and 2008-2009. Because breeding adult Caspian terns transport single whole fish in their bills (hereafter referred to as "bill loads") back to the colony to feed to their mates (courtship meals) or young (chick meals), taxonomic composition of the diet can be determined by direct observation of adults as they return to the colony with bill loads using binoculars and spotting scopes. Bill load observations were conducted at high tide and at low tide, to control for potential tidal and time of day effects on diet composition. Bill loads were identified to the lowest taxonomic grouping possible, usually to family. We were confident in our ability to distinguish salmonids from non-salmonids and to distinguish among most non-salmonid taxa based on direct observations from blinds. We also were confident in our ability to distinguish anadromous salmonids (i.e., primarily Chinook salmon and steelhead trout [*O. mykiss*]) from non-anadromous salmonids (i.e., resident trout) stocked in nearby reservoirs or rivers, based on fish body shape and coloration. Visual identifications were verified using voucher specimens and photographs whenever possible. We assumed that prey items brought back to the colony by breeding adults was representative of the overall diet of Caspian terns at that particular colony. This assumption is supported by data from the Columbia River estuary, where prey composition in gut contents did not differ significantly from prey composition in bill loads (Collis et al. 2002).

We attempted to identify from 200 to 350 tern bill loads per week at the Brooks Island colony and from 50 to 100 bill loads per week at the Knight Island and Eden Landing E-10 colonies. The percent of each prey type in tern diets, based on identifiable prey items, was calculated for each 2-week period throughout the nesting season. The diet composition of Caspian terns at each colony over the entire breeding season was based on the average of the percentages for the 2-week periods. This method was used to avoid a bias toward weeks with high sample sizes of identified bill loads; sample sizes varied among weeks due to seasonal fluctuations in the number of terns on-colony and their foraging success. The coefficient of variation was calculated to describe variability in average diet composition for each unique prey-type observed at each of the three primary study colonies (Knight Island, Brooks Island, and Eden Landing E-10). See Collis et al. (2002), Roby et al. (2002), Roby et al. (2003), and Antolos et al. (2005) for further details on the methodology used in this study for collecting data at Caspian tern colonies.

RESULTS

Colony Size

From 2003 to 2009 there was an average of 1,073 breeding pairs (range = 830 - 1,372) of Caspian tern nesting in the Bay Area, with a total of nine different islands occupied by nesting terns during the seven-year study period (Table 2). Six of these breeding colony sites in the San Francisco Bay area were used by nesting Caspian terns in 2009, when a total of 830 pairs nested (Table 2). This represents a 36% decline in the breeding population of Caspian terns from 2003, when about 1,287 pairs nested in the Bay Area (Table 2). The observed decline in the number of Caspian terns nesting in the Bay Area was due to first the decline and then the abandonment of the second largest Caspian tern colony in the Bay Area (Knight Island), and the subsequent decline in size of the largest Caspian tern colony in the Bay Area (Brooks Island) (Table 2).

The only Caspian tern colony in the North Bay during the study period was at Knight Island, a colony that was active during 2003-2005 but not since (Table 2). There were two Caspian tern colonies in the Central Bay (at Brooks Island and Agua Vista Park) throughout the study period (2003-2009), and these were the only two colonies that were active throughout the study period. The total number of Caspian terns nesting in the Central Bay in 2009 was 689 breeding pairs, the lowest level recorded during the study period (Table 2). In contrast to the North Bay and Central Bay, Caspian terns nesting in the South Bay increased both in the number of colonies (from two colonies in 2003 to four colonies in 2009) and in the total number of breeders (from 85 breeding pairs in 2003 to 141 breeding pairs in 2009; Table 2).

Most breeding pairs of Caspian terns in the San Francisco Bay area nested at the Brooks Island colony, including in 2009, the last year of our study, when 82% of the Bay Area breeding population nested on Brooks Island. The number of Caspian terns nesting on Brooks Island, however, has been declining since 2004, when 1,040 breeding pairs nested there (Table 2). The size of the Brooks Island Caspian tern colony in 2009 (about 681 breeding pairs) was the lowest recorded during our study (Table 2).

Nesting Success

Nesting success of Caspian terns breeding at colonies in the Bay Area averaged 0.39 fledglings produced per breeding pair over the seven-year study. Nesting success declined from a high of 0.55 fledglings per breeding pair in 2003 to a low of 0.17 fledglings per breeding pair in 2009 (Table 3). This decline was due to declines in nesting success for Caspian terns nesting at colonies in the North Bay and in the Central Bay (Table 3). In the South Bay, however, where tern nesting success was generally lower than it was in the North Bay and Central Bay at the outset of our study, nesting success has remained relatively stable throughout the study period, averaging 0.25 fledglings per breeding pair (Table 3). At Brooks Island, Caspian tern nesting success declined from a high of 0.62 fledglings per breeding pair in 2003 to a low of 0.14 fledglings per breeding pair in 2009 (Table 3).

Factors Limiting Colony Size and Nesting Success

Of the nine different Caspian tern colony sites used during the study period, most (67%) were located in and around salt ponds in either the North Bay or the South Bay (Table 1). Although salt ponds offer Caspian terns many potential sites for nesting, the area and quality of nesting habitat available at salt ponds was identified as a major limiting factor on tern colony size and nesting success (Table 4). Salt pond islands and breached levees used by nesting terns are small in area and consist of hard packed substrate that becomes sticky when wet, making it difficult for terns to dig nest scrapes and causing eggs to become cemented to the substrate after rain. Other major factors documented to limit nesting success for at least some of the tern colonies in the Bay Area were mammalian predators (e.g., raccoons and red foxes), avian nest predators (i.e., gulls), displacement by other colonial waterbirds, and human disturbance (Table 4). Food availability may also be a limiting factor for tern nesting success in years when marine forage fish are in short supply.

At Brooks Island, site of the largest Caspian tern colony in the Bay Area and the only colony site with good quality nesting substrate (i.e., coarse sand), tern colony size and nesting success was limited by the availability of un-vegetated nesting habitat, nest predation by gulls (California gulls [*Larus californicus*] and western gulls [*L. occidentalis*], competition for nest sites with gulls, and human disturbance (Table 4). Nesting habitat for terns on Brooks Island is restricted to a narrow band of bare sand between the vegetated areas that dominate the spit and the high tide line. The area of suitable habitat for tern nesting appears to vary from year to year based on expansion and contraction of un-vegetated habitat due to erosion and deposition of sandy material, plus vegetation encroachment on un-vegetated areas (primarily by native pickleweed (*Sarcocornia pacifica*), exotic ice plant (*Carpobrotus edulis*), and a non-native aster (*Aster* sp.), depending on the number and intensity of winter and spring storms. Annual dredging of the commercial shipping channel on the leeward side of the sand spit, where Caspian terns nest, contributes to loss of tern nesting habitat. These processes appear to be responsible for the fragmentation of the Brooks Island Caspian tern colony into two sub-colonies. Annual high tide events further limit the availability of suitable nesting habitat for terns by causing some terns nesting in low-lying areas to fail.

The expanding California gull colony on Brooks Island is another major factor limiting the size and productivity of the Brooks Island Caspian tern colony (Table 4). Since the California gull colony became established on Brooks Island (about year 2000; Strong et al. 2004), the colony has rapidly expanded and the Caspian tern colony is currently surrounded on three sides by nesting California gulls. Gull predation on Caspian tern eggs and chicks, sometimes associated with human disturbance, was frequently observed at the Brooks Island tern colony. Nest predation by both western gulls and California gulls increased substantially over the study period; in 2009 gull predation caused almost complete Caspian tern nest failure at the main sub-colony on Brooks Island.

Diet Composition

Marine forage fishes, in particular silversides (Atheridae), surfperch (Embiotocidae), anchovies (Engraulidae), and herring/sardines (Clupeidae; in that order), were the predominant component of Caspian tern diets in the San Francisco Bay area during the study period (Table 5). Caspian terns nesting on Brooks Island in the Central Bay were the most reliant on schooling marine forage fishes (76.7% of prey items), followed by terns nesting at Eden Landing in the South Bay (61.4% of prey items), and terns nesting at Knight Island in the North Bay (49.1% of prey items; Table 5). Other differences in tern diet composition were associated with colony location. Salmonids (*Oncorhynchus* spp.), gobies (Gobiidae), and sunfish/bass (Centrarchidae) were most prevalent in the diet of terns nesting in the North Bay and least prevalent in the diet of terns nesting in the South Bay. Juvenile sharks (Carcharhinidae), sculpins (Cottidae), and flatfishes (Pleuronectidae) were most prevalent in the diet of terns nesting in the South

Bay and least prevalent in tern diets in the North Bay (Table 5). Although the pooled diet composition data included several years at each colony, all of the regional differences in diet composition described above hold true (with the exception of differences in sculpin consumption) when the comparisons are restricted to diet data collected in 2003, the only year when diet data were collected at all three colonies.

Salmonids are of special conservation concern in the Bay Area, and were detected in the diets of Caspian terns nesting at all three colonies where detailed diet data were collected. Juvenile salmonids comprised 22.9% of the diet of terns nesting at Knight Island in the North Bay, 5.3% of the diet of terns nesting on Brooks Island in the Central Bay, and 0.1% of the diet of terns nesting at Eden Landing in the South Bay (Table 5). At the Brooks Island colony during 2003-2005, the proportion of juvenile salmonids in tern diets averaged 3.5%, but in 2008 and 2009 the proportion of salmonids was higher, 9.0% and 7.1% of the diet, respectively (Figure 2). In general, anadromous salmonid smolts made up the vast majority of the salmonids consumed by terns at Brooks Island, with the exception of 2003 when resident rainbow trout and anadromous salmonid smolts were observed in approximately equal numbers (Figure 2). During that year, the vast majority of the trout observed were resident, non-anadromous rainbow trout that had been stocked in nearby reservoirs. In subsequent years, the proportion of the trout consumed (average = 0.1% of prey items) was nearly equally divided between resident trout from local reservoirs and anadromous steelhead trout, which are distinguishable by their silvery appearance and elongated body shape relative to resident trout. Salmonid consumption by Brooks Island terns peaked in early June in 2003-2005 (7.7% of the diet) and in late May in 2008-2009 (18.5% of the diet; Figure 3).

DISCUSSION

Nesting Ecology

Although the number of breeding pairs of Caspian terns in the San Francisco Bay area declined over the course of this study, both the number of colonies used by nesting Caspian terns (6) and the size of the breeding population in the San Francisco Bay area (ca. 830 pairs) was the same as in 2001 (Shuford and Craig 2002). During our study, the number of Caspian terns nesting in the Bay Area fluctuated from a high of 1,372 breeding pairs in 2004, close to the highest reported breeding population size of 1,500 pairs in 1981 (Gill and Mewaldt 1983), to a low of 830 breeding pairs in 2009. Consequently, the total number of Caspian terns nesting in the Bay Area can be characterized as variable over short time periods (by nearly a factor of two), a conclusion supported by Strong et al. (2004). Despite the apparent stability in the number of breeding pairs of Caspian terns in San Francisco Bay over the past several decades, there have been dramatic changes in the colony locations used by nesting terns within the Bay Area (Table 2, Strong et al. 2004).

The pattern of extensive inter-colony movements of Caspian terns in the San Francisco Bay area is partly a reflection of the species' nesting ecology. Caspian terns prefer to nest on bare sand substrate (Quinn and Sirdevan 1998), at a safe elevation above the high tide line, and on islands without mammalian predators (Cuthbert and Wires 1999). These habitats are typically ephemeral, particularly in coastal environments, and can be created or destroyed during winter storm events. These habitats are also quickly colonized by pioneer vegetation and other colonial waterbirds that compete for similar nesting habitat. Breeding Caspian terns must be able to adapt to these changes in available nesting habitat. Consequently, Caspian terns appear to be pre-adapted to shifting their nesting activities from one site to another in response to stochastic events more so than most other colonial waterbirds (Cuthbert 1988, Cuthbert and Wires 1999, Strong et al. 2004).

Results from our study support the hypothesis of low colony-site fidelity by Caspian terns nesting in San Francisco Bay. Of the nine colony locations used by nesting Caspian terns during 2003-2009, only two (Brooks Island and Agua Vista Park) were active throughout the study period. Three other colony locations (Knight Island, Coyote Hills, and Alviso Ponds A-7) were active during the early part of the study period, but were abandoned before the end of the study. Two additional colonies (Eden Landing E-10 and Ravenswood) were active, abandoned, and re-colonized during the seven-year study period. Finally, the remaining two colonies (Stevens Creek B-2 and Redwood Shores) were not active until the last few years of the study period. Low-colony site fidelity and frequent shifts among colony locations by Caspian terns has been shown to be associated with three major factors; the quality and quantity of nesting habitat, disturbance (by predators or humans), and low reproductive success (Penland 1981, Shugart et al. 1979, Cuthbert 1981, Gill and Mewaldt 1983, Antolos et al. 2004). All of these factors played a role in colony abandonment and shifts among colony locations by Caspian terns in San Francisco Bay; Knight Island was abandoned in 2005 due to tidal inundation associated with the illegal breaching of a surrounding levee and high nest predation by western gulls; Eden Landing E-10 was abandoned in 2004 due to mammalian nest predation; Coyote Hills was abandoned in 2006 due to encroachment and high nest predation rates by an expanding California gull colony (C. Strong, personal communication); and Alviso Ponds A-7 was abandoned in 2006 perhaps due to changing water levels (when the former salt pond was converted to muted tidal habitat), allowing mammalian predators access to the tern colony (C. Strong, personal communication).

Relative to other colony locations in the San Francisco Bay area, colony-site fidelity at Brooks Island and Agua Vista Park was high, which is noteworthy given that the sites themselves could not be more different as tern nesting habitat. Brooks Island was the location of the largest (681 breeding pairs in 2009) and most continuously active (established in 1985; Strong et al. 2004) Caspian tern colony in the San Francisco Bay area. The Brooks Island tern colony is located on a sandy, low-lying spit that was built from material dredged from the adjacent Port of Richmond shipping channel. The nesting substrate on Brooks Island is loosely packed sand and shells, more typical of the nesting habitat preferred by Caspian terns (Quinn and Sirdevan 1998). The Brooks Island tern colony is surrounded by a much larger California gull colony and over the course of this study we observed disturbance by humans and mammalian predators (Table 4). Agua Vista Park is one of the smaller tern colonies in the Bay Area (8 breeding pairs in 2009) and has been continuously active for 8 years (Table 2, Strong et al. 2004). The tern colony is on decaying fragments of a former wooden pier (Pier 63) on the San Francisco waterfront. The section of pier nearest the shore has completely rotted away, leaving the outer sections unconnected to the mainland and thus free of mammalian predators. Caspian terns currently nest on one remaining section of pier, digging nest scrapes in the dirt and debris on the surface. Small numbers of western gulls nest adjacent to the tern colony and major disturbances (by predators or humans) have not been witnessed at the site. The reasons for the apparent high colony-site fidelity at Brooks Island and Agua

Vista Park are unknown, but may be due to the relatively high quality of the nesting substrate at the Brooks Island colony and the lack of disturbance at the Agua Vista Park colony.

Caspian tern nesting success in the San Francisco Bay area (0.17 – 0.55 fledglings per breeding pair) was considerably lower than at other well-studied Caspian tern colonies along the Pacific Coast (average of 1.1 young raised per breeding pair; Cuthbert and Wires 1999), and in some years nesting success in San Francisco Bay may not have been sufficient to compensate for annual adult and sub-adult mortality. Over the course of this study, nesting success at Caspian tern colonies in the Bay Area declined 69%, which was largely driven by the decline in nesting success at the Brooks Island colony (77%), the largest tern colony in the area, and was primarily due to intense nest predation pressure by California gulls. In general, factors affecting nesting success varied by colony site, but were often related to attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) vulnerability to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

Diet composition

Diet composition varied according to where within the Bay Area a Caspian tern colony was located (i.e., North Bay, Central Bay, or South Bay), despite the fact that the distances between colony locations (27-59 km) were well within the reported maximum foraging range of nesting Caspian terns (62-70 km; Soikkeli 1973, Gill 1976). Caspian terns nesting in the Central Bay (Brooks Island) consumed the highest percentage of marine forage fish (i.e., silversides, surfperch, anchovy, and herring/sardine), which comprised 76% of prey items, followed by terns nesting in the South Bay (Eden Landing

E-10: 61.4% of prey items) and the North Bay (Knight Island: 49.1% of prey items). The finding that marine fishes were most prevalent in the Central Bay is not surprising because terns nesting in the Central Bay were located closest to the ocean at the mouth of the Bay (18 km), as compared to terns nesting in the North Bay at Knight Island (42 km) and South Bay at Eden Landing E-10 (39 km; Figure 1). Caspian terns nesting in the North Bay consumed the highest percentage of salmonids, sunfish/bass, and gobies (41.6% of prey items), followed by terns nesting in the Central Bay (11.9% of prey items) and South Bay (5.8% of prey items). Of the three Caspian tern colonies in the Bay Area where diet composition was measured, terns nesting in the North Bay were located closest to the freshwater/estuarine habitats of the Sacramento-San Joaquin Delta (Figure 1), where anadromous salmonids and freshwater centrarchids are presumed to be more abundant relative to elsewhere in the Bay. Furthermore, gobies were found to be in greater relative abundance in tow net catches in the North Bay during 1995-2001 (ca. 36% of total catch; Dege and Brown 2004) as compared to trawl catches in the South Bay during 1992-2002 (ca. 5% of total catch; MSI 2002). Finally, Caspian terns nesting in the South Bay consumed the highest percentage of sculpins, flatfishes, and sharks (36.3% of prey items), followed by terns nesting in the Central Bay (3.5% of prey items) and North Bay (1.3% of prey items), prey types that were more abundant in South Bay trawl catches (MSI 2002) than in North Bay tow net catches (Dege and Brown 2004). These results suggest that Caspian terns nesting in the San Francisco Bay area tend to forage on fish that are abundant and available near their nesting colony, as was shown for Caspian terns nesting in the Columbia River estuary (Roby et al. 2002, Lyons et al. 2005, Lyons et al. 2007).

Caspian terns nesting at Knight Island in the North Bay had the highest percentage of juvenile salmonids in their diet (22.9%), while terns nesting at Eden Landing E-10 in the South Bay had the lowest percentage of salmonids in the diet (0.1%). While the percentage of juvenile salmonids in the diet of terns nesting at Brooks Island in the Central Bay was intermediate to that of terns nesting in the North Bay and South Bay, we observed a ca. 130% increase in the percentage of salmonids in the diet from 2003-2005 to 2008-2009, causing some concern because this is both the largest Caspian tern colony in the Bay Area and has been identified as a site for future tern colony expansion as part of a comprehensive plan to reduce impacts of Caspian tern predation on salmonids in the Columbia River estuary (USFWS 2005, USFWS 2006; see below for further discussion). These results prompted further investigation into which salmonid species (Chinook salmon, steelhead trout), runs (winter, spring, fall, and late-fall), and rear-types (hatchery and wild) were most susceptible to Caspian tern predation at Brooks Island and elsewhere in the San Francisco Bay area (Evans et al. in press).

Results from this and a related study (Evans et al. in press) suggest that most of the juvenile salmonids consumed by Caspian terns nesting in the Bay Area are hatchery-reared smolts belonging to species not listed under the U.S. Endangered Species Act. In 2003 we observed a nearly equal proportion of salmon and trout in the diet of Brooks Island terns, with the vast majority of the trout being hatchery-reared rainbow trout stocked in nearby reservoirs. Gill (1976) first documented Caspian terns foraging on rainbow trout in Bay Area reservoirs, when 12 tagged and 21 untagged trout were recovered from a tern colony site in the South Bay in 1971. In 2008 and 2009, the juvenile salmonids in the diet of Brooks Island Caspian terns appeared to be mostly hatchery-reared fall-run Chinook salmon released from nearby net pens in eastern San Pablo Bay (see FFC 2008 for further information on net pen releases). This hypothesis is supported by Evans et al. (in press), whose recovery of salmonid coded wire tags (n = 2,079) on the Brooks Island tern colony in 2008 revealed that 98% of the known origin salmonid smolts consumed by terns were non-listed, hatchery fall-run Chinook salmon released from net pens in San Pablo Bay. Of the ca. 518,000 wild origin spring- and fall-run Chinook salmon that were coded wire tagged and released in the Sacramento River in 2008, none were recovered on the Brooks Island tern colony (Evans et al. in press). Results from this study and Evans et al. (in press) suggest that recent increases in the percentage of salmonids in the diet at the Brooks Island tern colony may be related to terns keying in on the large and increasing numbers of hatchery-reared Chinook salmon released from net pens in San Pablo Bay (see FFC 2008). Currently, Caspian terns nesting in the San Francisco Bay area do not appear to be having an appreciable impact on wild, ESA-listed salmonid stocks in the region (Evans et al. in press).

MANAGEMENT IMPLICATIONS

Results from this study suggest that suitable nesting habitat for Caspian terns may be limiting in the San Francisco Bay area. Over the course of this study both the total number of terns nesting and their productivity has declined in the Bay Area, likely associated with the instability and poor quality of historical and existing tern nesting habitat within the bay, and a third of the colonies used by nesting terns were abandoned. All of these colony sites were located on islands in, or levees surrounding, salt ponds. While salt ponds seem to offer Caspian terns many sites for nesting (two-thirds of the colony locations used by terns during this study were in or near salt ponds), the quality of the existing nesting substrate (generally hard pan dirt that becomes sticky when wet), changing water levels (nests become flooded in high water or land bridges provide mammalian predators access to the colony in low water), and displacement by other colonial waterbirds all pose problems for terns nesting in this habitat. Loss of additional tern nesting habitat in salt ponds (Eden Landing E-10) and elsewhere (Agua Vista Park) is expected in the coming years (J. Krause, California Department of Fish and Game, personal communication). At Brooks Island, the largest tern colony site in the bay, colony size has declined 35% from its high in 2004 (1,040 nesting pairs) to its low in 2009 (681 nesting pairs), which explains much of the decline (40%) in total breeding population size for Caspian terns in the San Francisco Bay area from 2004 to 2009. This decline was associated with many factors, including encroaching vegetation, beach erosion, and an expanding California gull colony that not only competed with terns for nest sites, but also preyed on tern eggs and chicks. Any effort to stabilize or enhance the Caspian tern breeding population in the San Francisco Bay area will likely require active management to provide suitable nesting habitat for terns.

Three sites within San Francisco Bay have been identified as potential alternative nesting sites for Caspian terns displaced from East Sand Island in the Columbia River estuary. The original plan, as it is outlined in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* (USFWS 2005, 2006), called for the construction or enhancement of Caspian tern nesting habitat at two sites in the South Bay (at Hayward Regional Shoreline and Don Edwards National Wildlife Refuge) and one site in the Central Bay (Brooks Island).

These proposed actions would help reduce the number of terns nesting in the Columbia River estuary, thereby reducing the impact of Caspian tern predation on juvenile salmonids from throughout the Columbia River basin, most of which are imperiled. Additionally, implementation of this plan would ensure that there is a network of suitable colony sites available for Caspian terns on a regional scale and help conserve the breeding population of Caspian terns in the San Francisco Bay area.

Results from our study suggest that locating new and improved colony sites for Caspian terns in the South Bay would not jeopardize salmonid stocks. Diet data from the South Bay at Eden Landing E-10 (located between Hayward Regional Shoreline and Don Edwards NWR) indicate that very few, if any, juvenile salmonids (0.1% of prey items) would be consumed at the proposed tern colony restoration sites in the South Bay.

Creation or enhancement of Caspian tern nesting habitat in the South Bay has a high probability of success given the long history of tern nesting in this area. The key to success of the proposed plan would require active management to create the nesting habitat that Caspian terns prefer; that is, islands with bare, loosely-packed substrate that are at a safe elevation above the high tide line and that provide protection from mammalian predators and human disturbance. Once islands are built or modified, social attraction (i.e., sound systems and tern decoys; Kress 1983, 1998) would be needed to attract Caspian terns to these sites, Further management at the tern colonies may be necessary to prevent vegetation encroachment and high nest predation rates on terns by gulls and other avian predators (Kress 1983). Finally, regular in-season monitoring of the newly created or restored tern colony sites will be necessary to assess the outcome of implemented management initiatives and help ensure their success.

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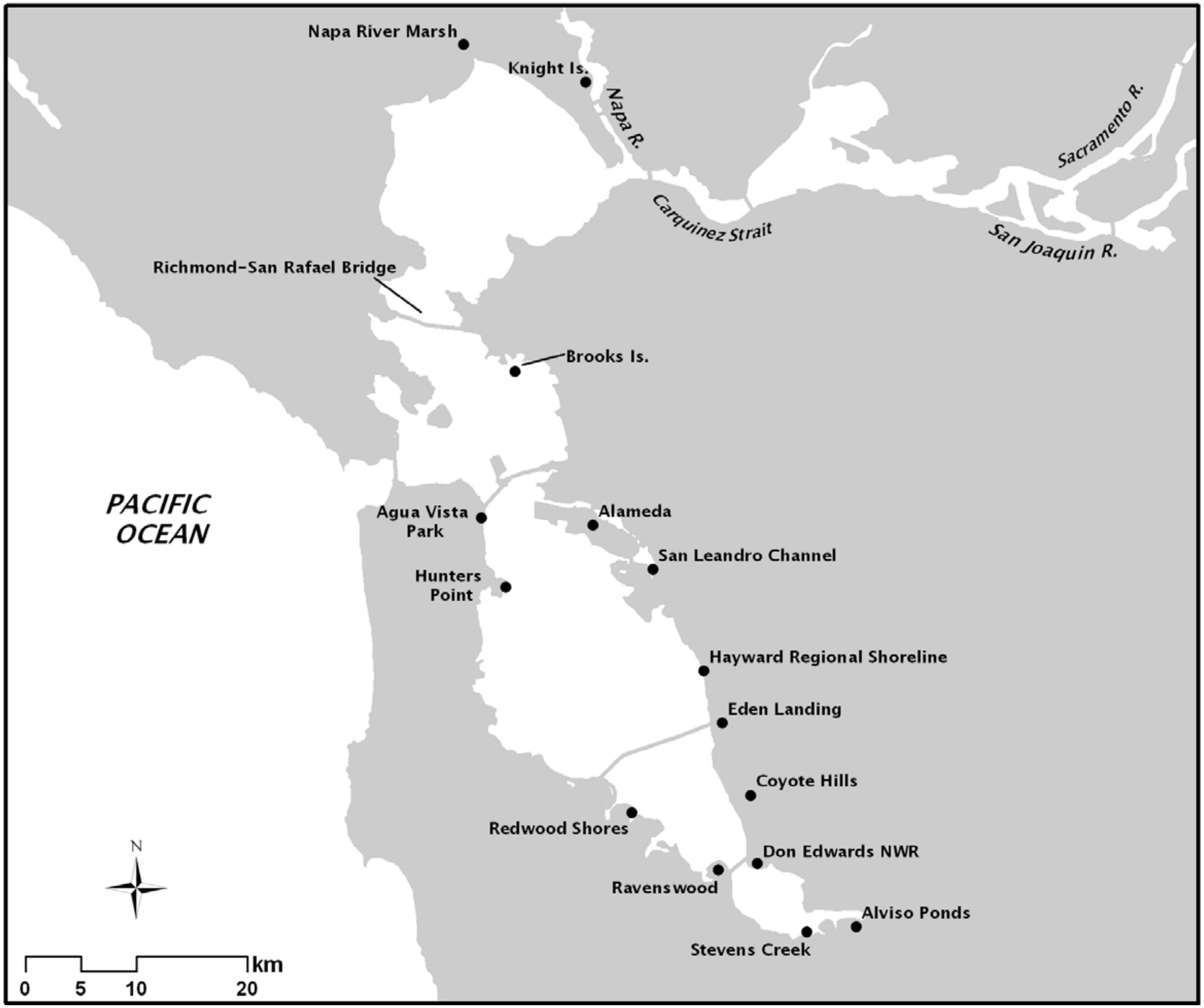
FIGURE CAPTIONS

Fig. 1. San Francisco Bay study area showing the locations of past, present, and future (planned) Caspian tern nesting colonies and other locations mentioned in the text.

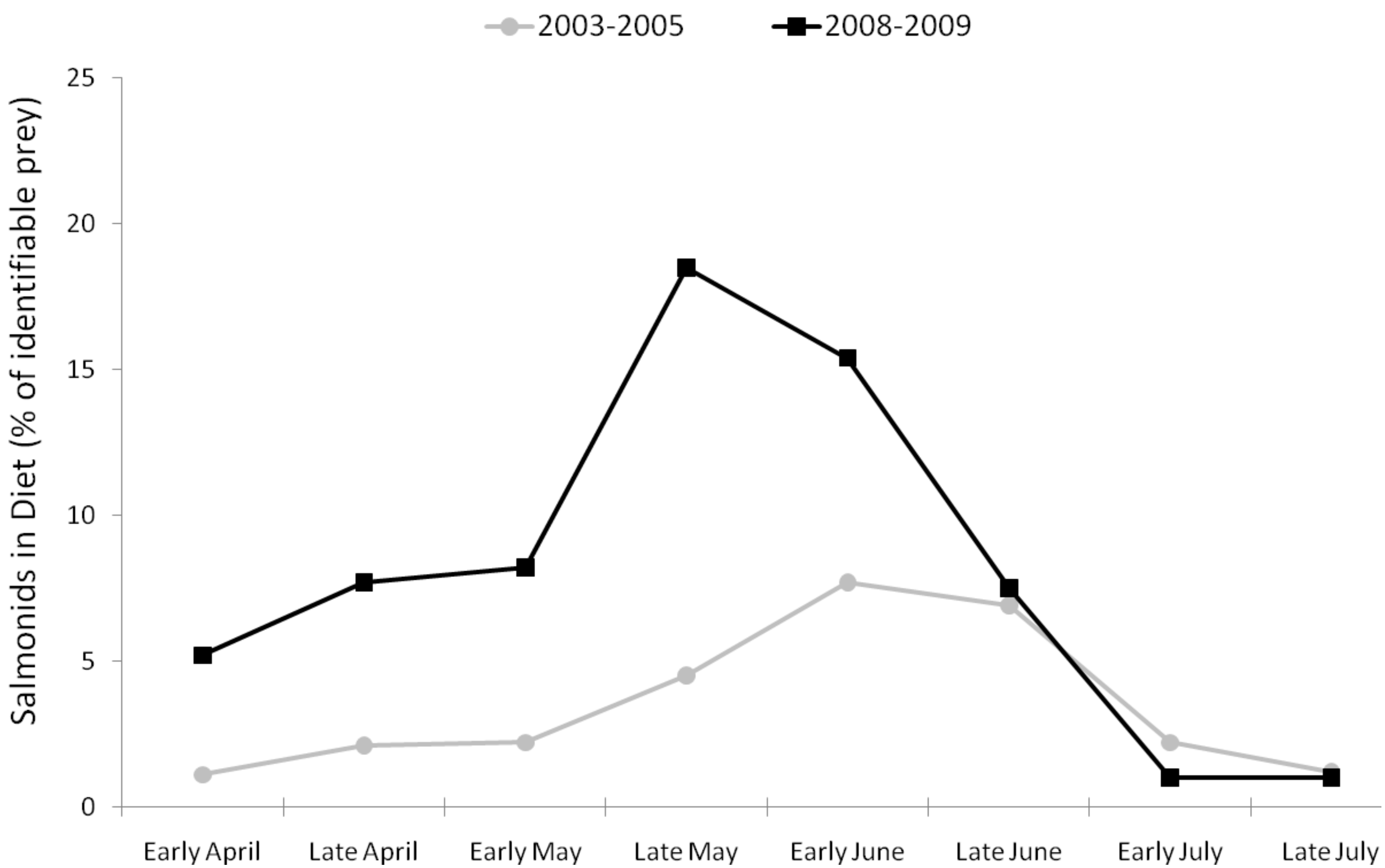
Fig. 2. Salmon and trout as a percentage of identifiable prey in the diet of Caspian terns nesting on Brooks Island based on bill load observations during 2003-2005 and 2008-2009.

Fig 3. Seasonal contributions (by number) of salmonids to the diet of Caspian terns nesting on Brooks Island from bill load observations in 2003-2005 and 2008-2009.



Napa River Marsh
Knight Is.
Napa R.
Sacramento R.
Carquinez Strait
San Joaquin R.
Richmond-San Rafael Bridge
Brooks Is.
PACIFIC
OCEAN
Agua Vista
Park
Alameda
San Leandro Channel
Hunters
Point
Hayward Regional Shoreline
Eden Landing
Coyote Hills
Redwood Shores
Don Edwards NWR
Ravenswood
Alviso Ponds
Stevens Creek
N
0
5
10
20
km

Salmon
Trout
Salmonids in Diet (% of identifiable prey)
10%
8%
6%
4%
2%
0%
2003
2004
2005
2008
2009
Year



2003-2005
2008-2009
Salmonids in Diet (% of identifiable prey)
0
5
10
15
20
25
Early April
Late April
Early May
Late May
Early June
Late June
Early July
Late July

Table 1. Caspian tern colony descriptions in the San Francisco Bay area in 2003-2009.

Colony	Nesting habitat	Management Authority	Number of years colony was active	Extant in 2009 (Y/N)
North Bay				
Knight Is.	Salt pond island	California Dept. of Fish and Game	3	N
Central Bay				
Brooks Is.	Sandy spit adjacent natural island	East Bay Parks District	7	Y
Agua Vista Park	Old wooden pier	San Francisco Port Authority	7	Y

South Bay				
Eden Landing E-10	Salt pond island	California Dept. of Fish and Game	4	Y
Coyote Hills	Salt pond levee	U.S. Fish and Wildlife Service [a]	2	N
Alviso Ponds A-7	Salt pond island	U.S. Fish and Wildlife Service [a]	4	N
Stevens Creek B-2	Salt pond island	U.S. Fish and Wildlife Service [a]	3	Y
Ravenswood	Salt pond island	U.S. Fish and Wildlife Service [a]	2	Y

Redwood Shores	Sewage treatment pond	South Bayside System Authority	1	Y

[a] Part of Don Edwards San Francisco Bay National Wildlife Refuge

Table 2. Number of breeding pairs for Caspian terns nesting in the San Francisco Bay area in 2003-2009. Blanks indicate that tern no nesting occurred.

Colony	2003	2004	2005	2006[a]	2007[a]	2008	2009
North Bay							
Knight Is.[b]	300	238[c]	45[d]				
Central Bay							
Brooks Is.[e]	859	1040[c]	954[f]	931	888	812	681
Agua Vista Park	43	38	18	19	9	14	8
South Bay							
Eden Landing E-10	35	28[d]				56	75
Coyote Hills			49[g]	42			
Alviso Ponds A-7	50	28	18	35			

Stevens Creek B-2					12	118[h]	64[h]
Ravenswood				1	1		1
Redwood Shores							1
Totals							
San Francisco Bay	1287	1372	1084	1028	910	1000	830
North Bay	300	238	45				
Central Bay	902	1078	972	950	897	826	689
South Bay	85	56	67	78	13	174	141

[a] Colony status and counts in 2006-7 provided by San Francisco Bay Bird Observatory (C. Strong, personal communication) for Agua Vista and all the South Bay colonies and by U.S. Fish and Wildlife Service (G. McChesney, personal communication) and Humboldt State University (P. Capitolo, personal communication) for Brooks Island and Knight Island (see Capitolo et al. 2009)

[b] Includes Caspian terns nesting on the South and Northeast sub-colonies

[c] Minimum estimate due to re-nesting that occurred after the aerial survey was conducted

[d] Colony was abandoned during the breeding season; some of these terns may have re-nested at other colonies in the Bay area

[e] Includes Caspian terns nesting on Main and Northwest sub-colonies

[f] Includes influx of late nesting terns, some of which may have come from abandoned tern colony at Knight Island

[g] Count provided by San Francisco Bay Bird Observatory (C. Strong, personal communication)

[h] Minimum estimate because entire colony area not visible from the observation blind

Table 3. Nesting success (i.e., fledglings produced per breeding pair) and number of fledglings produced (in parentheses) at Caspian tern colonies in the San Francisco Bay area in 2003-2009. Blanks indicate that no tern nesting occurred. Zeros indicate that tern nesting occurred but no fledglings were produced. Dashes indicate that tern nesting occurred but no census of fledgling terns was done.

Colony	2003	2004	2005	2006[a]	2007[a]	2008	2009
North Bay							
Knight Is.	0.46[b]	0.32[c]	0.0				
	(139)	(76)	(0)				
Central Bay							
Brooks Is.	0.62	0.48[c]	0.31[d]	—	—	0.42	0.14
	(535)	(504)	(295)			(341)	(97)
Agua Vista Park	0.42[c]	0.82[c]	1.00[c]	—	—	—	—
	(18)	(31)	(18)				

South Bay							
Eden Landing E-10	0.43	0.0				0.81	0.41
	(15)	(0)				(48)	(31)
Coyote Hills			0.02[c]	—			
			(1)				
Alviso Ponds A-7	0.08[b]	0.50[c]	0.61[c]	—			
	(4)	(14)	(11)				
Stevens Creek B-2					—	—	0.16[c]
							(10)
Ravenswood				—	—		0.00
							(0)
Redwood Shores							0.00
							(0)
Totals							
San Francisco Bay	0.55	0.46	0.30	—	—	—	0.17[e]
	(711)	(625)	(325)				(138)

North Bay	0.46	0.32	0.00				
	(139)	(76)	(0)				
Central Bay	0.61	0.50	0.32	—	—	—	0.14[e]
	(553)	(535)	(313)				(97)
South Bay	0.22	0.25	0.18	—	—	—	0.29
	(19)	(14)	(12)				(41)

[a] Colony status and counts in 2006-7 provided by San Francisco Bay Bird Observatory (C. Strong, personal communication) for Agua Vista and all the South Bay colonies and by U.S. Fish and Wildlife Service (G. McChesney, personal communication) and Humboldt State University (P. Capitolo, personal communication) for Brooks Island and Knight Island (see Capitolo et al. 2009)

[b] Maximum estimate because estimate includes smaller chicks that may not have survived to fledging

[c] Minimum estimate because entire colony area not visible from the observation blind

[d] Minimum estimate because it excludes small chicks produced by late nesting terns that remained on the colony at the end of the field season

[e] Minimum estimate because it excludes chicks produced at Agua Vista Park

Table 4. Potential limiting factors for colony size and nesting success at Caspian tern colonies in San Francisco Bay area in 2003-2005 and 2008-2009. "**X**" denotes an observed factor of significance, "x" denotes an observed factor of minor importance, and "?" denotes a suspected factor. Contaminants are also a possible limiting factor at some colonies in San Francisco Bay (e.g., Thompson et al. 2007), but this study does not address that issue directly.

	North Bay	Central Bay		South Bay					
	Knight Is.	Brooks Is.	Augua Vista	Eden Landing	Coyote Hills	Alviso Ponds	Stevens Creek	Ravenswood	Redwood Shores
Availability of nesting habitat	**X**[a]	**X**[h]	**X**[n]	**X**[p]	**X**[t]	**X**[p]	**X**[y]	x[p]	x[y]
Quality of nesting habit	x[b]		**X**[o]	**X**[b]	x[b]	**X**[b]	**X**[b]	**X**[b]	**X**[b]

Prey fish availability	?[c]	?[c]	?[c]	?[c]	?[c]	?[c]	?[c]	?[c]	?[c]
Mammalian predators	**X**[d]	?[i]		**X**[q]	?	?[u]		?	?
Displacement by other waterbirds	**X**[e]	**X**[j]		**X**[r]	**X**[j]	?[v]	?[v]	?	?
Gull kleptoparasitism	x[f]	x	?		?[j]	?[w]	?	?	?
Gull nest predation	**X**[f]	**X**[k]	?		?[j]	?[w]	?	?	?
Other avian predators	x	x		?[s]		?[s]		?	?
Human disturbance	?[g]	**X**[l]		?[g]	?[g]	?[g]	?[g]	?[g]	?[z]
Aircraft		x[m]				x[x]			

[a] Tidally influenced since dike was breached in 2003; during high tide nesting habitat reduced, during low tide land bridges provide access to predators; vegetation encroachment due to reduced salinity in pond

[b] Sticky when wet and terns have difficulty digging scrapes; eggs can become cemented to substrate

[c] Limited availability of marine forage fish in some years

[d] Unknown mammalian predator caused nest failure and partial colony abandonment in 2003

[e] Expanding double-crested cormorant colony in 2003-2004

[f] Large numbers of immature western gulls in 2004-2005; possibly attracted by expanding double-crested cormorant colony

[g] Island in close proximity to nearby levees frequented by researchers and land managers

[h] Encroaching pickleweed and other vegetation; high spring tides associated with extreme weather flooding low lying nests

[i] Raccoons, red fox, and rats observed on island; mammalian predators removed from island in some years

[j] Expanding California gull colony

[k] By California and western gulls; gull nest predation the primary factor in extremely low nesting success in 2009

[l] Disturbance mostly from recreational kayakers, boaters, and wind surfers

[m] Low flying military, Coast Guard, and regional law enforcement helicopters occasionally flush terns from the colony

[n] Habitat shrinking due to continued slow collapse of pier (i.e., area used by nesting terns) into bay

[o] Nesting on pier deck where there is little or no nesting substrate

[p] Changing water levels due to mitigation for hyper-saline conditions in adjacent salt ponds; encroaching vegetation

[q] Grey fox, red fox, long-tailed weasel, and domestic cats sighted on adjacent levee; mammal tracks found on colony in some years

[r] Tern eggs and nests trampled by roosting white pelicans and double-crested cormorants

[s] Raven nests on nearby power poles

[t] Terns nesting on narrow levee dividing salt ponds; strong winds during breeding season causes large waves and foam builds up along levees in salt pond

[u] Grey fox tracks observed on adjacent levee in some years

[v] American white pelicans used island as roost

[w] Over 6,500 nesting pairs of California gulls are within 1 km of tern colony

[x] Massive colony disturbances caused during air show in some years

[y] Encroaching vegetation limits available nesting habitat

[z] Island in close proximity to public dog park

Table 5. Average diet composition (percentage of identifiable prey items in bill loads) of Caspian terns nesting on Knight Island (North Bay), Brooks Island (Central Bay), and Eden Landing (South Bay) in 2003-2005 and 2008-2009. Only prey types comprising more than 5% of the tern diet from at least one of colonies is listed in the table. Prey types comprising less than 5% of the tern diet at each of the three colonies are listed in the footnotes in the order of their prevalence (ranked highest to lowest) at the colony. Coefficient of variation of the mean is provided in parentheses.

Prey type	Knight Island 2003-2005	Brooks Island 2003-2005, 2008-2009	Eden Landing 2003, 2008-2009
Silverside	25.9	13.6	26.2
Atherinidae	(27.3)	(39.7)	(26.7)
Surfperch	7.3	26.3	20.6
Embiotocidae	(90.1)	(23.5)	(42.2)
Anchovy	3.1	24.4	10.3
Engraulidae	(93.3)	(32.3)	(40.8)

Herring, sardine	12.8	12.4	4.3
Clupeidae	(52.7)	(45.4)	(79.9)
Salmon, trout	22.9	5.3	0.1
Oncorhynchus spp.	(39.1)	(48.8)	(39.3)
Goby	11.3	5.2	4.8
Gobiidae	(19.7)	(67.3)	(48.6)
Shark	0.0	0.1	11.1
Carcharhinidae	(na)	(57.3)	(26.3)
Sculpin	1.2	3.1	6.6
Cottidae	(105.8)	(40.8)	(91.3)
Sunfish, bass	7.4	1.4	0.9
Centrarchidae	(32.7)	(70.1)	(42.9)
Flatfish	0.1	0.3	7.5
Pleuronectidae	(na)	(141.4)	(88.4)

Other	8.1[a] (57.6)	7.8[b] (50.2)	7.6[c] (46.3)
No. of identified prey	3,043	24,287	3,687

[a] Unidentified non-salmonids, toadfish (Batrachoididae), smelt (Osmeridae), croaker (Sciaenidae), striped bass (*Morone saxatilis*), catfish (Ictaluridae), minnow/carp (Cyprinidae), butterfish (Stromateidae), cod/haddock (Gadidae), shrimp (Crangonidae), and sucker (Catostomidae)

[b] Unidentified non-salmonids, toadfish (Batrachoididae), smelt (Osmeridae), cod/haddock (Gadidae), butterfish (Stromateidae), croaker (Sciaenidae), Pacific sand lance (*Ammodytes hexapterus*), striped bass (*Morone saxatilis*), minnow/carp (Cyprinidae), kelpfish (Clinidae), needlefish (Belonidae), sablefish (Anoplopomatidae), shrimp (Crangonidae), Pacific saury (*Cololabis saira*), catfish (Ictaluridae), lamprey (Petromyzontidae), and pipefish (Syngnathidae)

[c] Toadfish (Batrachoididae), unidentified non-salmonids, smelt (Osmeridae), catfish (Ictaluridae), butterfish (Stromateidae), croaker (Sciaenidae), cod/haddock (Gadidae), shrimp (Crangonidae), and sucker (Catostomidae)