Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon

DRAFT 2009 ANNUAL REPORT

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE) implemented management actions for Caspian terns (*Hydroprogne caspia*) nesting in the Columbia River estuary beginning in 2008, management that was 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, and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island in the Columbia River estuary to alternative colony sites in interior Oregon and the San Francisco Bay area by 2015. The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin. Thirteen of 20 evolutionarily significant units (ESUs) of Columbia Basin salmonids are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA).

As part of this management plan the USACE completed construction of two 1-acre islands and two 0.5-acre islands at sites in interior Oregon. These specially-designed tern islands included a 1-acre island on Fern Ridge Reservoir near Eugene, Oregon (completed February 2008), a 1-acre island on Crump Lake in the Warner Valley, northeast of Lakeview, Oregon (completed March 2008), and two 0.5-acre islands at Summer Lake Wildlife Area in south-central Oregon near the town of Summer Lake (completed March 2009). Following the construction of these islands and before the arrival of Caspian terns from their wintering grounds, Caspian tern decoys and acoustic playback systems that broadcast Caspian tern calls were deployed on all the islands to attract nesting Caspian terns.

Field crews monitored the islands on Crump Lake and in Summer Lake Wildlife Area throughout the nesting season because there was a prior history of Caspian terns nesting there. In 2009, Caspian terns quickly colonized the tern island on Crump Lake and both tern islands in Summer Lake Wildlife Area, where approximately 670 and 15 breeding pairs nested, respectively. Nesting terns at both locations were successful in rearing young to fledging; an average of 0.17 and 0.80 young were raised per breeding pair at Crump Lake and Summer Lake Wildlife Area, respectively. Prior to island construction in 2008 and 2009, the main factor limiting colony size and nesting success of Caspian terns at Crump and Summer lakes was fluctuating water levels that either inundated the available nesting habitat or land-bridged nesting islands to the mainland, allowing access by mammalian nest predators. In 2009, nest predation by gulls and food availability near the tern islands were apparently the most significant factors limiting tern colony size and nesting success.

The diet composition of Caspian terns nesting on Crump Lake and in Summer Lake Wildlife Area consisted primarily of tui chub (*Gala bicolor*; 75.6% and 82.7% of the identifiable prey items, respectively). In 2009, one sucker (0.02% of identifiable prey items) was observed by researchers at the Crump Lake tern colony during the nesting

season, but this juvenile sucker could not be positively identified as either an ESA-listed sucker (i.e., Warner sucker [*Catostomus warnerensis*]) or an unlisted sucker (i.e., Sacramento sucker [*C. occidentalis*]). A total of 46 rainbow trout (*Salmo gairdneri*; 13.1% of identifiable prey items) were observed at the Summer Lake tern colonies in 2009; these trout were likely hatchery-raised and released in nearby reservoirs and streams.

A total of 63 Caspian terns that were previously banded were re-sighted at the tern islands on Crump Lake and in Summer Lake Wildlife Area during the 2009 nesting season. Of these, 24 had been banded at East Sand Island in the Columbia River estuary, over 500 km to the northwest. Based on the number of terns banded on East Sand Island relative to the size of that colony, we estimate that the majority of the Caspian terns that colonized the tern islands at Crump and Summer lakes had originated from the East Sand Island colony. These band re-sightings demonstrate that Caspian terns can be recruited to new colony sites from existing breeding colonies over considerable distances.

Because there has been no prior history of Caspian terns nesting at Fern Ridge Reservoir or elsewhere in the Willamette Valley of Oregon, video cameras were used instead of direct observation by a field crew as the primary means to monitor the Fern Ridge tern island. Review of video footage and periodic site visits indicated that Caspian terns did not attempt to nest on the island in 2009, but did visit the island late in the breeding season and during the post-breeding season. Caspian terns were regularly observed on the Fern Ridge tern island from late June to late August (on 31 of 33 days when video footage was recorded), and as many as eight Caspian terns were observed on the island in amongst the tern decoys at one time. Video footage also revealed frequent visits to the Fern Ridge tern island by avian predators of Caspian terns (i.e., bald eagles, great horned owls, and peregrine falcons), and one instance of predation by an adult bald eagle on two hatch-year Caspian terns that were roosting on the island. Based on our review of video footage recorded at the Fern Ridge tern island, avian predators and possibly human disturbance may have precluded Caspian terns from nesting on the Fern Ridge tern island in 2009.

Although no management action was undertaken to enhance Caspian tern nesting habitat in the San Francisco Bay area prior to the 2009 nesting season, we monitored existing Caspian tern colonies in the Bay area to gain a better understanding of current colony status, diet composition, and factors limiting both colony size and nesting success in preparation for potential colony expansion at Brooks Island in the Central Bay and island construction/restoration in the South Bay. There were six known breeding colonies of Caspian terns in the San Francisco Bay area during 2009, where a total of approximately 830 breeding pairs nested. This represents a 40% decline in the number of Caspian terns nesting in the Bay Area in 2009 relative to 2004, when the number of breeding pairs in the Bay Area peaked. This decline was largely driven by the decline in size of the breeding colony at Brooks Island, the largest Caspian tern colony in the Bay Area, where colony size was estimated at 681 breeding pairs in 2009, compared to 1,040 breeding pairs in 2004. Nesting success at tern colonies in the Bay Area declined 69% from 2003 to 2009, which again was driven by the decline in nesting success at the Brooks Island

colony (0.62 and 0.14 fledglings produced per breeding pair in 2003 and 2009, respectively, a 77% decline). Factors affecting colony size and nesting success were related to attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) susceptibility to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

Marine forage fishes, including silversides (Atheridae), surfperches (Embiotocidae), anchovies (Engraulidae), were the predominant component of Caspian tern diets at colonies in the San Francisco Bay area. Diet composition varied among colonies within the Bay Area, however, suggesting that fish assemblages near colony sites differed and nesting terns tended to forage near their nesting colony. In 2009, juvenile salmonids comprised 7.1% of prey items for terns nesting at Brooks Island in the Central Bay, and 0.1 - 0.2% of the diet of terns nesting at Eden Landing and Stevens Creek in the South Bay. A radio telemetry study of Caspian terns raising young at the Brooks Island colony, combined with recoveries of coded wire tags from smolts on the colony, revealed that the vast majority of salmonid smolts consumed by Brooks Island Caspian terns in 2009 were hatchery-reared, non-listed fall-run Chinook salmon smolts that had been released from net pens in eastern San Pablo Bay. Results indicate that the implementation of proposed tern management initiatives in the Central and South San Francisco Bay will not jeopardize ESA-listed salmonid stocks and will help restore the breeding population of Caspian terns in the region. Restoration of Caspian tern colonies in southern San Francisco Bay is very unlikely to have any appreciable impact on survival of juvenile salmonids, either from ESA-listed or unlisted stocks.

The preliminary conclusions from this study of Caspian terns nesting in interior Oregon and the San Francisco Bay area during 2009 are (1) Caspian terns can be recruited to new colony sites (i.e., islands in Crump Lake and Summer Lake Wildlife Area) from existing breeding colonies (i.e., East Sand Island) over considerable distances; (2) Caspian terns are more easily recruited to nest at sites with a prior history of tern nesting, as compared to sites with no history of tern nesting (i.e., Fern Ridge Reservoir); (3) the diet of Caspian terns nesting at alternative colony sites identified in the FEIS (i.e., Brooks Island, Crump Lake, and Summer Lake Wildlife Area) consisted mostly of forage fishes that are neither listed under the U.S. Endangered Species Act nor of significant economic value for commercial, recreational, or subsistence fisheries; (4) availability of suitable sites for breeding colonies was the main factor limiting the number and size of tern colonies in both the San Francisco Bay area and interior Oregon; (5) nesting success at existing colonies was limited by attributes of those colony sites as they influenced (a) quality of nesting substrate, (b) susceptibility to mammalian and avian nest predators, (c) displacement by other colonial waterbirds, and (d) human disturbance.

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) in 2008 began to implement the Caspian tern (*Hydroprogne caspia*) management actions 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). This management plan, which was developed jointly by the USACE, the U.S. Fish and Wildlife Service, and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island in the Columbia River estuary, the largest colony of its kind in the world, to alternative colony sites in interior Oregon and the San Francisco Bay area by 2015. The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids (salmon and steelhead) in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin. Thirteen of 20 evolutionarily significant units (ESUs) of Columbia Basin salmonids are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA).

The Caspian Tern Management Plan calls for the creation of approximately 7-8 acres of new or restored Caspian tern nesting habitat in interior Oregon (specifically Fern Ridge Reservoir, Crump Lake, and Summer Lake Wildlife Area) and in the San Francisco Bay area (specifically Don Edwards National Wildlife Refuge, Hayward Regional Shoreline, and Brooks Island) and to actively attract Caspian terns to nest at these colony sites. As alternative Caspian tern nesting habitat is created or restored, the available tern nesting habitat on East Sand Island in the Columbia River estuary will be reduced from its historical size (approximately 5 acres) to 1.0 - 1.5 acres.

Creation of tern nesting habitat at alternative colony sites and the reduction of nesting habitat at East Sand Island will be accomplished in phases and at a ratio of two new acres of habitat provided for each acre of habitat eliminated on East Sand Island. Once fully implemented, the management plan is expected to reduce the East Sand Island Caspian tern colony from its recent size (approximately 10,700 nesting pairs in 2008) to about 3,125 – 4,375 nesting pairs, or a reduction in colony size of 60% - 70%. This reduction in colony size is estimated by NOAA Fisheries to increase the annual population growth rate of three ESA-listed ESUs of Columbia Basin steelhead by 1% or greater. Steelhead were the focus of NOAA Fisheries' analysis because previous studies had revealed that Caspian tern predation rates on juvenile steelhead exceeded those of other salmonid species in the Columbia Basin. The reduction in the size of the Caspian tern colony at East Sand Island is expected to reduce consumption of juvenile salmonids (smolts) from the Columbia River basin by 2.5 – 3.0 million fish annually. Annual consumption of juvenile salmonids by Caspian terns during the period 2001-2009 averaged approximately 5.3 million smolts.

The potential for reduction in Caspian tern nesting habitat at East Sand Island to 1 acre is addressed in the RODs. Before nesting habitat on East Sand Island can be reduced below 1.5 acres, additional alternative colony sites for Caspian tern would need to be developed (the criteria for selection of alternative sites are described in Appendix G of the FEIS).

Two additional sites in northeastern California, Tule Lake National Wildlife Refuge and Lower Klamath National Wildlife Refuge, were identified as part of this process and environmental assessments were prepared for each site prior to island construction (see below). A reduction in the size of the East Sand Island Caspian tern colony size to 2,500 - 3,125 pairs could be accomplished with the development of these additional alternative tern colony sites.

Prior to the 2009 tern nesting season, the USACE and its state and federal partners completed construction of four tern islands (ca. 3 total acres of nesting habitat) specifically designed as Caspian tern colony sites, as described in the Caspian Tern Management Plan. Two islands were built prior to the 2008 breeding season (Fern Ridge Reservoir and Crump Lake), and two islands were built prior to the 2009 breeding season (East Link Impoundment and Dutchy Lake in Summer Lake Wildlife Area; Map 1). As stipulated in the FEIS and RODs, the amount of Caspian tern nesting habitat prepared on East Sand Island was reduced to 3.5 acres prior to the 2009 nesting season (see Section 1.1).

The USACE had planned to build three new Caspian tern islands in southern San Francisco Bay and restore/improve about 1 acre of Caspian tern nesting habitat on Brooks Island in central San Francisco Bay prior to the 2015 nesting season. In partnership with the U.S. Fish and Wildlife Service, the USACE was planning to build two 1-acre islands on working salt ponds within Don Edwards National Wildlife Refuge (see Map 2). In partnership with East Bay Regional Parks, the USACE planned to enhance the habitat on two existing islands in former salt ponds at Hayward Regional Shoreline to create a total of about 1 acre of suitable nesting habitat for Caspian terns (see Map 2). Restoration of Caspian tern nesting habitat at Brooks Island (see Map 2) in central San Francisco Bay, also in partnership with East Bay Regional Parks, is pending further study of the potential impact of an expanded Brooks Island Caspian tern colony on survival of juvenile salmonids from the Sacramento River basin, some stocks of which are listed under the Endangered Species Act.

The objectives of the present study were to determine the diet composition, colony size, and nesting success of Caspian terns nesting at colonies in the San Francisco Bay area and at newly created/restored tern nesting islands in interior Oregon (i.e., Fern Ridge Reservoir, Crump Lake, and Summer Lake Wildlife Area). This is a continuation of previously funded work (2003-2005) that investigated the food habits of Caspian terns at prospective alternative colony sites in interior Oregon and San Francisco Bay to assess the potential impacts of larger, permanent tern colonies on local stocks of forage fishes, particularly fish species of special concern (e.g., juvenile salmonids and Warner suckers [*Catostomus warnerensis*]; Roby et al. 2003b, 2004, 2005). This study will also investigate whether low food availability or locally abundant nest predators may render some former or prospective tern colony sites as population sinks (Penland 1982).

STUDY SITES

There were 10 different Caspian tern colony sites monitored in 2009, six active colonies in the San Francisco Bay area (see Map 2) and four recently constructed islands specifically designed for Caspian tern nesting in interior Oregon (see Map 1). In the San Francisco Bay area, the study sites were Caspian tern colonies at Brooks Island, Eden Landing, Stevens Creek, Agua Vista Park, Ravenswood, and Redwood Shores (Map 2). The primary study sites in the San Francisco Bay area during the 2009 nesting season were Brooks Island in the Central Bay and Eden Landing (formerly known as "Baumberg Ponds") and Stevens Creek in the South Bay, all sites with a prior history of nesting by Caspian terns. In interior Oregon, the study sites were two islands constructed prior to the 2008 breeding season; one at Crump Lake in the Warner Valley, northeast of Lakeview, and the other at Fern Ridge Reservoir near Eugene (see Map 1). We also monitored two additional islands constructed prior to the 2009 breeding season; both islands (Dutchy Lake and East Link Impoundment) are located at Summer Lake Wildlife Area in south-central Oregon near the town of Summer Lake (see Map 1). Prior to island construction, Crump Lake and Summer Lake Wildlife Area had a history of intermittent nesting by Caspian terns (Shuford and Craig 2002, Roby et al. 2003a, Roby et al. 2003b), reflecting annual variation in water levels and resultant changes in the availability of suitable nesting habitat and an adequate food supply. In drought years, the islands formerly used by nesting terns became land-bridged to the mainland, providing mammalian predators with easy access to the colony site. Conversely, during high water years, the islands became inundated, eliminating all suitable nesting habitat.

Although Caspian terns have been regularly observed in the Willamette Valley generally and at Fern Ridge Reservoir specifically, there is no prior history of Caspian terns nesting in the Willamette Valley, presumably due to the lack of suitable nesting habitat prior to island construction at Fern Ridge. We monitored the newly constructed islands in Crump Lake, Summer Lake Wildlife Area, and Fern Ridge Reservoir to determine whether Caspian terns used the sites for nesting and, if so, what factors limited the size and nesting success of the new Caspian tern colonies. We also conducted aerial, road-based, and boat-based surveys of sites in central Oregon, south-central Oregon, southeastern Oregon, and northeastern California searching for other active Caspian terns colonies in the region.

METHODS

We constructed observation blinds at the periphery of each existing and potential Caspian tern colony site where monitoring efforts were focused (Brooks Island, Eden Landing, Stevens Creek, Crump Lake island, Dutchy Lake island, East Link island, and Fern Ridge island) to facilitate colony observations without disturbing nesting terns; other colonies in the San Francisco Bay area (Agua Vista Park, Ravenswood, and Redwood Shores) were observed from a mainland vantage point that was sufficiently distant from the colony so as not to have a noticeable effect on tern nesting behavior. Data on number of terns on the colony, diet composition, and causes of tern nesting failure were collected by observers 3-7 days per week at Brooks Island, Eden Landing, Dutchy Lake island, East Link island,

and Crump Lake island. Other colonies (Stevens Creek, Agua Vista Park, Ravenswood, Redwood Shores) were visited on a less frequent basis (generally 1 day per week) to determine colony status and to estimate the number of nesting pairs. Because there has been no prior history of Caspian terns nesting at Fern Ridge Reservoir or elsewhere in the Willamette Valley, video cameras installed in the blind were used as the primary means to monitor the island instead of direct observation by a field crew.

With the exception of the large Caspian tern colony on Brooks Island in San Francisco Bay, the numbers of Caspian tern pairs breeding at colonies in San Francisco Bay and interior Oregon were estimated from ground counts of incubating adult terns near the end of the incubation period. At Brooks Island, colony size was estimated by counting the total number of Caspian terns in aerial photos taken of the colony late in incubation. These counts were then adjusted to reflect the total number of breeding pairs by determining the ratio of sitting terns to total terns on plots visible from an observation blind adjacent to the tern colony. Nesting success (number of young raised per breeding pair) at each colony was estimated from ground counts of young at the colony at the beginning of the fledging period. Previously-banded Caspian terns were re-sighted at all colonies, where feasible, to estimate survival rates, post-breeding dispersal, and movements among colonies for Caspian terns in the Pacific Coast population. Tern chicks near fledging age were banded at Brooks Island, Eden Landing, and Crump Lake island (the three largest nesting colonies). Each tern fledgling was banded with a federal numbered metal leg band and two plastic, colored leg bands on the left leg and a plastic leg band engraved with a unique alphanumeric code on the right leg to allow for the identification of individual terns at a distance (i.e., at roosts or on colonies).

In addition, a sample of adult Caspian terns nesting at Brooks Island was radio-tagged in order to assess where terns from this colony foraged. Adult terns (n = 50) were captured on the Brooks Island colony using noose mats placed around active nests. Trapping of nesting terns on Brooks Island was conducted during late incubation to minimize nest abandonment due to disturbance (Sirdevan and Quinn 1997). Once captured, each adult was banded (see description above) and radio-tagged using a 12-g VHF radio transmitter affixed to the central tail feathers. These transmitters are shed by the terns when they molt their tail feathers after the nesting season. Radio-tagged terns were also marked on the back and upper wing coverts with rhodamine-B dye to aid in re-sighting radio-tagged individuals on-colony. Nesting status of radio-tagged adults was confirmed by observing their behavior while on-colony.

We conducted 13 aerial surveys from May 15 to June 14 to relocate radio-tagged terns while foraging off-colony during the chick-rearing period. Aerial surveys were conducted from a Cessna fixed-winged aircraft with a single dipole antenna mounted on each wing. Antennae were connected to a radio telemetry receiver through a switch box that allowed the tracker to listen to one antenna at a time (while tracking a single bird) or both simultaneously (while scanning for birds). Once in the vicinity of a radio-tagged tern, the pilot “boxed in” the signal by circling with one wing in the direction of the strongest signal, while the location was marked with a GPS receiver. Radio-tracking was also performed from the ground using a truck mounted dual antennae null peak system (used

for additional off-colony detections), several fixed antennae, data collection computer (DCC) sites around the bay, and a fixed antenna DCC erected adjacent to the Brooks Island tern colony (used to monitor colony attendance). The aerial and road-based surveys were designed to identify key foraging areas for Caspian terns nesting at the Brooks Island colony.

Diet composition at selected study colonies (i.e., Brooks Island, Eden Landing, Dutchy Lake island, East Link island, and Crump Lake island) was determined by visually identifying fish brought back to the colony in the bills of nesting adults with the aid of binoculars and spotting scopes. Forage fishes were identified to the lowest taxonomic grouping possible using visual observation. Visual identifications were verified using voucher specimens whenever possible. In addition, fish tags (coded wire tags, PIT tags, and floy tags) were recovered on selected tern colonies to estimate tern predation rates on fish species of special concern to resource managers (i.e., juvenile salmonids in San Francisco Bay and Warner suckers at Crump Lake).

In 2009 we continued a study initiated in 2008 to assess the impact of Caspian terns nesting in San Francisco Bay on salmonid smolts through the recovery of coded wire tags (CWTs) on tern colonies. CWTs were recovered by sifting through substrate (sand, shells, guano, bones, etc.) used by nesting Caspian terns on Brooks Island, Eden Landing, and Stevens Creek in 2009. This was accomplished by removing nesting substrate from several haphazardly selected 1-m^2 plots from each of the three tern colonies during August, after the 2009 nesting season had ended. Once removed, the substrate was ground (to breakup up guano), sifted (to remove shell, rocks, bones, and other large material), and poured into a magnetized trough or hopper to recover salmonid CWTs. Tags collected within the magnetized section of hopper were then removed, cleaned with isopropyl alcohol, and the tag's unique code read with a specially-designed MagniViewer (Northwest Marine Technology, Inc., Shaw Island, WA). Release information on CWT fish from the Sacramento and San Joaquin rivers were obtained by querying the Regional Mark Processing Center (RMISD 1977), a database of CWT salmonids from the Pacific Coast Region of North America.

The numbers of CWT fish released (by species, run-type, and release location) were compared to the number recovered on the Brooks Island, Eden Landing, and Stevens Creek tern colonies to generate minimum estimates of predation rates (see Appendix 1 for results). Our analysis focused on predation of ESA-listed fish tagged and released into the basin in 2009. We also investigated the link between fish release date and release location to determine if certain groups of fish were more susceptible to tern predation than others. A detailed report of the 2009 CWT Recovery Study can be found in Appendix 1.

Colony monitoring methodology followed standardized observational and data collection protocols described in Collis et al. (2002), Roby et al. (2002), and Roby et al. (2003c). Use of these protocols ensures that results from different colonies and across years are comparable and provide managers with reliable information necessary to (1) assess the

efficacy of implemented management initiatives and (2) make future management decisions.

RESULTS AND DISCUSSION

San Francisco Bay Area

Brooks Island

Background: 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. Brooks Island has been the site of the largest nesting colony of Caspian terns in the Bay area for the last decade. This tern colony is located on a sandy, low-lying spit that extends to the northwest of the island, built from material dredged from the adjacent shipping channel to the Port of Richmond. The Caspian tern colony was estimated at ca. 950 breeding pairs and ca. 815 breeding pairs in 2005 and 2008, respectively (Roby et al. 2009). Caspian terns nest on the upper part of the beach on the leeward (northeast) shore of the spit. The size and productivity of the Brooks Island Caspian tern colony is currently limited by suitable nesting habitat, which has been declining due to shoreline beach erosion, spread of invasive vegetation, and expansion of a recently formed California gull (*L. californicus*) colony. The terns nest in close proximity to two species of gulls, western gulls (*Larus occidentalis*) and California gulls; western gulls have traditionally nested on Brooks Island, but the California gull colony has recently become established on the spit and is expanding rapidly.

The plan "*Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*," which seeks to redistribute a portion of the East Sand Island tern colony to alternative colony sites in Oregon and California, identifies Brooks Island as one of three sites in the San Francisco Bay Area where resource managers intended to create or enhance Caspian tern nesting habitat by 2015 (USFWS 2005). No immediate plans are in place, however, to restore or increase the amount of Caspian tern nesting habitat on Brooks Island because of concerns over potential impacts on salmonid stocks from the Sacramento/San Joaquin Basin.

Nesting Chronology, Colony Size, and Nesting Success: Nesting chronology of Caspian terns at the Brooks Island colony in 2009 was somewhat advanced compared to previous years (2003-2005 and 2008); the dates when the first tern arrived at the colony, the first tern egg was laid, and the first tern chick was hatched were the earliest we had observed at the Brooks Island Caspian tern colony (Figure 1). The Caspian tern nesting habitat near the observation blind (hereafter referred to as the "Main Sub-colony") was occupied by terns first, and later a separate satellite colony formed further down the beach to the northwest (hereafter referred to as the "NW Satellite Sub-colony"); there was also a satellite tern colony in this general area during 2003-2005 and 2008. Most of the Main Sub-colony could be observed and numbers of adult terns counted from the observation

blind, but some nesting adults were obscured by vegetation or topography. The NW Satellite Sub-colony could not be observed from the observation blind, and numbers of adult terns in attendance could only be estimated by observers in a skiff offshore. Consequently, counts of adult terns on-colony are minimums and generally less than the number of active nests in the Main and NW Satellite sub-colonies combined.

Average weekly colony attendance at the Brooks Island Caspian tern colony in 2009 was similar to the average weekly colony attendance observed in previous years up until mid-May, after which average weekly colony attendance at Brooks Island was well below what had been observed in 2003-2005 and 2008 (Figure 2). Based on counts from aerial photography, corrected using ground counts of sitting terns, we estimated the size of the Main Sub-colony as ca. 420 breeding pairs and the size of the NW Satellite Sub-colony as ca. 260 breeding pairs, or a total of ca. 680 pairs of Caspian terns nesting on Brooks Island. As was the case in 2003-2005 and 2008, Brooks Island was by far the largest Caspian tern colony in the Bay Area in 2009, with 82% of the entire San Francisco Bay breeding population nesting at this one site (Table 1). Colony size at the Brooks Island Caspian tern colony in 2009 was below the average colony size during 2003-2005 and 2008 (Figure 3). The number of Caspian terns nesting on Brooks Island appears to be slowly declining since 2004 (Figure 3). The decline in colony size is apparently due to a reduction in the availability of suitable nesting habitat on Brooks Island, the increase in size of the nesting colony of California gulls on Brooks Island, and increased competition with and nest predation from gulls nesting on the same spit.

We estimated that approximately 100 young terns fledged from the Brooks Island colony in 2009, or ca. 90 and 10 young terns fledged from the Main and NW Satellite sub-colonies, respectively. Productivity was ca. 0.21 and ca. 0.04 young raised per breeding pair for the Main and NW Satellite sub-colonies, respectively, or ca. 0.14 fledglings per breeding pair for the entire Brooks Island tern colony. Nesting success at the Brooks Island tern colony in 2009 was the lowest ever recorded and, with the exception of 2008, has been on a steady decline since our monitoring began in 2003 (Figure 4). Our recent estimates of nesting success at the Brooks Island tern colony suggest that productivity is not sufficient to compensate for annual adult and sub-adult mortality, and without immigration from other colonies, will likely result in further declines in the size of that colony in the future.

Adult and Chick Banding and Re-sightings of Banded Adults: On May 12-13, 51 adult Caspian terns were banded at Brooks Island during radio-tagging (see above for description of radio-tagging methods). Each adult tern was banded with a federal numbered metal leg band and two plastic, colored leg bands on the left leg and a plastic leg band engraved with a unique alphanumeric code on the right leg. On June 24, 37 Caspian tern chicks near fledging age were banded using the same banding scheme as with adults; an additional 30 tern chicks that were too young to be banded with alphanumeric bands were banded with just a federal numbered metal band.

In 2009, 61 previously-banded Caspian terns were re-sighted at the Brooks Island tern colony. All 61 banded terns were identified to the year each was banded, its age class

when banded (i.e., adult or chick), and the location where it was banded. Of these 61 banded individuals, 45 (74%) were banded at Brooks Island (33 as adults and 12 as chicks), 9 (15%) were banded at East Sand Island in the Columbia River estuary (4 as adults and 5 as chicks; Map 1), 6 (10%) were banded as chicks at Knight Island in San Pablo Bay (northern San Francisco Bay area; Map 1), and 1 (2%) was banded as an adult at Crescent Island on the mid-Columbia River near Pasco (Map 1).

Analysis of the band re-sighting data is on-going and will allow us to estimate adult survival, juvenile survival, average age at first reproduction, colony site fidelity, inter-colony movement rates, and other factors important in determining the status of the Pacific Coast population of Caspian terns. Moreover, by tracking movements of breeding adult terns between colonies, either within or between years, we can better assess the consequences of various management strategies.

Diet Composition: A large number of Caspian tern bill loads (N = 4,291) were identified at the Brooks Island colony in 2009. As was the case during 2003-2005 and 2008, the diet of Caspian terns nesting at Brooks Island in 2009 consisted primarily of marine forage fishes, in particular surfperch (Embiotocidae; 32.9% of identifiable prey items), silversides (Atherinidae; 15.6%), anchovies (Engraulidae; 11.5% of identifiable prey items), and herring/sardines (Clupeidae; 8.7%; Figure 5). Additional fish taxa that represented more than 1% but less than 10% of prey items in the diet during 2009 included salmonids (Salmonidae; 7.1%), gobies (Gobiidae; 6.5%), smelt (Osmeridae; 5.1%), sculpins (Cottidae; 3.1%), sunfish (Centrarchidae; 2.3%), and toadfish (Batrachoididae; 1.5%). Eight other prey taxa represented less than 1% of the diet.

During 2003-2005, small numbers of juvenile salmonids (primarily Chinook salmon smolts, *O. tshawytscha*) were identified in the diet of terns nesting on Brooks Island (ca. 3% of prey items in the diet; Figure 6). In 2008 and 2009, the proportion of the diet of Brooks Island terns that was juvenile salmonids averaged ca. 8%, raising concerns that relocation of Caspian terns from the Columbia River estuary to Brooks Island might reduce survival of ESA-listed salmonids from the Sacramento/San Joaquin River basin. A radio telemetry study of Brooks Island terns (see below), combined with recoveries of smolt coded wire tags from the Brooks Island tern colony (see Appendix 1), revealed that nearly all salmonid smolts consumed by Caspian terns from this colony during 2008 and 2009 were hatchery-reared, non-listed fall-run Chinook salmon smolts that had been released from net pens in eastern San Pablo Bay. In both 2008 and 2009, juvenile salmonids were released from net pens in eastern San Pablo Bay from early April through mid-June (see Appendix 1), which roughly coincided with when juvenile salmonids peaked in the diet of Caspian terns nesting on Brooks Island (Figure 7).

Radio-Telemetry of Nesting Adults: A total of 36 radio-tagged Caspian terns that were actively nesting at the Brooks Island colony were relocated off-colony during aerial surveys in 2009. The areas with the highest density of off-colony relocations (n = 102) were eastern San Pablo Bay (from Pt. San Pablo north to the mouth of Carquinez Strait) and the Pacific Ocean just outside the Bay. Similar to 2008, very few relocations were recorded in the South Bay. Relocations collected during road surveys indicated similar

relative densities of radio-tagged terns at foraging areas to those collected during aerial surveys, with the South Bay providing very few relocations and eastern San Pablo Bay characterized by a high frequency of detections of radio-tagged Caspian terns. Preliminary results suggest that relocations of radio-tagged terns in eastern San Pablo Bay were associated with the release of hatchery-reared fall Chinook salmon from net pens in that area.

Factors Limiting Colony Size and Nesting Success: The primary factors limiting the size and productivity of the Brooks Island Caspian tern colony in 2009 appeared to be (1) availability of suitable tern nesting habitat, (2) gull predation o tern nests, (3) displacement of nesting terns by other colonial waterbirds, and (4) human disturbance (Table 2). Nesting habitat for terns on Brooks Island was restricted to a narrow band of bare sand habitat between the vegetated areas that dominate the spit and the high tide line. The area of suitable nesting habitat for terns appears to vary from year to year based on expansion and contraction of the beaches and vegetated areas (primarily native pickleweed, exotic ice plant, and a non-native aster), depending on the number and intensity of winter and spring storms. Shoreline erosion removes nesting substrate from the seaward side of the spit and annual dredging of the commercial shipping channel contributes to beach loss on the leeward side of the spit, where Caspian terns nest. These two processes appear to be responsible for the fragmentation of the Brooks Island tern colony into two sub-colonies. Annual high tide events during the nesting season further limit the available beach area suitable for tern nesting and cause some tern nests in low-lying areas to fail.

The expanding California gull colony on Brooks Island appears to be another major factor limiting the size and productivity of the Brooks Island Caspian tern colony. As was the case in previous years, the California gull colony on Brooks Island was in close proximity to the Caspian tern colony in 2009. Gull predation on Caspian tern eggs and chicks, sometimes associated with human disturbance, was observed daily at the Brooks Island tern colony and has increased considerably compared to previous years, to the point where gull predation caused almost complete tern nesting failure in 2009.

Eden Landing

Background: Eden Landing/Pond E10 (formerly Baumberg Ponds/Pond B10) is a former salt pond in southern San Francisco Bay, near the east end of the San Mateo Bridge. Eden Landing/Pond E10 was created for industrial salt production by building a levee around low-lying inter-tidal marsh, but is now owned and managed by the California Department of Fish and Game. In 1998, Caspian terns began nesting on a very small island in Pond E10 near the west levee and continued to nest there until 2004, when all of the active tern nests with eggs were depredated or abandoned early in the breeding season. Subsequently, a tide gate malfunction led to the draining of the salt pond, providing a land bridge to the surrounding levee where foxes, raccoons, and weasels were seen. No terns attempted to nest at this site during 2005-2007, but the site was recolonized in 2008, when ca. 55 breeding pairs nested and ca. 50 young terns were fledged (Roby et al. 2009).

Nesting Chronology, Colony Size, and Nesting Success: Nesting chronology of Caspian terns at the Eden Landing colony in 2009 was advanced compared to previous years (2003 and 2008); the dates when the first tern arrived at the colony, the first egg was laid, the first chick was hatched, and the first tern chick fledged was nearly two weeks earlier than the earliest dates observed in previous years (Figure 8). Weekly colony attendance at the Eden Landing Caspian tern colony was higher throughout the 2009 breeding season compared to the average in 2003 and 2008 (Figure 9). In 2009, the Eden Landing Caspian tern colony (75 breeding pairs) was larger than in 2008 (56 breeding pairs; Figure 10).

We estimated that approximately 31 young terns fledged from the Eden Landing colony in 2009. Nesting success at the Eden Landing Caspian tern colony in 2009 (0.4 young raised/breeding pair) was only about half what it was in 2008 (Figure 11). Although Caspian terns attempted to nest at Eden Landing in 2004, all tern nests failed prior to hatching, presumably due to nest predation by mammalian predators. Nesting success at the Eden Landing Caspian tern colony was the highest observed in the Bay Area in 2009, but was still 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).

Chick Banding and Re-sightings of Banded Adults: Fourteen Caspian tern chicks were banded at Eden Landing in 2009. Each tern was banded with a federal numbered metal leg band and two plastic, colored leg bands on the left leg and a plastic leg band engraved with a unique alphanumeric code on the right leg; an additional 16 tern chicks that were too young to be banded with alphanumeric bands were banded with just a federal numbered metal band.

In 2009, 15 previously-banded Caspian terns were re-sighted at the Eden Landing tern colony. All 15 re-sighted banded terns were identified to the year when banded, age class when banded (i.e., adult or chick), and banding location. Of the 15 banded individuals that were re-sighted at Eden Landing in 2009, 8 (53%) were banded at Brooks Island (5 as adults and 3 as chicks), 6 (40%) were banded at East Sand Island in the Columbia River estuary (1 as an adult and 5 as chicks; Map 1), and 1 (7%) was banded at Knight Island in San Pablo Bay (northern San Francisco Bay area; Map 2) as a chick.

Four of the 15 banded terns re-sighted at Eden Landing Island were also re-sighted at Brooks Island in 2009, suggesting that there were movements of individuals between these two colonies. Possible explanations for these observation are (1) some terns were prospecting for breeding sites at both colonies, (2) some individuals breeding at one site in the Bay area were using the other site as a loafing area, (3) individuals that failed to nest at one site emigrated to the other colony for re-nesting.

Diet Composition: A total of 1,729 bill load fish were identified at the Eden Landing tern colony in 2009. The diet of Caspian terns nesting at Eden Landing was dominated by silversides (Atherinidae; 34.0% of identifiable prey items), flatfish (Pleuronectidae; 15.0%), surfperch (Embiotocidae; 12.0%), and anchovies (Engraulidae; 10.1%; Figure 12). Additional fish taxa that represented more than 1% but less than 10% of the

identified prey items included juvenile sharks (Carcharhinidae; 7.8%), gobies (Gobiidae; 5.6%), sculpins (Cottidae; 5.3%), smelt (Osmeridae; 2.4%), herring/sardine (Clupeidae; 1.6%), and sunfish (Centrarchidae; 1.3%). Five other prey taxa each represented less than 1% of the diet.

In 2009, three juvenile salmonids were identified among the 1,729 identifiable prey items, or 0.11% of all prey items identified at the Eden Landing colony (Figure 13). The general trend that has emerged from our research is that the further south Caspian terns nest in San Francisco Bay, the fewer juvenile salmonids they consume. Terns nesting at Eden Landing, a South Bay site, are less reliant on juvenile salmonids as a food source than terns nesting at Brooks Island, a Central Bay site (3 - 9% of prey items), which are less reliant on salmonids than terns that nested on the now abandoned colony site at Knight Island, a North Bay site (10 - 26% of prey items).

Factors Limiting Colony Size and Nesting Success: The primary factors limiting the size and productivity of the Caspian tern colony at Eden Landing are (1) availability of suitable nesting habitat, (2) the quality of nesting substrate, (3) nest predation by mammalian predators, and (4) encroachment by roosting American white pelicans (*Pelecanus erythrorhynchos*) and double-crested cormorants (*Phalacrocorax auritus*; Table 2). The island is very small and much of it consists of fine-grained sediment that turns mucky after a rain, which negatively affects egg hatchability. We suspect that some of the active Caspian tern nests on the Eden Landing colony were destroyed during the 2009 season by American white pelicans and double-crested cormorants that used the small island as a roosting site.

Stevens Creek

Background: Stevens Creek (Pond B2) is in southern San Francisco Bay near the town of Moffet (CA), and is part of the Don Edwards NWR. Caspian terns were first observed nesting at this site in 2007 (12 breeding pairs) and grew to ca. 120 breeding pairs in 2008 (Roby et al. 2009).

Colony Size and Nesting Success: We estimate that ca. 65 breeding pairs of Caspian terns nested at Stevens Creek in 2009 (Table 1), about half the size of te colony in 2008. We estimated that approximately 10 young terns fledged from the Stevens Creek colony in 2009. Nesting success at the Stevens Creek Caspian tern colony in 2009 (0.16 young raised/breeding pair) was similar to the nesting success of terns nesting on Brooks Island in 2009, and is considered low.

Chick Banding and Re-sightings of Banded Adults: Tern chicks were not banded at the Stevens Creek colony due to the relatively small colony size and concern over the potential impact of disturbance during banding activities on the productivity of this colony.

Re-sightings of previously banded adult Caspian terns were not conducted at the Stevens Creek colony in 2009.

Diet Composition: A total of 1,267 bill load fish were identified at the Stevens Creek tern colony in 2009. The diet of Caspian terns nesting at Stevens Creek was dominated by gobies (Gobiidae; 40.6%) and silversides (Atherinidae; 12.8% of identifiable prey items). Additional fish taxa that represented more than 1% but less than 10% of the identified prey items included catfish (Ictaluridae; 9.8%), surfperch (Embiotocidae; 7.9%), sculpins (Cottidae; 7.4%), flatfish (Pleuronectidae; 3.4%), sunfish (Centrarchidae; 3.4%), anchovies (Engraulidae; 3.1%), herring/sardine (Clupeidae; 2.3%), juvenile sharks (Carcharhinidae; 2.2%), and smelt (Osmeridae; 1.5%). Six other prey taxa each represented less than 1% of the diet.

In 2009, four juvenile salmonids were identified among the 1,267 identifiable prey items, or 0.24% of all prey items identified at the Stevens Creek colony. Like the Eden Landing Caspian tern colony, Stevens Creek is located in the South Bay, where the diet of nesting Caspian terns has included very few juvenile salmonids as compared to Caspian terns nesting at colonies in the North Bay or Central Bay.

Factors Limiting Colony Size and Nesting Success: The primary factors limiting the size and productivity of the Caspian tern colony at Stevens Creek in 2009 appeared to be the availability of suitable nesting habitat and the quality of nesting substrate (Table 2). The island is small and much of it consists of fine-grained sediment that turns mucky after a rain, which negatively affects egg hatchability.

Agua Vista Park

Background: The small Caspian tern colony near Agua Vista Park was discovered during the 2002 nesting season and was estimated to consist of 38 nesting pairs in 2004, although the size of the colony has declined in recent years. The colony formerly existed on two decaying fragments of a former wooden pier (Pier 63) on the San Francisco waterfront, just south of Pacific Bell Park (home of the SF Giants). The colony gets its name from a very small park of that name on the shores of the Bay adjacent to the collapsing pier. 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. In 2008, Caspian terns nested on one remaining section of the pier (ca. 40 breeding pairs; Roby et al. 2009), digging nest scrapes in the dirt and debris on the surface. Several pairs of western gulls nested in the vicinity, including on the section of pier where the terns nested. This pier fragment appears to be in imminent danger of collapsing. The owner of the property is the San Francisco Port Authority.

Colony Size and Nesting Success: Based on periodic visits to Agua Vista Park throughout the breeding season in 2009, we estimate that 8 breeding pairs of Caspian terns nested there (Table 1), down from 14 breeding pairs the previous year. This colony has been steadily declining in size since 2003 (Roby et al. 2003b, 2004; USFWS unpublished data). Although we think that a few young terns were fledged from this colony in 2009, we were not able to verify nesting success. Based on our research during 2003-2005,

average nesting success (0.75 young per breeding pair) at this colony was considered fair to good compared to other well-studied colonies in the Pacific Region.

Chick Banding and Re-sightings of Banded Adults: Tern chicks were not banded at the Agua Vista Park colony due to the inaccessibility of the colony and the danger associated with attempting to access the colony on the decaying pier structure.

We were not able to determine if any banded adult terns frequented the Agua Vista Park tern colony in 2009 due to the distance between the colony and our observation site (> 300 m).

Diet Composition: Diet data were not collected at the Agua Vista tern colony in 2009. Based a small number of Caspian tern bill loads identified in 2003-2004, terns nesting at Agua Vista cosume mostly schooling marine forage fish (i.e., surfperch, anchovies, silversides, and herring/sardines). Juvenile salmonids comprised between 0.1% and 1.4% of the identified prey items during 2003-2004.

Factors Limiting Colony Size and Nesting Success: The primary factors limiting the size and productivity of the Agua Vista Caspian tern colony appeared to be the quality of nesting substrate and the availability of suitable nesting habitat (Table 2). Suitable nesting substrate is certainly the proximate factor limiting the size of the tern colony on the remaining pier fragment, but because terns are nesting at this site it is evident that the availability of suitable nesting habitat for Caspian terns is extremely limited in that part of San Francisco Bay.

Other San Francisco Bay Sites

Two additional Caspian tern nesting sites were discovered in the South Bay during 2009. One breeding pair nested at Redwood Shores, located near Redwood City, and one breeding pair nested at Ravenswood, a historical tern nesting site near East Palo Alto (Map 2). Both breeding pairs were successful in hatching at least one tern chick, but neither pair successfully fledged a chick.

Interior Oregon and Northeastern California

Crump Lake

Background: Crump Lake is located in the Warner Valley in south-central Oregon, near Adel, Oregon. All islands and seasonally inundated wetlands associated with the lake are owned and managed by the Oregon Division of State Lands. A low-lying rocky island that was used by a variety of colonial nesting waterbirds in years when the water level in the lake was low was located near the center of Crump Lake, north of the peninsula that nearly bisects the lake. In the early part of the 20th Century this natural island supported large numbers of breeding colonial waterbirds, but in the 1950s, when the lake dried out, heavy equipment was used to break up the island in the search for Native American

artifacts, which resulted in a lower elevation island that was subject to erosion and was completely inundated in high water years. In the early 1990s, following another drought year, the Oregon Department of Fish and Wildlife attempted to restore the island so that it would offer perennial nesting habitat for colonial waterbirds, but subsequent wind and wave erosion again reduced island elevation so that it was inundated during high-water periods in spring and early summer, preventing nesting on the island in at least some years. Caspian terns were observed nesting on Crump Lake island in 2000, when approximately 150 breeding pairs nested in association with a larger colony of California gulls, but no Caspian terns nested on the island in 2001 or 2002 due to high water levels. In 2003, a temporary wooden nesting platform was constructed on the submerged island and equipped with Caspian tern decoys and acoustic playback systems to attract nesting terns (Kress 2000, Kress and Hall 2002); 49 pairs of Caspian terns nested successfully on the platform, and subsequently 22 breeding pairs nested on the island, once the lake level had dropped sufficiently to expose part of the island.

As part of the implementiion of the plan "*Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*" (USFWS 2005), the U.S. Army Corps of Engineers completed construction of a 1-acre rock-core island in Crump Lake at the location of the pre-existing island in March of 2008. The island was designed so as to resist erosion and remain well above lake levels, even at full pool, and the surface was covered with gravel and sand to provide nesting substrate for Caspian terns. Caspian tern decoys and acoustic playback systems that broadcast Caspian tern calls were installed on the island in order to attract terns to nest at the site (Kress 2000, Kress and Hall 2002). In 2008, Caspian terns were quick to colonize the new island, where ca. 430 breeding pairs eventually nested and ca. 150 young terns survived to fledging (Roby et al. 2009).

Nesting Chronology, Colony Size, and Nesting Success: In 2009, the first Caspian terns were observed at the tern island in Crump Lake on 21 April (Figure 14), approximately two weeks earlier than the first arrival of terns at the island in 2008 (Roby et al. 2009). The first tern egg was laid on 14 May, the first tern chick hatched on 14 June, and the first tern chick fledged on 29 July (Figure 14). Nevertheless, Caspian tern nesting chronology at the Crump Lake tern island in 2009 was 2-4 weeks behind the nesting chronology of Caspian terns at colonies in the Columbia River basin (BRNW 2010). Numbers of Caspian terns counted on the Crump Lake tern island from late May to late June in 2009 were much greater than during the same period in 2008, while in July of 2009 tern counts were less in 2009 compared to 2008 (Figure 15). We estimate that ca. 670 breeding pairs of Caspian terns nested at the Crump Lake colony in 2009, a 63% increase in colony size compared to the previous year (Figure 16).

We estimated that approximately 117 young Caspian terns fledged from the Crump Lake tern colony in 2009, or an average of 0.17 young fledged per breeding pair (Figure 17). This is less than the productivity measured at the Crump Lake tern colony in 2008 (ca. 0.34 young fledged per breeding pair; Figure 17), and is considered very low compared to other well-studied colonies in the Pacific Region.

As was the case in 2008, high nest predation rates on Caspian tern eggs by California gulls at the Crump Lake tern island necessitated removal of problem gulls using firearms (under permit); a total of nine California gulls that were preying on tern eggs were removed in 2009.

Adult and Chick Banding and Re-sightings of Banded Adults: On June 16, 31 adult Caspian terns were banded at Crump Lake tern island with a federal numbered metal leg band and two plastic, colored leg bands on the left leg and a plastic leg band engraved with a unique alphanumeric code on the right leg. On August 4, 63 Caspian tern chicks near fledging age were banded using the same banding scheme as adults; an additional 20 tern chicks that were too young to band with alphanumeric bands were banded only with federal numbered metal bands.

In 2009, 49 previously-banded Caspian terns were re-sighted at the tern nesting island on Crump Lake. Forty-six of the re-sighted terns had been banded by our research team and were identified to the year when banded, age class when banded (i.e., adult or chick), and banding location; the other three re-sighted adults had been banded in 1999 in Stillwater, Nevada by another research team. Of the 46 individuals banded by our crew, 18 (39%) were banded at East Sand Island in the Columbia River estuary (2 as adults and 16 as chicks), 14 (30%) were banded at Crescent Island on the mid-Columbia River near Pasco, WA (1 as an adult and 13 as chicks), 5 (11%) were banded as chicks at Goose Island in Potholes Reservoir near Moses Lake, WA, 4 (9%) were banded as chicks at Crump Lake, 2 (4%) were banded as chicks at Solstice Island in Potholes Reservoir, 2 (4%) were banded as chicks at Brooks Island in San Francisco Bay, and 1 (2%) was banded as a chick at Dungeness Spit on the Olympic Peninsula, WA.

Based on the re-sighting of Caspian terns on the Crump Lake colony that had been banded on East Sand Island, the Crump Lake tern colony currently serves as an alternative nesting site for terns dispersing from the large colony on East Sand Island, over 500 km away. Further reductions in the available Caspian tern nesting habitat on East Sand Island are imminent as part of the Caspian Tern Management Plan (USFWS 2005), suggesting that more Caspian terns nesting on East Sand Island will emigrate to the Crump Lake tern island. The proportion of Caspian terns at East Sand Island that are color-banded is small (e.g., about 5% of fledglings were banded in 2003), whereas the proportion of color-banded terns at some other sites is significantly higher (e.g., about 67% of fledglings at Crescent Island were banded in 2004; Table 3). Consequently, it is likely that the majority of Caspian terns that colonized the Crump Lake tern island in 2009 originated from the colony on East Sand Island (Table 3).

Diet Composition: A large number of Caspian tern bill loads (N = 3,529) were identified at the Crump Lake colony in 2009. As was the case in 2003 and 2008, the diet composition of Caspian terns nesting on Crump Lake consisted primarily of tui chub (*Gala bicolor*; 75.6% of the identifiable prey items), followed by crappie (Centrarchidae; 15.4%), and bullhead catfish (Ictaluridae; 8.8%; Figure 18). The remaining 0.2% of identified prey items consisted of nine rainbow trout (*Oncorhynchus mykiss*) and one sucker (*Catostomus* spp.). The one sucker (0.02% of identifiable prey items) that was

observed on the colony during the nesting season could not be positively identified as an ESA-listed sucker (i.e., Warner sucker [*C. warnerensis*]). In 2008, five suckers were observed in the bills of Caspian terns nesting on the Crump Lake tern island, one of which was positively identified as a Warner sucker (Roby et al. 2009).

Factors Limiting Colony Size and Nesting Success: Prior to 2008, the main factor limiting nesting success of Caspian terns at Crump Lake was fluctuating water levels that either inundated the available nesting habitat or caused the nesting island to be connected to the mainland, allowing access by mammalian nest predators. In 2008-2009, gull predation was the most significant factor limiting the size and nesting success of Caspian terns nesting on the Crump Lake tern island (Table 2). In 2009, low forage fish availability late in the nesting season apparently contributed to the low nesting success.

Summer Lake

Background: The Summer Lake Wildlife Area is located in south-central Oregon near the town of Summer Lake (OR) and is owned and managed by the Oregon Department of Fish and Wildlife. The Summer Lake Wildlife Area consists of an extensive area of wetlands, moist soil units, and freshwater impoundments associated with the Ana River, which flows into the north end of Summer Lake. A small breeding colony of Caspian terns (< 50 breeding pairs) formerly nested on a small island at the north end of Summer Lake proper in association with a much larger colony of California and ring-billed gulls. In 2001 and 2002, this colony failed to produce any young due to declining water levels in Summer Lake, which provided access to the island for mammalian predators (e.g., coyotes, raccoons, skunks). In 2002, Caspian terns attempted to nest on a small push-up island in East Link Impoundment in Summer lake Wildlife Area, but this nesting attempt also failed. Prior to the arrival of Caspian terns to the Summer Lake area in spring of 2003, improvements were made to the push-up island in East Link Impoundment; 5 pairs of Caspian terns subsequently attempted to nest there in 2003 and produced 2 young. Nesting attempts by Caspian terns in the Summer Lake area have been recorded in only one year since 2003 (3 breeding pairs in 2005; M. St. Louis, ODFW, personal communication). Summer Lake Wildlife Area is listed as one of three sites in interior Oregon where resource managers intend to create nesting habitat for Caspian terns in an effort to provide alternative habitat for the large tern colony on East Sand Island in the Columbia River estuary.

The USACE, in partnership with the Oregon Department of Fish and Wildlife, built two half-acre nesting islands for Caspian terns at Summer Lake Wildlife Area prior to the 2009 nesting season. Construction was initiated in December 2008 and completed by early March 2009. One half-acre island was constructed in East Link Impoundment, the site of the most recent Caspian tern nesting activity on the Summer Lake Wildlife Area. A second half-acre island has been built on Dutchy Lake; this island consists of a floating platform instead of a rock-core island because Dutchy Lake is a permanent body of water. The Dutchy Lake floating island was constructed by Floating Islands West of modules of recycled plastic impregnated with foam, assembled on the shores of the lake, and anchored near the middle of the lake.

Nesting Chronology, Colony Size, and Nesting Success: As was the case following the construction of the Crump Lake tern island in 2008, Caspian terns were quick to colonize the newly constructed tern islands in Summer Lake Wildlife Area during 2009. The first Caspian terns were observed at the Summer Lake tern islands on 20 April 2009 (Figure 19). The first tern egg was laid on 17 May, the first tern chick hatched on 14 June, and the first tern chick fledged on 19 July at the Summer Lake tern islands (Figure 19). The nesting chronology of Caspian terns nesting at Summer Lake Wildlife Area was very similar to that at Crump Lake in 2009. This is noteworthy considering that Caspian terns had not nested at Summer Lake Wildlife Area since 2005, while terns nested at Crump Lake tern island the previous year. These results suggest that it did not take Caspian terns any longer to find and colonize the newly constructed islands at Summer Lake Wildlife Area compared to the existing tern colony at Crump Lake. Weekly colony attendance at the Summer Lake tern islands was generally higher and more protracted in 2009 as compared to 2003 (the last time tern nesting at Summer Lake was intensively monitored; Figure 20). Eight breeding pairs of Caspian terns nested on the Dutchy Lake floating island and seven breeding pairs nested on the East Link Impoundment rock-core island, or a total of 15 breeding pairs at Summer Lake Wildlife Area in 2009 (Figure 21). By comparison, only five breeding pairs attempted to nest at Summer Lake Wildlife Area in 2003 (Roby et al. 2003b).

We estimated that five young terns were fledged from the Dutchy Lake floating island and seven were fledged from the East Link island in 2009. Combined Caspian tern productivity at the Summer Lake tern islands was 0.80 young fledged per breeding pair, higher than Caspian tern productivity at Summer Lake in 2003 (Figure 22), and the highest Caspian tern nesting success observed at any colony monitored by our group in 2009 (BRNW 2010).

Gull control was not necessary at the Summer Lake tern islands in 2009, but may be required in future years if gulls start exploiting the tern colonies in Summer Lake Wildlife Area as a source of food (i.e., tern bill-load fish, tern eggs, or tern chicks).

Re-sightings of Banded Adults: In 2009, 14 previously-banded Caspian terns were re-sighted at either the East Link or Dutchy Lake tern islands in Summer Lake Wildlife Area. Of the 14 banded individuals, 6 (43%) were banded at East Sand Island, 6 (43%) were banded at Crescent Island, 2 (14%) were banded at Goose Island, and 1 (7%) was banded at Crump Lake. All of them were banded as chicks. Two of them were also re-sighted at Crump Lake tern island, suggesting that there were movements of individuals between colonies at Summer and Crump lakes.

Diet Composition: A moderate number of Caspian tern bill loads (N = 819) were identified at the Summer Lake colonies in 2009. As was the case in 2003, the diet composition of Caspian terns nesting at Summer Lake Wildlife Area consisted primarily of tui chub (*Gala bicolor*; 82.7% of the identifiable prey items), followed by rainbow trout (*Oncorhynchus mykiss*; 13.1%), and sunfish (Centrarchidae; 3.0%; Figure 23).

Factors Limiting Colony Size and Nesting Success: Prior to 2009, the main factor limiting nesting success of Caspian terns at Summer Lake was declining water levels that caused the nesting island to be connected to the mainland, thereby allowing access by mammalian nest predators to the colony site. In 2009, the main limiting factor to colony size may have been that Caspian terns from other sites had not yet found the newly constructed islands at Summer Lake Wildlife Area. It may take several years before other factors limit colony size and nesting success (Table 2).

Fern Ridge Reservoir

Background: Fern Ridge Reservoir is a shallow and expansive flood control reservoir in the southern Willamette Valley near the city of Eugene (OR). It is owned and managed by the U.S. Army Corps of Engineers. Although Caspian terns have been observed to use the lake during migration, the species has not been previously recorded to nest in the area. In 2008, the U.S. Army Corps of Engineers began implementing the plan "*Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*" described in the Final Environmental Impact Statement (FEIS) and Records of Decision (RODs) signed in November 2006 (USFWS 2005, 2006). Fern Ridge Reservoir is one of three sites in interior Oregon where resource managers created nesting habitat for Caspian terns as part of this plan. In February 2008, the U.S. Army Corps of Engineers completed construction of a 1-acre island in Fern Ridge Reservoir near the Fern Ridge Wildlife Area, which is managed jointly by the Oregon Department of Fish and Wildlife and the Corps of Engineers. The island was revetted with rip-rap to prevent erosion and topped with pea gravel as a nesting substrate for Caspian terns. Caspian tern decoys and acoustic playback systems broadcasting Caspian tern recordings were installed on the island in an effort to attract terns to nest at the site (Kress 2000, Kress and Hall 2002). Although Caspian terns visited the island after the breeding season in 2008 (presumably post-breeding terns that had dispersed from other nesting sites), terns apparently did not attempt to nest there in 2008 (Roby et al. 2009).

Results in 2009: As was the case in 2008, Caspian terns did not attempt to nest on the tern island at Fern Ridge Reservoir in 2009. Review of video footage revealed that Caspian terns visited the island late in the breeding or during the post-breeding season, presumably once terns dispersed from other nesting colonies. From late June to late August, Caspian terns were regularly observed (on 31 of 33 days when video footage was recorded) on the Fern Ridge Reservoir tern island, with as many as eight Caspian terns observed amongst the tern decoys on the island at one time. Video footage also revealed frequent visits to the Fern Ridge Reservoir tern island by avian predators (i.e., bald eagles, great-horned owls, and peregrine falcons). These avian predators were seen attacking Caspian tern decoys on the island and, on 24 July, an adult bald eagle was observed to attack and kill two hatch-year Caspian terns that were roosting among the decoys on the island. Earlier in July the lower mandible of an adult Caspian tern was found in the rock revetment on the edge of the island, suggesting predation by a bald eagle. Finally, human activity was observed on or near the Fern Ridge Reservoir tern island on five different occasions. Based on our review of video footage at the Fern Ridge Reservoir tern island, it appears that avian predation, and possibly human

disturbance, may be important factors precluding the initiation of nesting by Caspian terns on Fern Ridge island.

Other Interior Oregon and Northeastern California Sites

During the 2009 nesting season, we conducted aerial, road-based, and boat-based surveys for nesting Caspian terns at potential colony locations in central Oregon, including Wickiup Reservoir, Crane Prairie Reservoir, Davis Lake, Agency Lake, Swan Lake, Spring Lake, Whiteline Reservoir, and Upper Klamath Lake. We also surveyed potential Caspian tern colony sites in south-central Oregon, including Summer Lake, Willow Valley Reservoir, Lake Abert, Gerber Reservoir, Drews Reservoir, Greaser Reservoir, Pelican Lake, Crump Lake, Hart Lake, Anderson Lake, Flagstaff Lake, Mugwump Lake, Swamp Lake, Upper Campbell Lake, Campbell Lake, Stone Coral Lake, Turpin Lake, Bluejoint Lake, and Goose Lake. We also surveyed for potential Caspian tern colonies in south-eastern Oregon, including Malheur Lake, Mud Lake, Harney Lake, Baca Lake, Knox Pond, Krumbo Lake, Warm Springs Valley, Owyhee Reservoir, Antelope Reservoir, Lower Cow Lake, and Upper Cow Lake. Finally, we also surveyed for Caspian tern colonies in northeastern California, including Meiss Lake, Big Sage Reservoir, Clear Lake Reservoir, Tule Lake, Raker Reservoir, and Thomas Reservoir. Based on aerial surveys conducted during 27-29 May 2009, Caspian tern nesting activity was detected at only one additional site: on an island in the eastern arm of Clear Lake Reservoir, Clear Lake NWR. Thirty-five breeding Caspian terns were counted within a large mixed colony of American white pelicans, double-crested cormorqnts, and gulls. No other Caspian tern nesting activity was detected in interior Oregon or northeastern California during 2009.

ACKNOWLEDGMENTS

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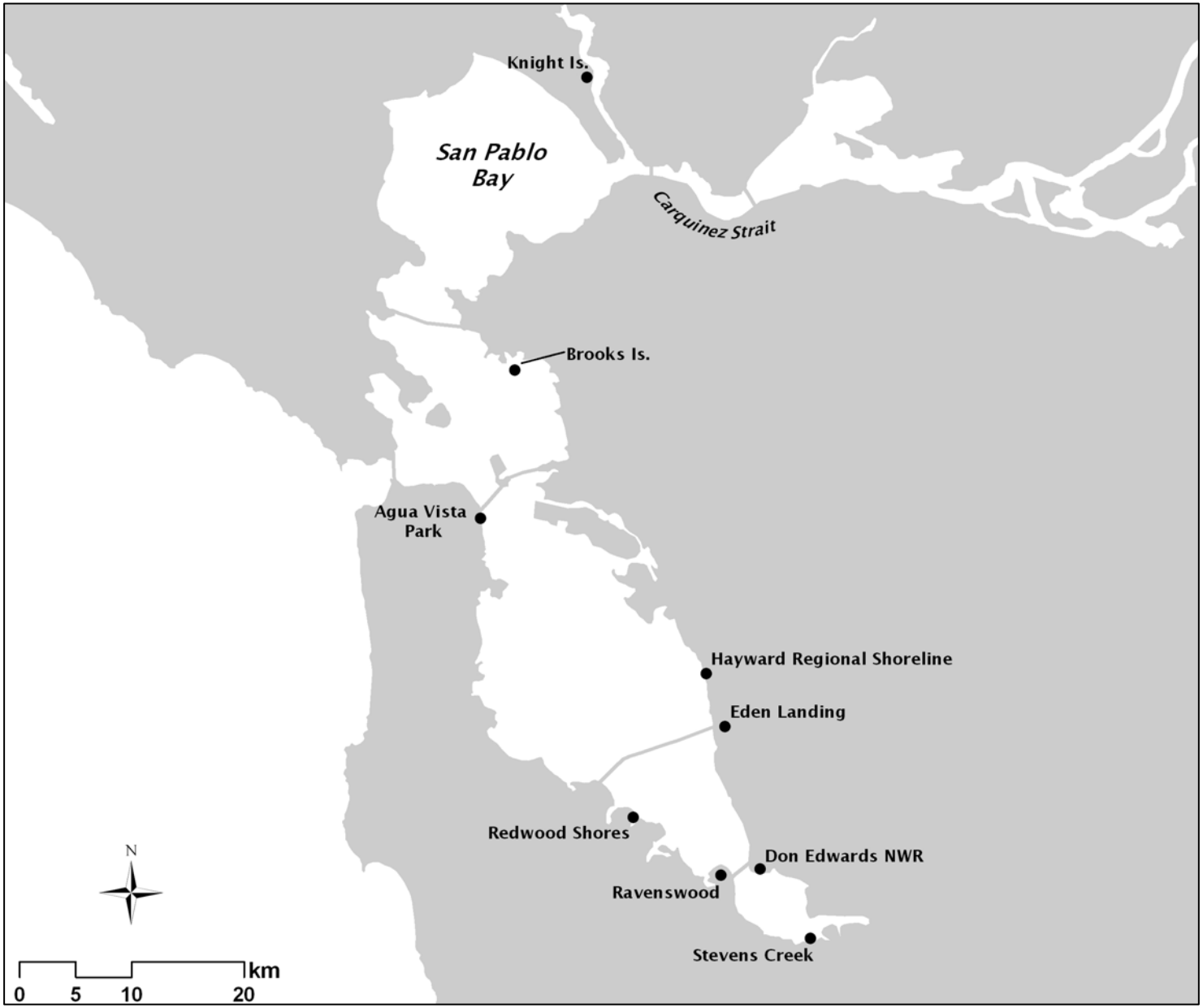
Map 1. Study area in interior Oregon and northeastern California, plus locations of other Caspian tern nesting colonies in Washington, Oregon, and Nevada that are mentioned in this report.



Map 2. Study area in the San Francisco Bay area, showing locations of Caspian tern nesting sites mentioned in this report.

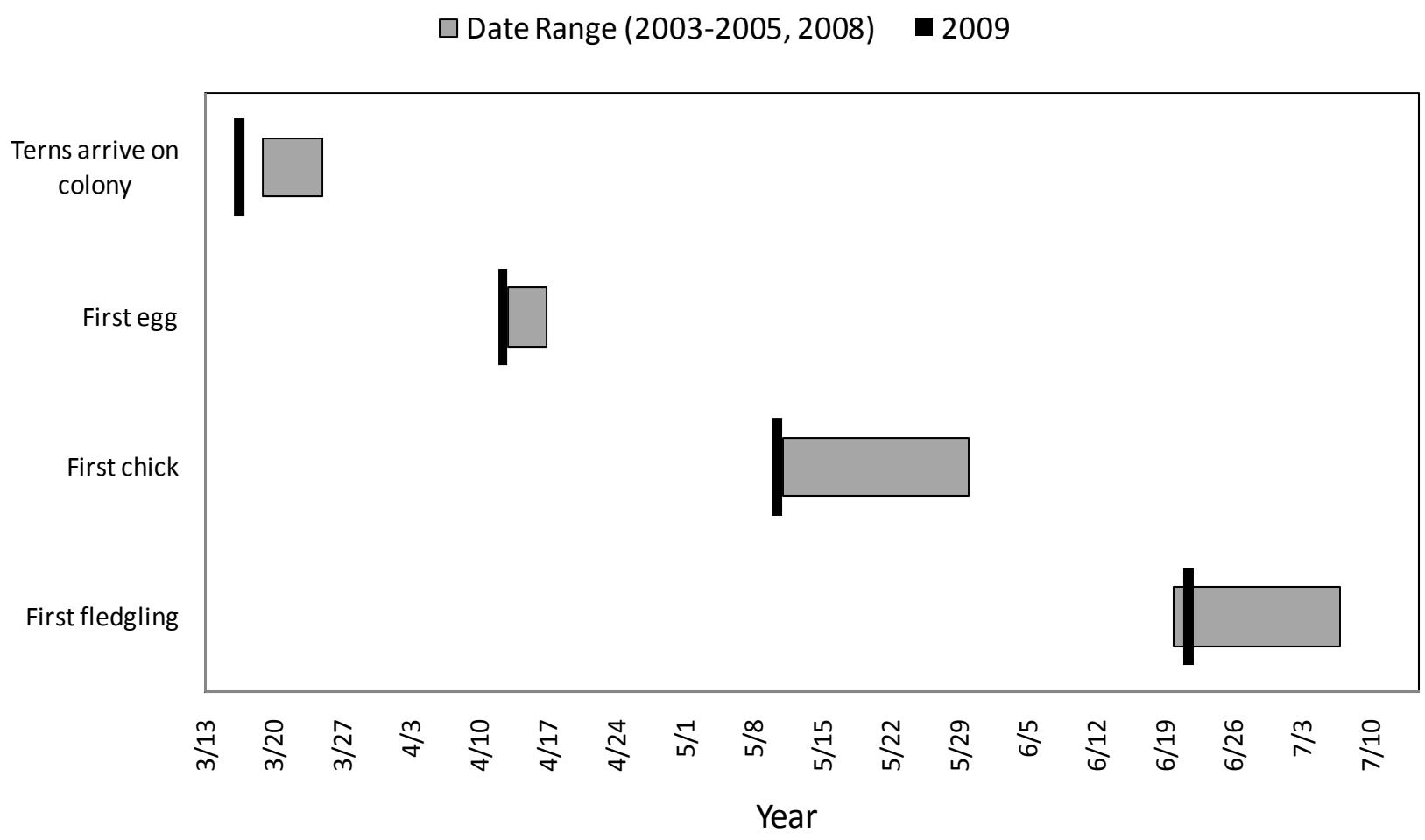


Figure 1. Nesting chronology at the Brooks Island Caspian tern colony, San Francisco Bay. during 2009

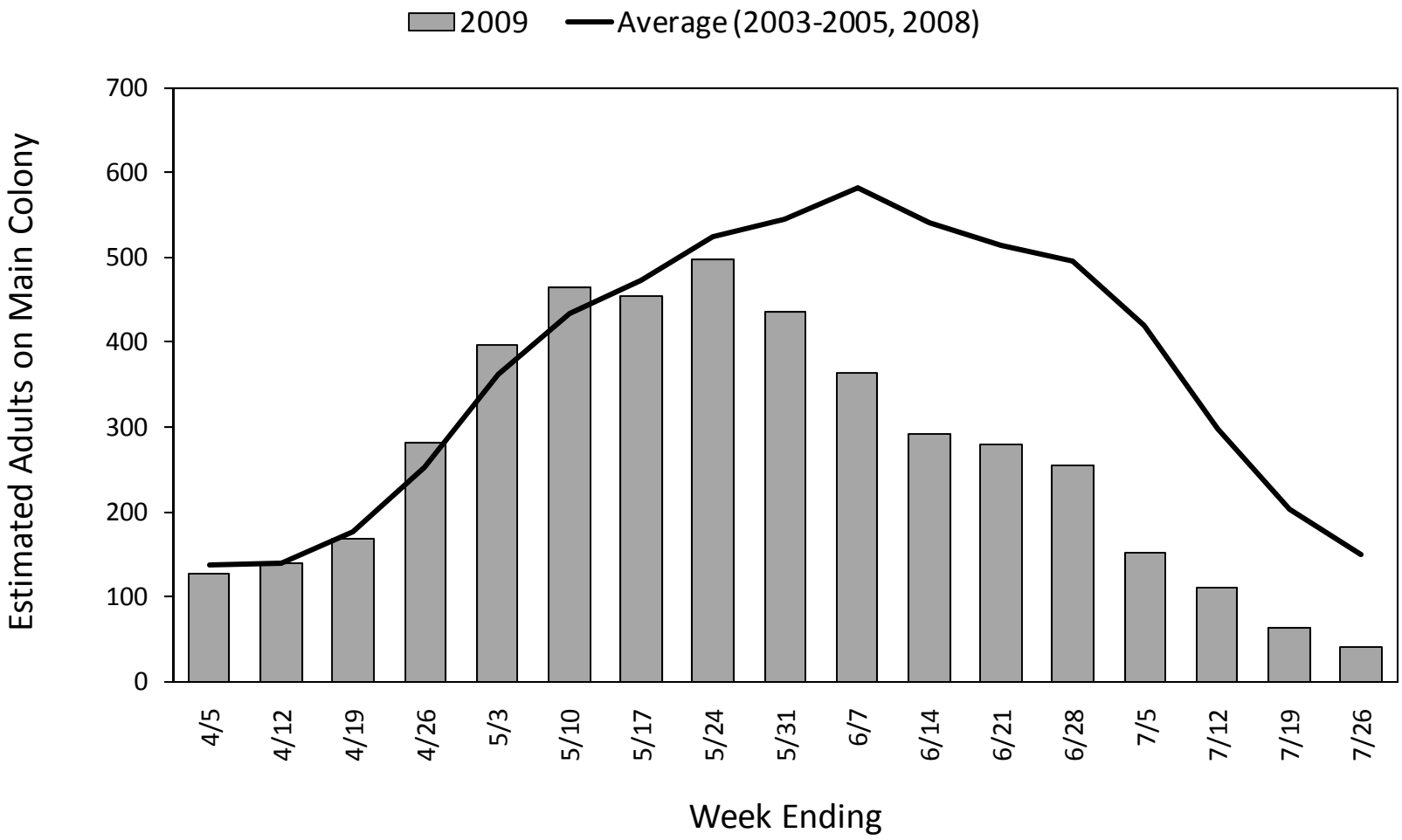


Figure 2. Weekly estimates from the ground of the number of adult Caspian terns on the Brooks Island colony, San Francisco Bay, during 2009.

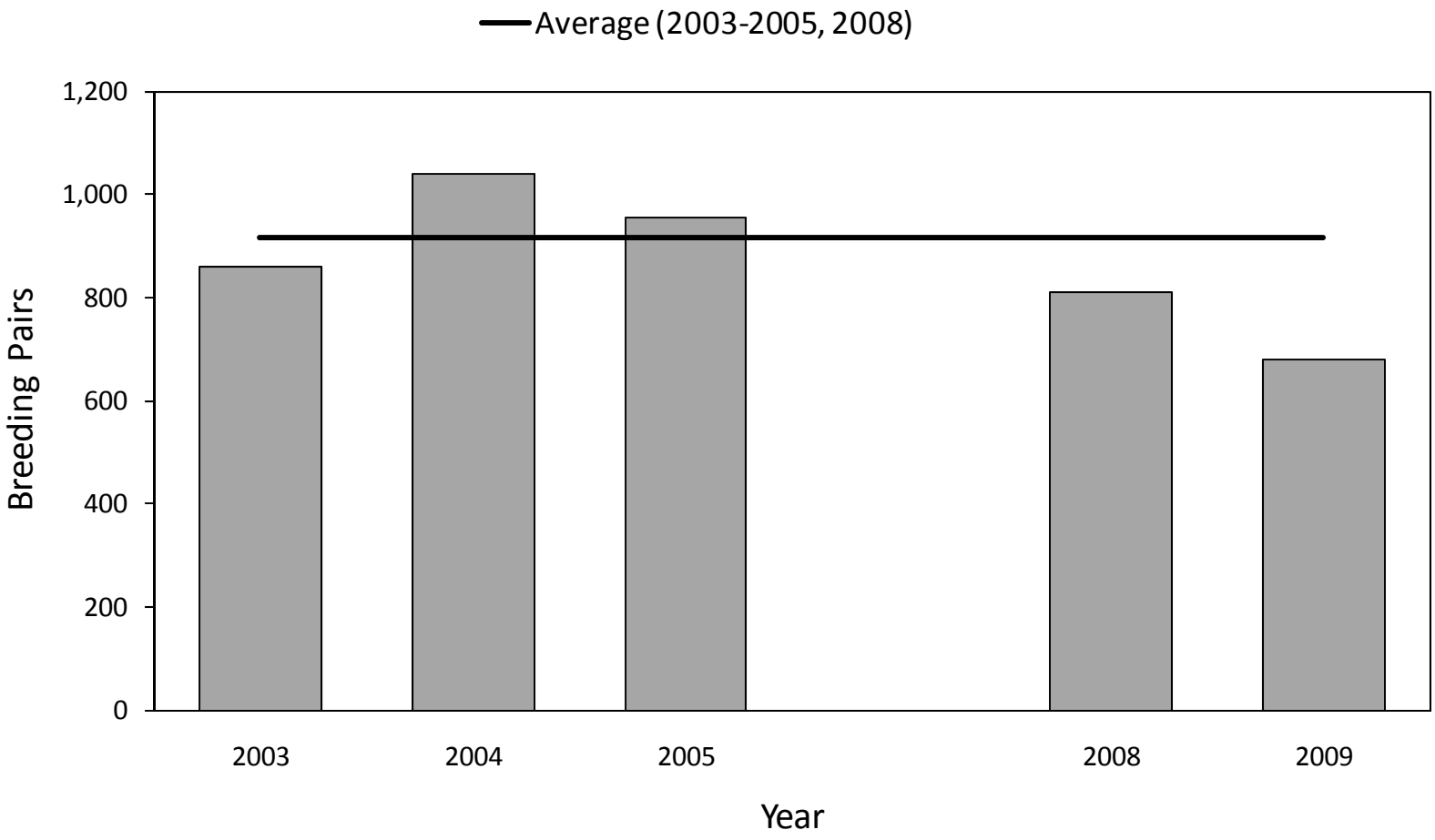


Figure 3. Caspian tern colony size on Brooks Island, San Francisco Bay, during 2009 compared to 2003-2005 and 2008.

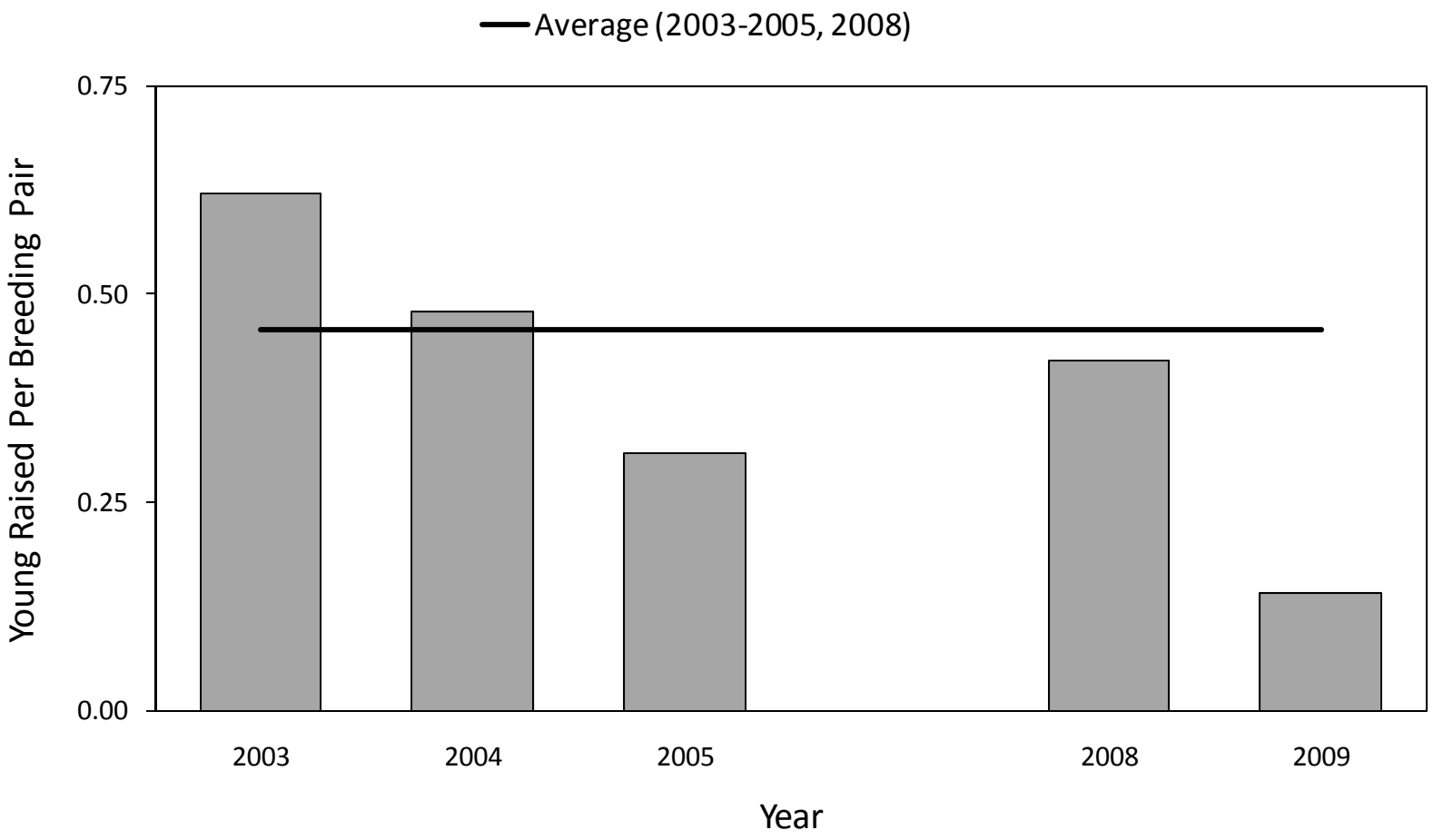


Figure 4. Caspian tern nesting success on Brooks Island, San Francisco Bay, during 2009 compared to 2003-2005 and 2008.

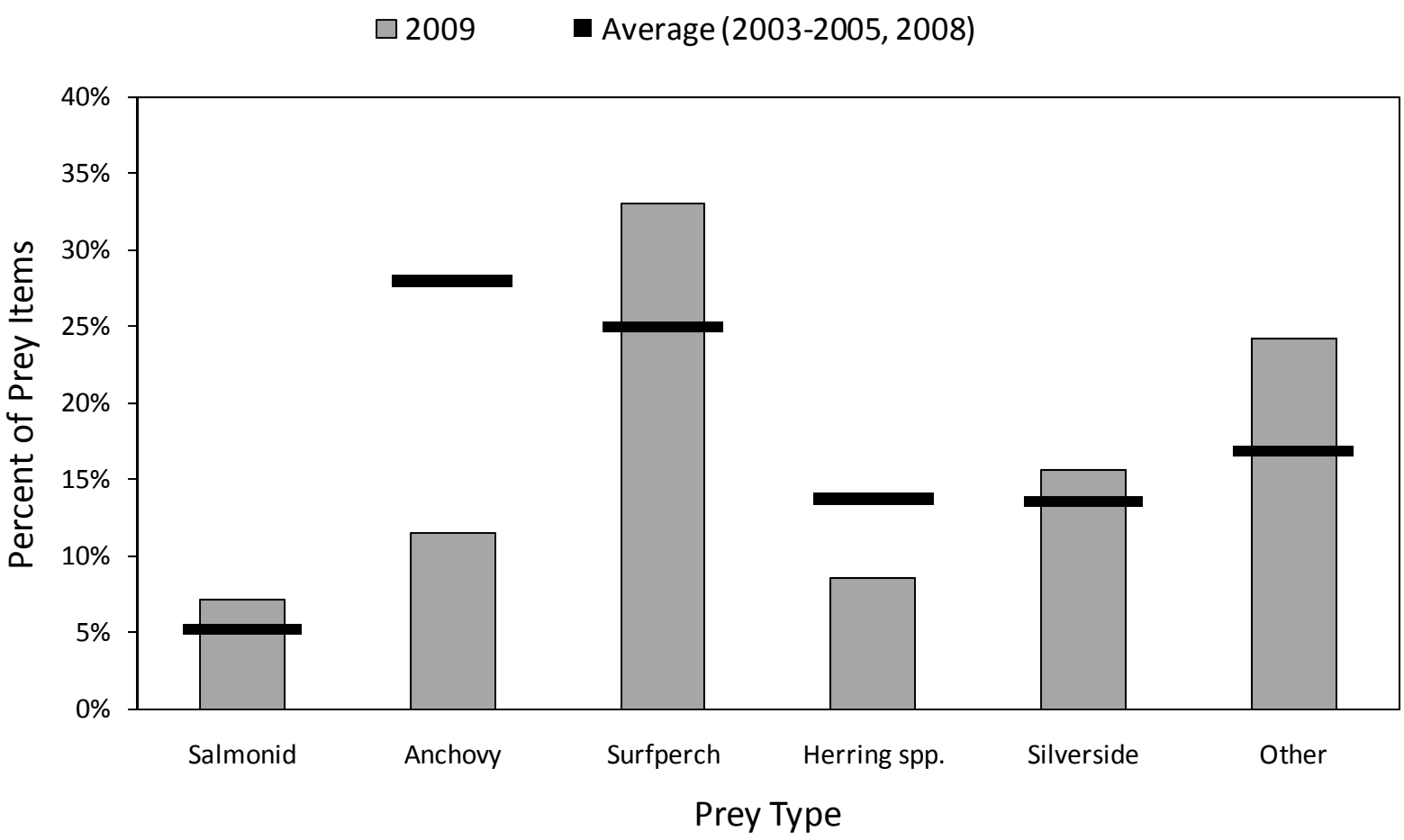


Figure 5. Diet composition of Caspian terns nesting on Brooks Island, San Francisco Bay, during 2009.

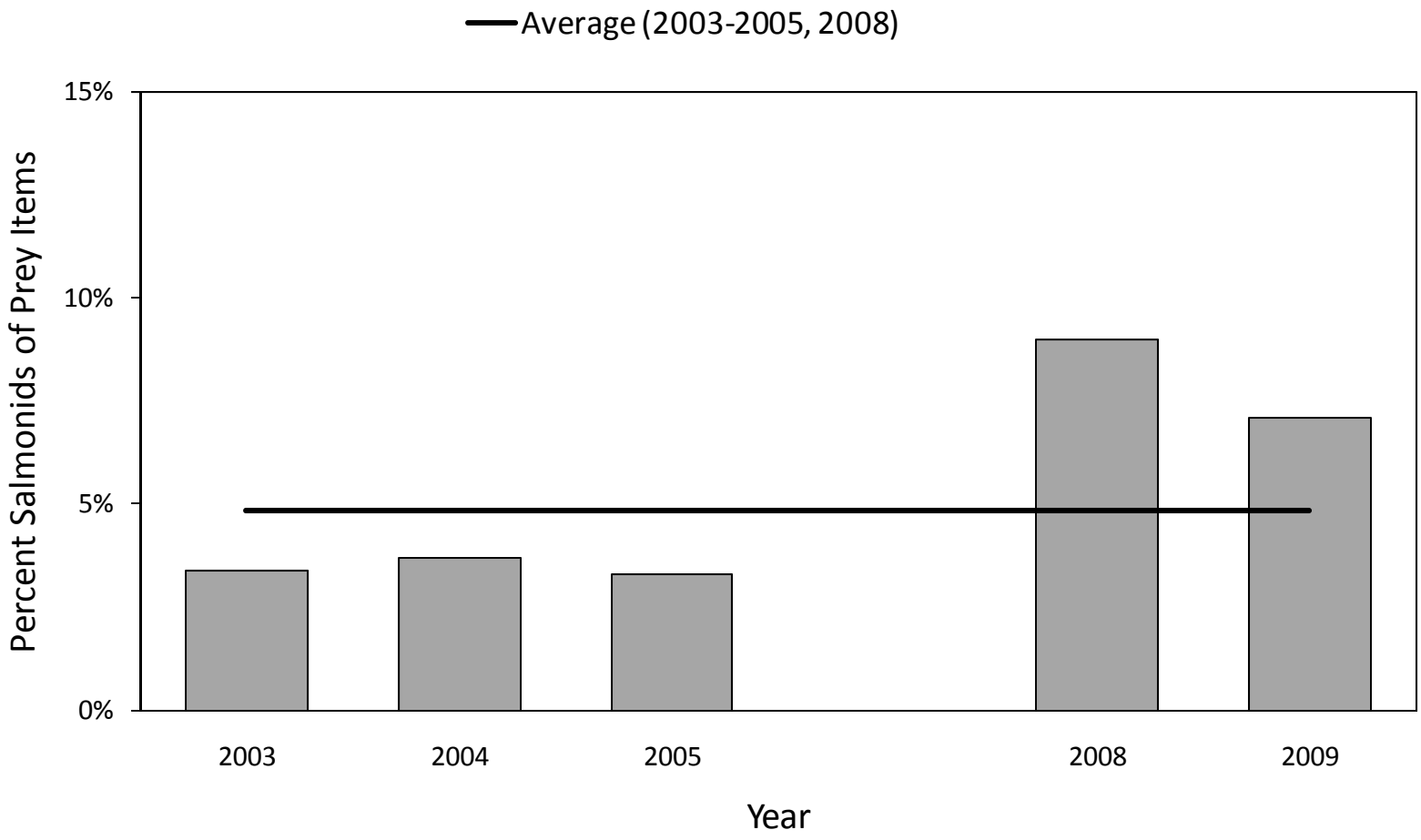


Figure 6. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Brooks Island, San Francisco Bay, during 2009 compared to 2003-2005 and 2008.

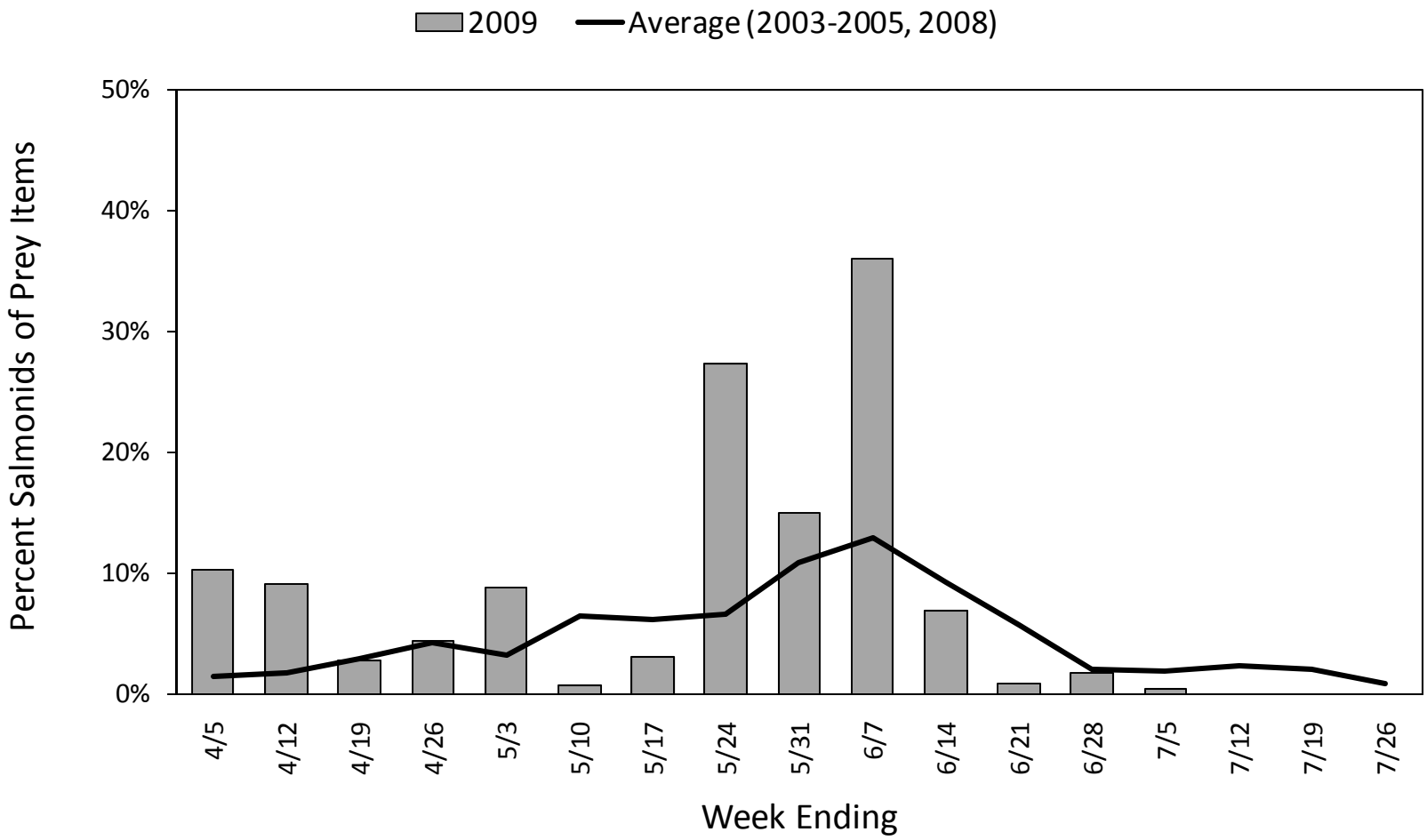


Figure 7. Weekly proportions of juvenile salmonids in the diet of Caspian terns nesting on Brooks Island, San Francisco Bay, during 2009.

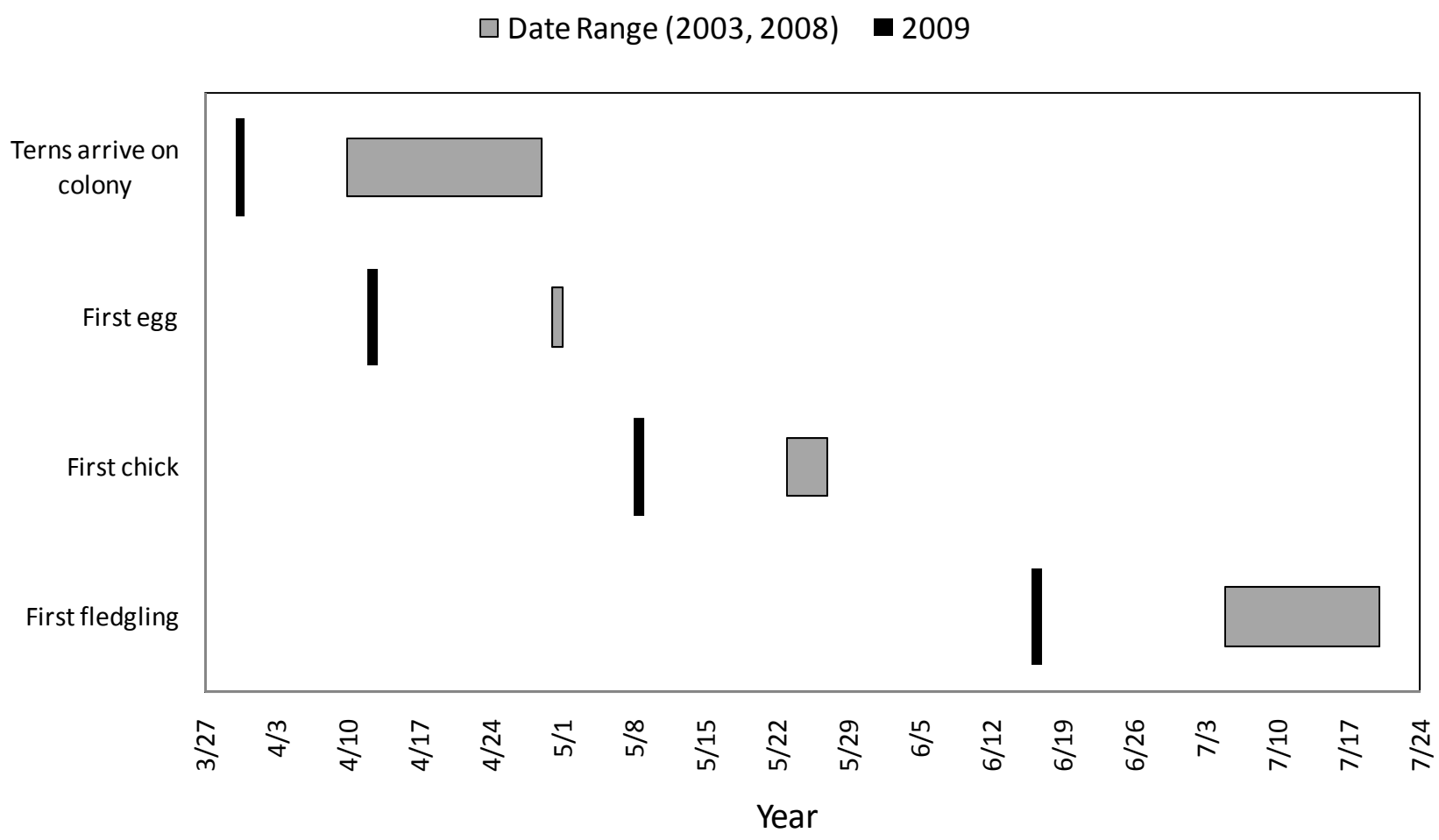


Figure 8. Nesting chronology at the Eden Landing Caspian tern colony, San Francisco Bay, during 2009.

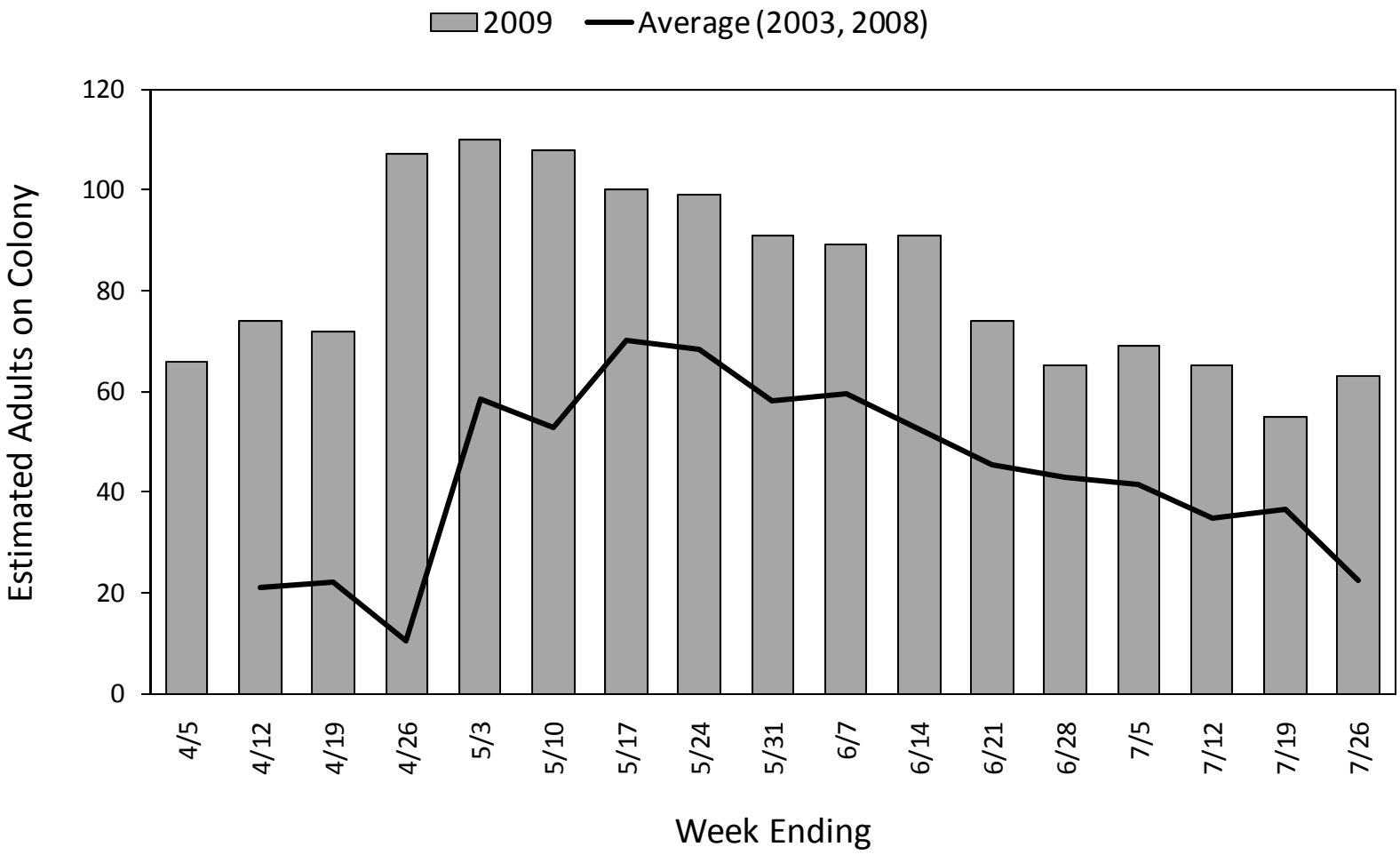


Figure 9. Weekly estimates from the ground of the number of adult Caspian terns on the Eden Landing colony, San Francisco Bay, during 2009.

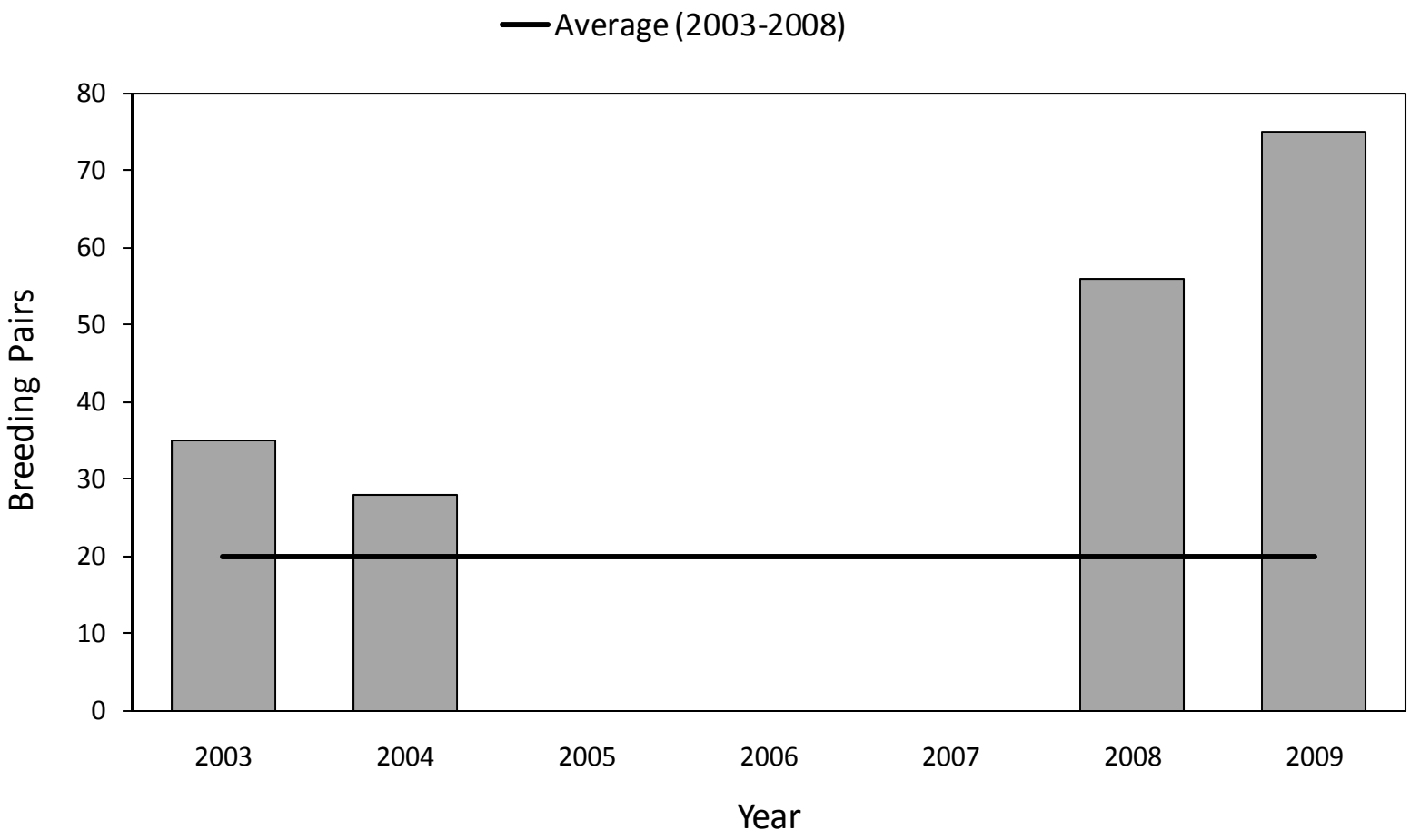


Figure 10. Caspian tern colony size at Eden Landing, San Francisco Bay, during 2009 compared to 2003-2004 and 2008. Caspian terns did not nest at Eden Landing during 2005-2007.

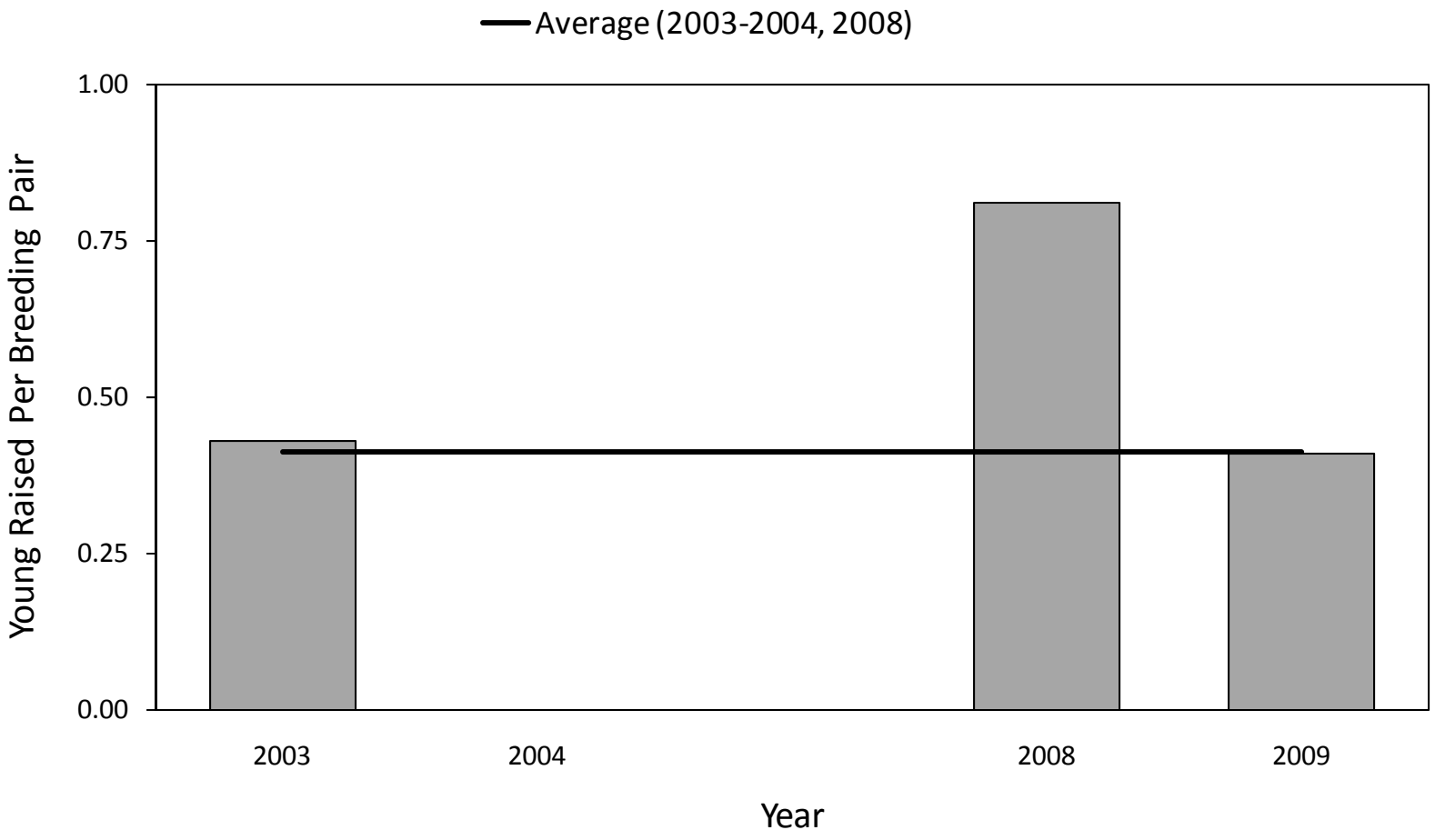


Figure 11. Caspian tern nesting success at Eden Landing, San Francisco Bay, during 2009 compared to 2003-2004 and 2008. Caspian terns nested at Eden Landing in 2004, but were not successful in fledging any young during that year. Caspian terns did not nest at Eden Landing during 2005-2007.

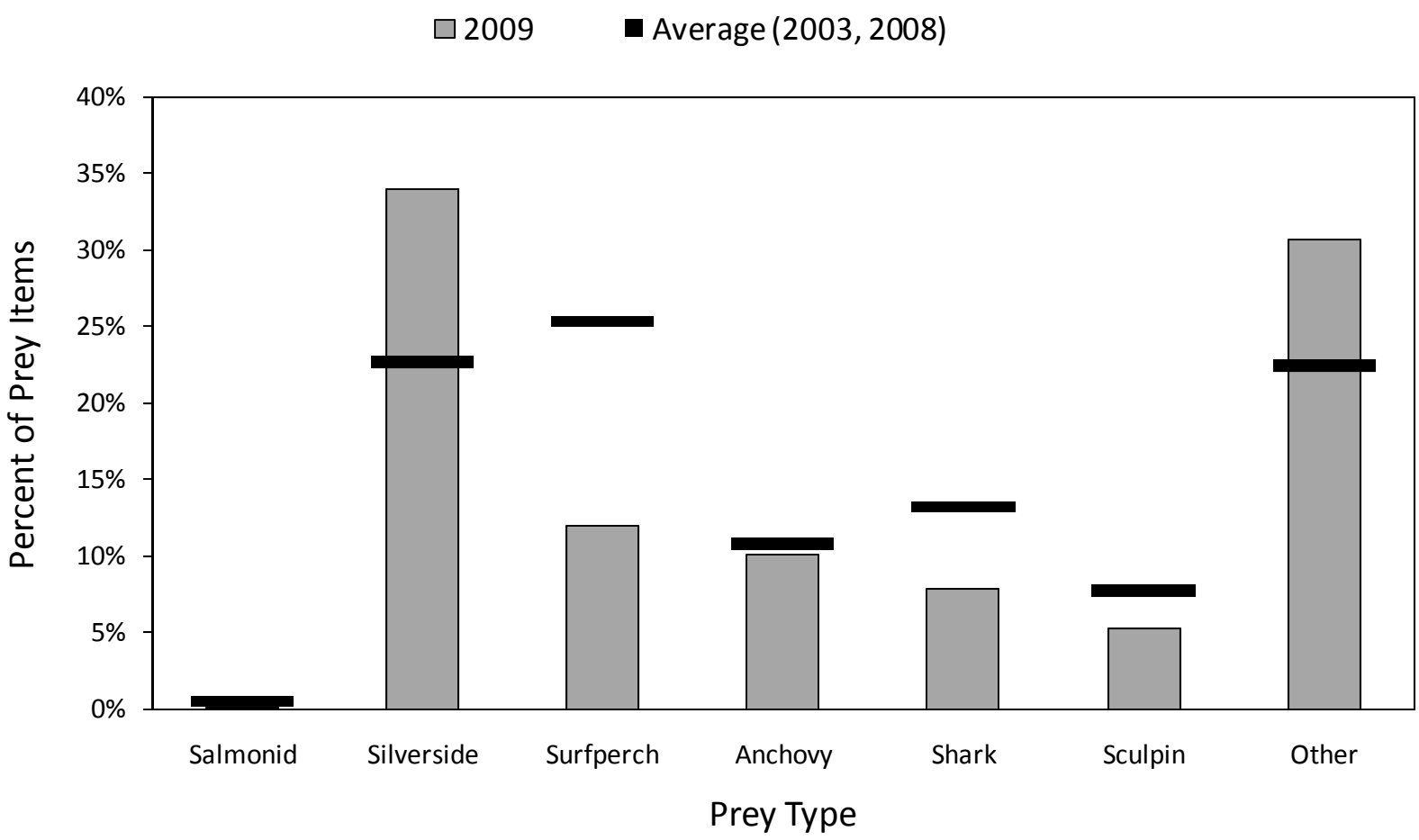


Figure 12. Diet composition of Caspian terns nesting at Eden Landing, San Francisco Bay, during 2009 compared to 2003 and 2008.

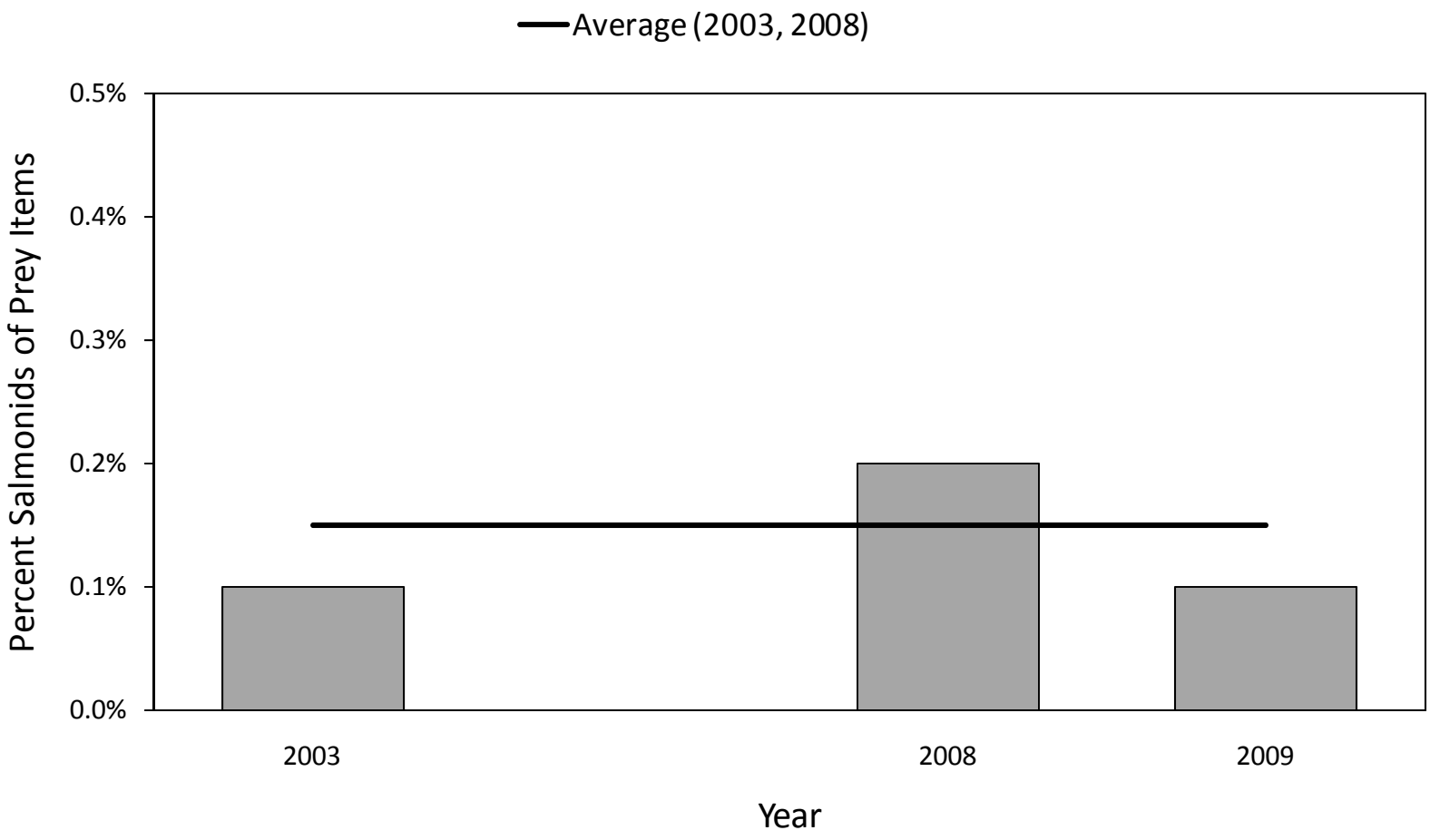


Figure 13. Proportion of juvenile salmonids in the diet of Caspian terns nesting at Eden Landing, San Francisco Bay, during 2009 compared to 2003 and 2008.

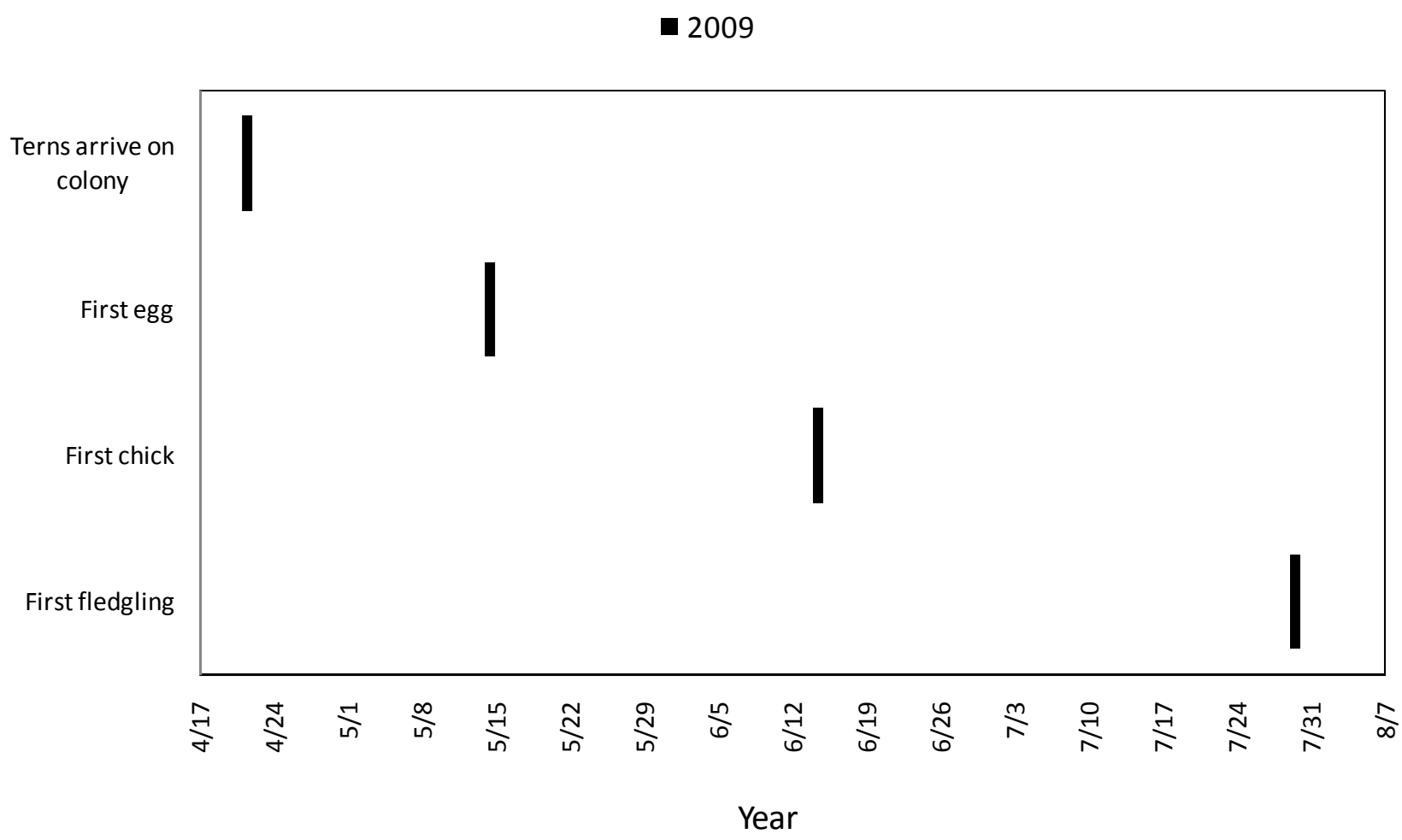


Figure 14. Nesting chronology at the Crump Lake Caspian tern colony, Warner Valley, Oregon, during 2009.

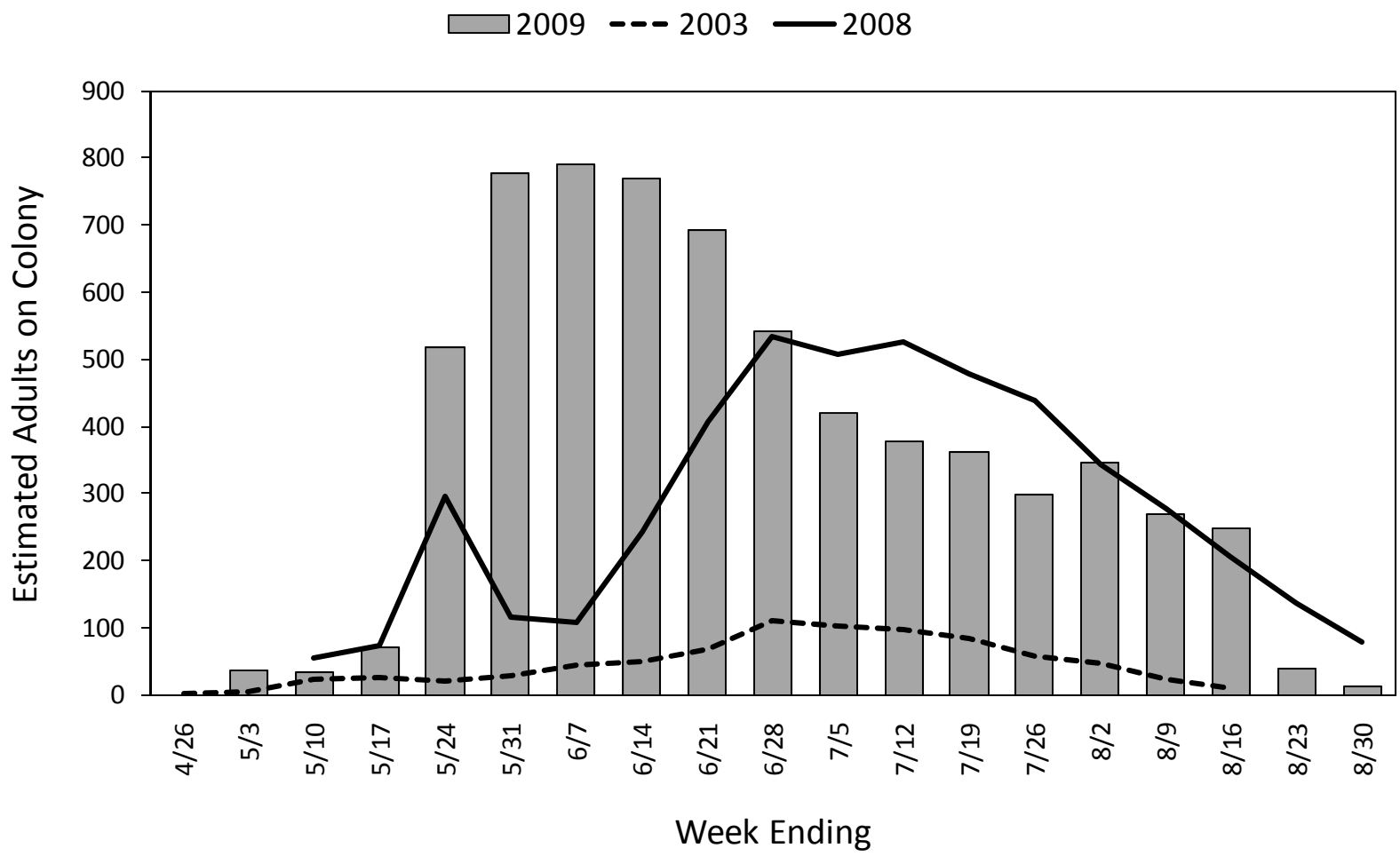


Figure 15. Weekly estimates from the ground of the number of adult Caspian terns at the Crump Lake colony, Warner Valley, Oregon, during 2009 compared to 2003 and 2008.

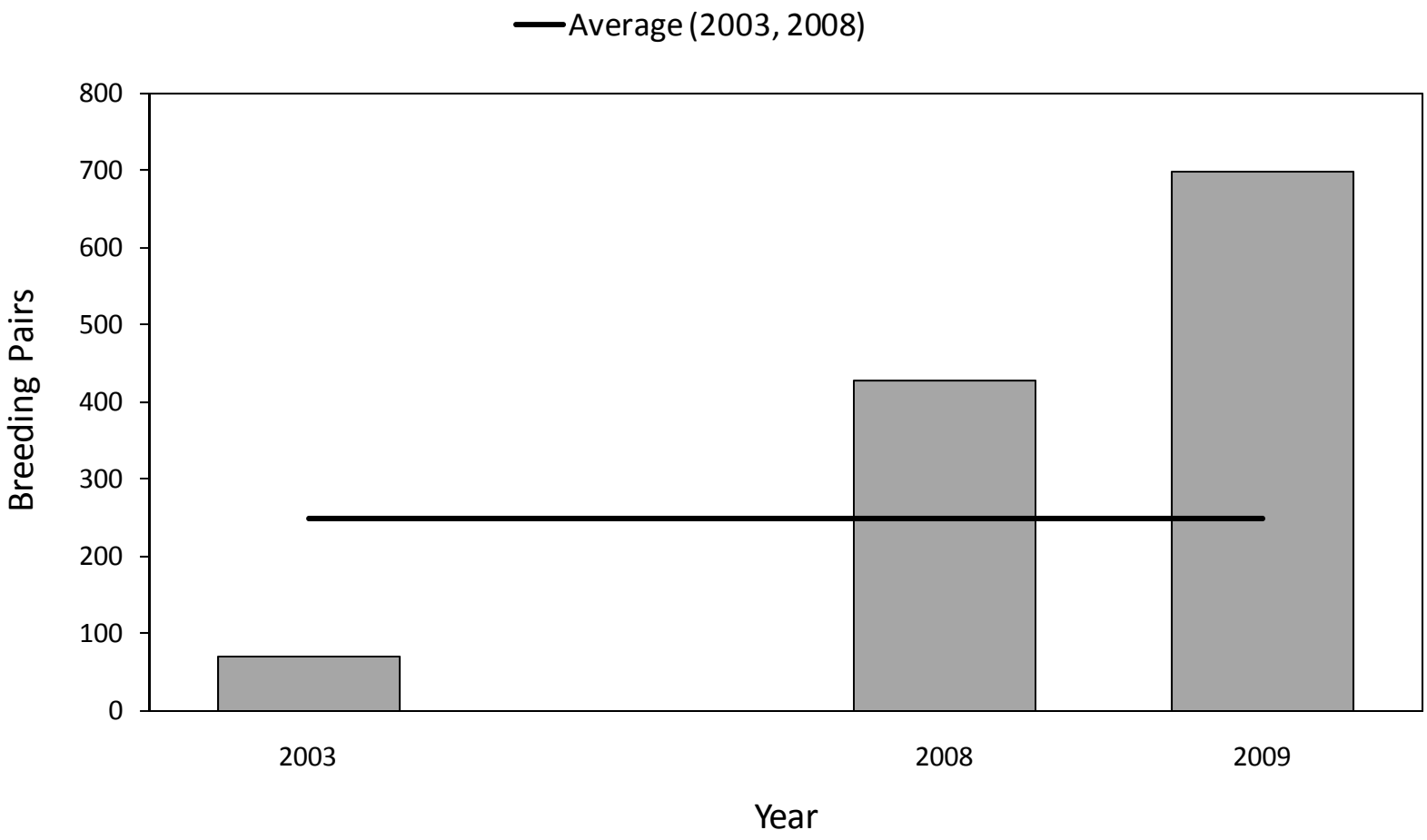


Figure 16. Caspian tern colony size at Crump Lake, Warner Valley, Oregon, during 2009 compared to 2003 and 2008.

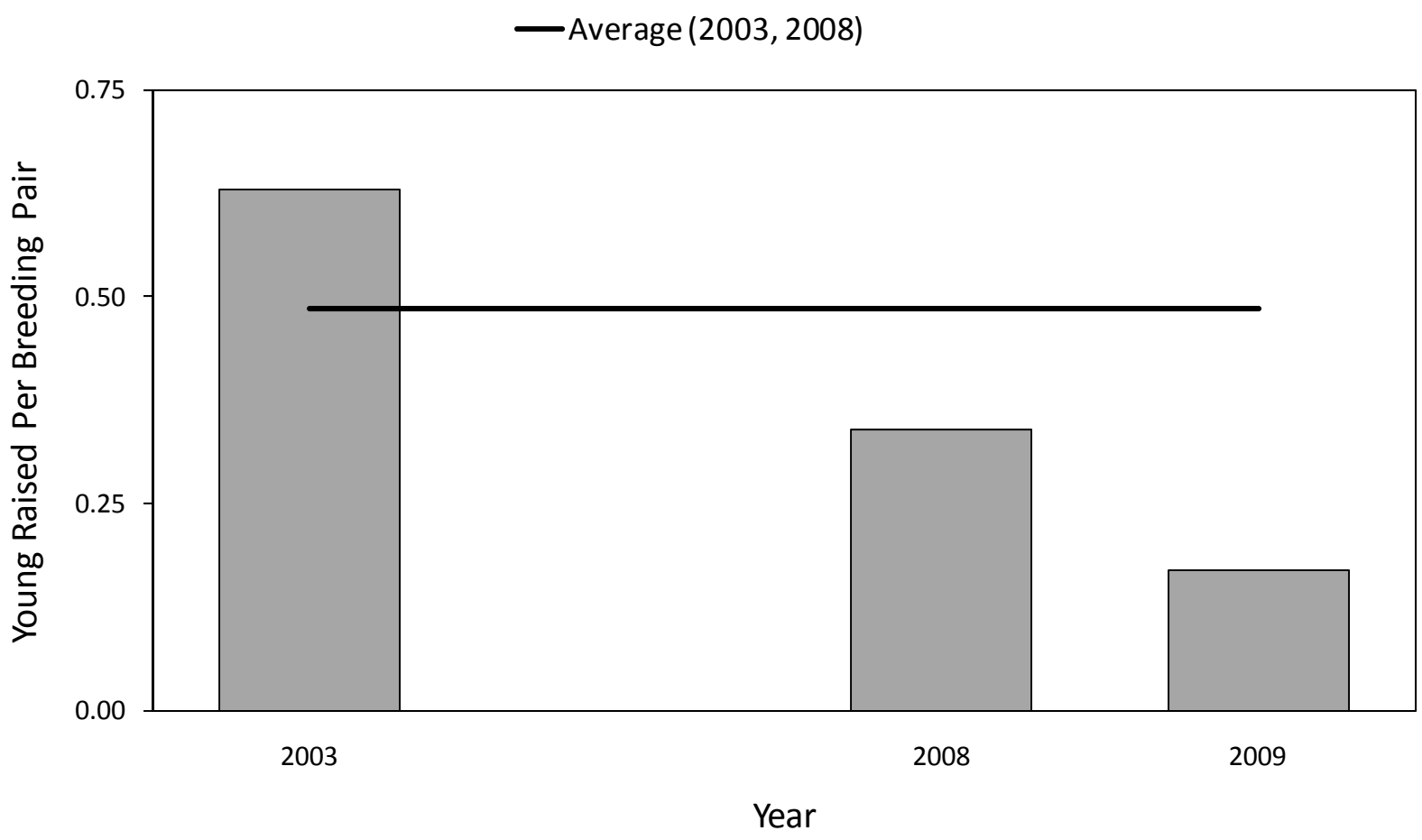


Figure 17. Caspian tern nesting success at Crump Lake, Warner Valley, Oregon during 2009 compared to 2003 and 2008.

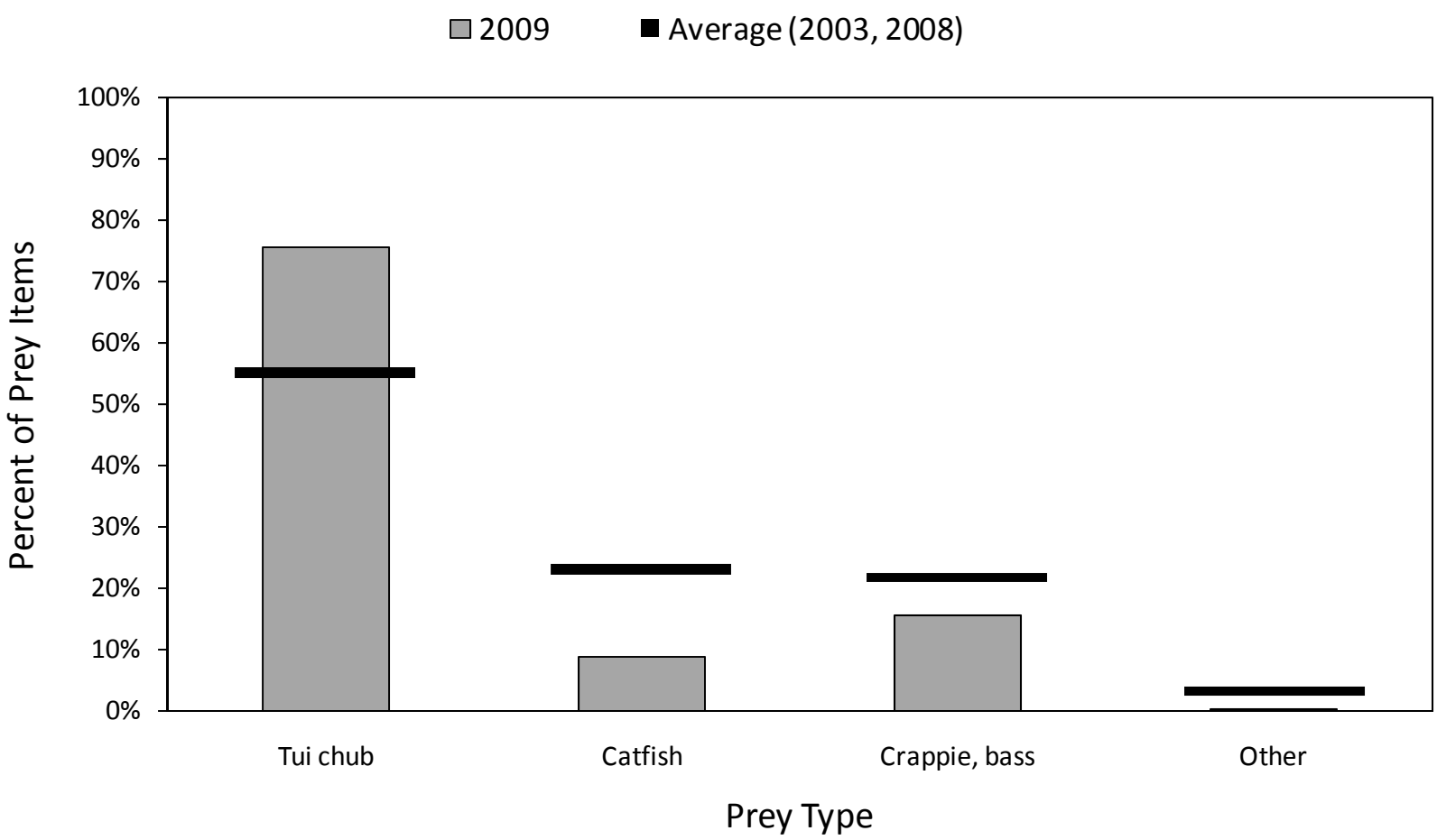


Figure 18. Diet composition of Caspian terns nesting at Crump Lake, Warner Valley, Oregon, during 2009 compared to 2003 and 2008.

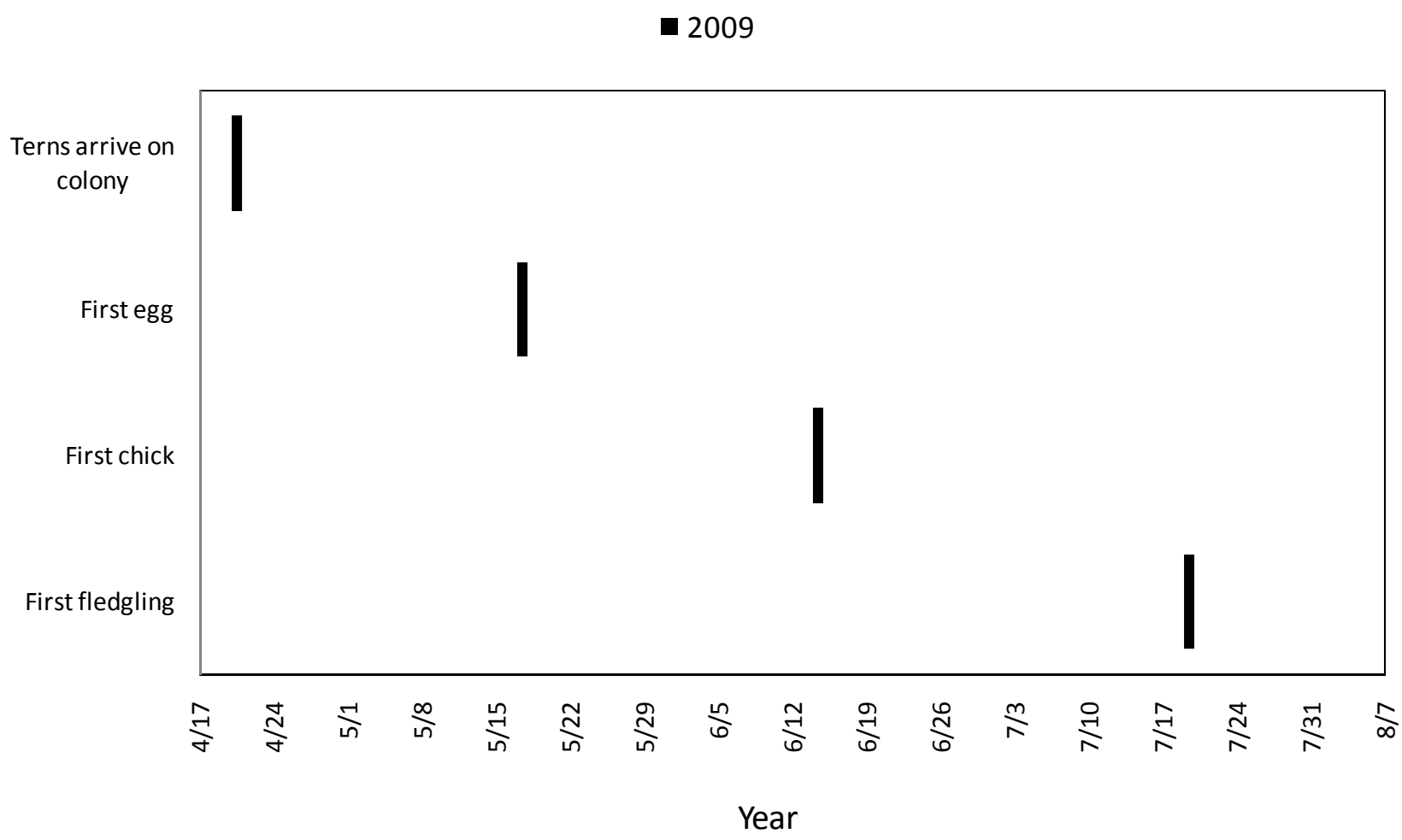


Figure 19. Nesting chronology of the Caspian tern colonies in Summer Lake Wildlife Area, Oregon during 2009.

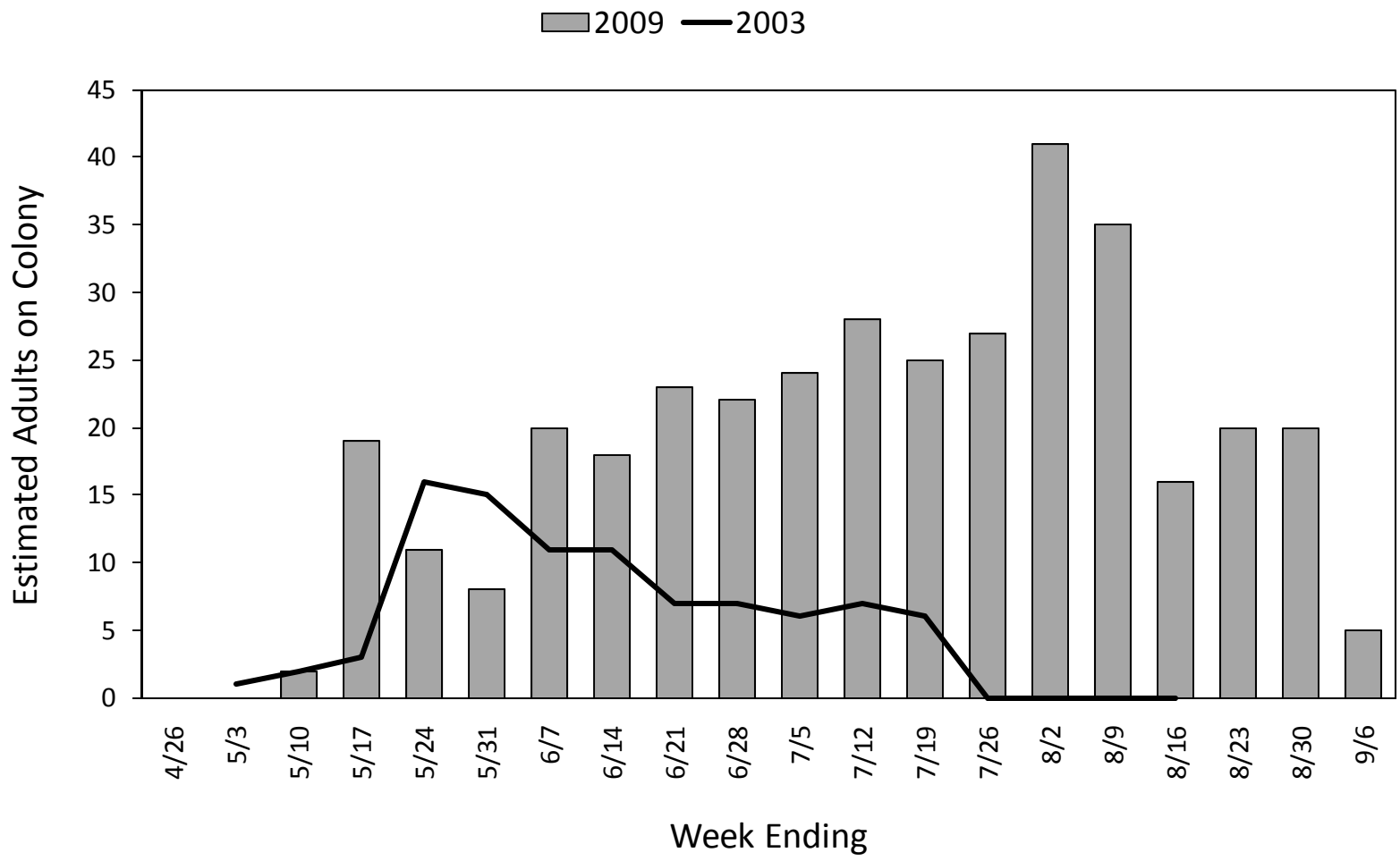


Figure 20. Weekly estimates from the ground of the number of adult Caspian terns at the two colonies in Summer Lake Wildlife Area, Oregon, during 2009 compared to 2003.

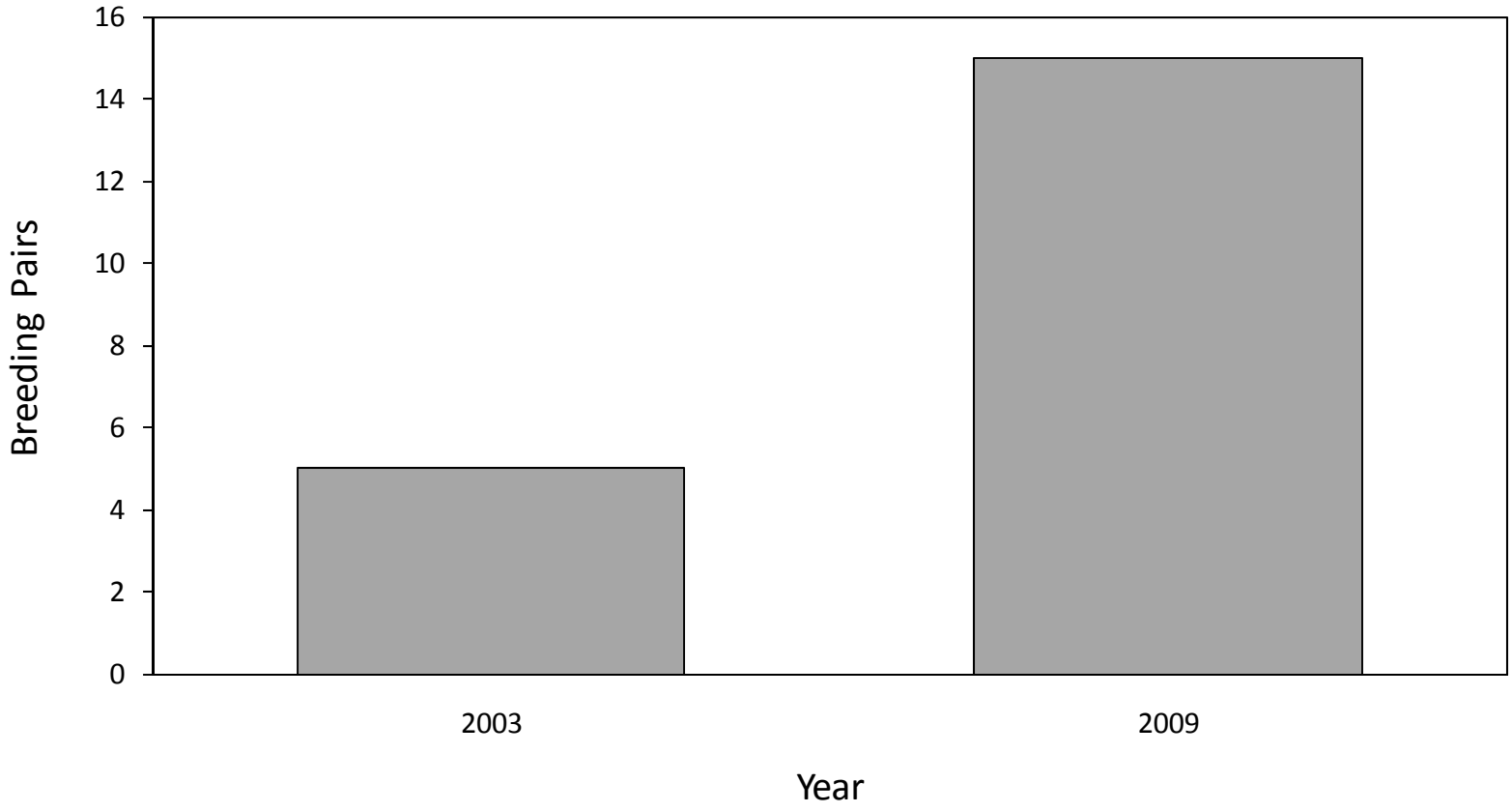


Figure 21. Number of pairs of Caspian terns nesting at Summer Lake Wildlife Area, Oregon, during 2009 compared to 2003.

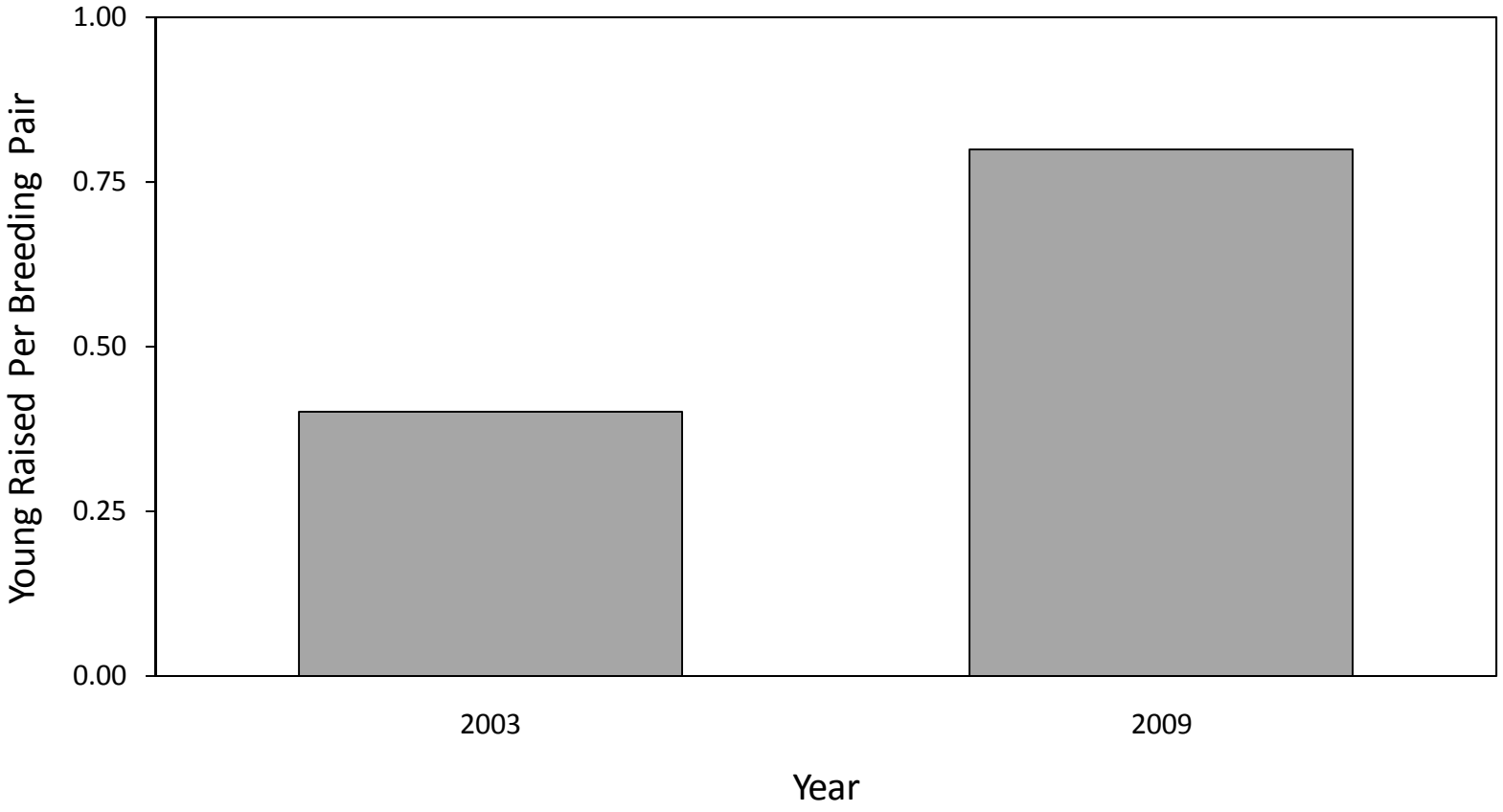


Figure 22. Caspian tern nesting success at Summer Lake Wildlife Area, Oregon, during 2009 compared to 2003.

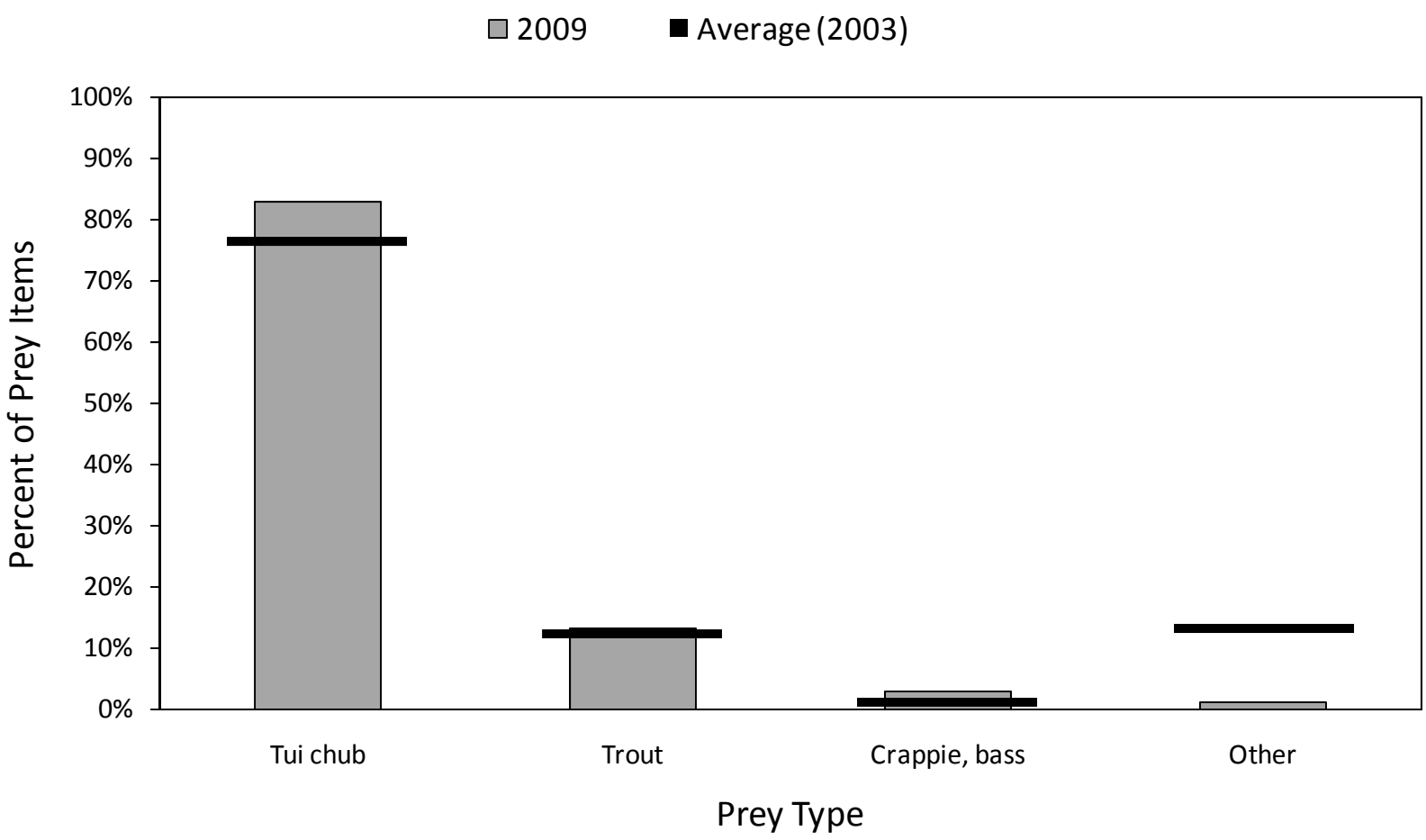


Figure 23. Diet composition of Caspian terns nesting at Summer Lake Wildlife Area, Oregon, during 2009 compared to 2003.

Table 1. Data collected in 2009 for piscivorous colonial waterbirds nesting at colonies in San Francisco Bay and interior Oregon. Species include Caspian tern (CATE), California gull (CAGU), ring-billed gull (RBGU), and western gull (WEGU).

Location/Colony	Species	2009 Data: Colony Size (number of breeding pairs)	2009 Data: Nesting success (fledglings/breeding pair)	2009 Data: Salmonids in diet (percent of prey items)	Notes
San Francisco Bay					
Brooks Is.	CATE	681	0.14	7.1	
	WEGU	≈200			
	CAGU	1577			
Eden Landing	CATE	75	0.41	0.1	
Stevens Creek	CATE	64	0.16	0.2	
	CAGU				Colony present, size unknown
Agua Vista Park	CATE	8			Nesting success and diet data not available
	WEGU				Colony present, size unknown
Ravenswood	CATE	1	0.00		Diet data for CATE not available, nesting by other waterbirds unknown
Redwood Shores	CATE	1	0.00		Diet data for CATE not available, nesting by other waterbirds unknown
Interior Oregon					
Crump Lake	CATE	697	0.17	0.2	Salmonids were resident rainbow trout
	RBGU	1700			Number of adults on colony (not nesting pairs)
	CAGU	700			Number of adults on colony (not nesting pairs)
Summer Lake	CATE	15	0.80	13.1	8 pairs nested on Dutchy Lake island and 7 pairs nested on East Link island; salmonids were resident rainbow trout
	RBGU	~ 150			Colony present on East Link island only, nesting success unknown
	CAGU	~10			Colony present on East Link island only, nesting success unknown
Fern Ridge Reservoir	CATE	0			Terns used site as a roost, but did not nest

Table 2. Potential limiting factors for colony size and nesting success at Caspian tern colonies in the San Francisco Bay area and in interior Oregon during 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, but this study does not address that issue directly. Limiting factors for colony size and nesting success at Ravenswood and Redwood Shores unknown at this time.

	San Francisco Bay				Interior Oregon			
	Brooks Is.	Eden Landing	Stevens Creek	Agua Vista	Crump Lake	Fern Ridge Reservoir	East Link, Summer Lake	Dutchy Lake, Summer Lake
Availability of nesting habitat	**X**[1]	**X**[4]	x[9]	**X**[11]				
Quality of nesting substrate		**X**[5]	?[5]	**X**[12]				
Prey fish availability					?[13]	?[15]	?[15]	?[15]
Mammalian predators		x[6]						
Displacement by other colonial waterbirds	**X**[2]	**X**[7]			?[14]			
Avian predators (other than gulls)	x	x				**X**[16]	?[17]	
Gull kleptoparasitism	x		?[10]	?[10]	x[14]			
Gull nest predation	**X**		?[10]	?[10]	**X**[14]		?[18]	
Human disturbance	**X**[3]	?[8]	?[8]			x[19]		
Nesting history in area						?[20]	?[20]	?[20]

[1] encroaching pickleweed and other vegetation; high spring tides associated with extreme weather
[2] expanding California gull colony
[3] disturbance mostly from recreational kayakers, boaters, and wind surfers
[4] changing water levels flooding low lying nests and encroaching pickle weed
[5] sticky when wet and terns have difficulty digging scrapes
[6] two red foxes, and a domestic cat are using adjacent dikes
[7] tern eggs and nests trampled by roosting white pelicans and double-crested cormorants
[8] island in close proximity to nearby levees frequented by researchers and land managers
[9] encroaching vegetation limits available nesting habitat
[10] nesting and loafing gulls may impact tern nesting success
[11] Pier birds are nesting on is slowly collapsing into bay
[12] nesting on pier deck where there is little or no nesting substrate
[13] scarcity of prey fish in drought years
[14] California and ring-billed gulls nesting in large numbers may limit success of Caspian tern
[15] available foraging may limit prey base
[16] Bald eagles confirmed predators; great horned owl and peregrine falcon likely predators
[17] Great horned owl visited island
[18] Suspected nest predation by gulls
[19] Video monitors captured recreational boaters on island
[20] Little or no history of Caspian tern nesting in the area

Table 3. The estimated number of Caspian terns that visited the Crump Lake tern island from other tern colonies in 2009. These data assume (1) that banded fledglings and adults are representative of all fledglings and adults at the colony and (2) that differnces in time elapsed since a tern was banded did not influence its chances of being re-sighted at Crump Lake island in 2009.

Location banded	Year banded	Age	No. of terns re-sighted at Crump in 2009	Total no.of terns banded	Best estimate of no. of terns (unbanded + banded) at site/year	No. of terns (unbanded + banded) potentially present at Crump Lake in 2009, from other tern colonies.	Total no. of terns (all year and age class; unbanded + banded) potentially present at Crump Lake in 2009
East Sand Island	2001	Chick	3	347	12477	108	1223
	2002	Chick	1	372	10715	29	
	2003	Chick	6	450	8977	120	
	2004	Chick	3	451	8741	58	
	2005	Adult	1	38	17644	464	
	2006	Adult	1	45	17858	397	
	2006	Chick	3	427	6628	47	
Crescent Island	2003	Chick	4	100	280	11	43
	2004	Chick	6	223	329	9	
	2005	Adult	1	57	952	17	
	2005	Chick	2	164	262	3	
	2006	Chick	1	71	193	3	
Goose Island	2006	Chick	4	60	60	4	5
	2007	Chick	1	138	138	1	
Solstice Island	2001	Chick	2	101	101	2	2
Crump Lake	2003	Chick	4	45	45	4	4
Dungeness Spit	2005	Chick	1	109	558	5	5
Brooks Island	2003	Chick	1	82	535	7	9
	2005	Chick	1	150	299	2	
Nevada	1999	Chick	3	N/A	N/A	N/A	N/A
TOTAL			49	3430	85400	1291	1291

Recovery of Salmonid Coded Wire Tags on Caspian Tern Colonies in San Francisco Bay during 2009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By

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Figure 2: Average detection efficiency of coded wire tags intentionally sown on the Brooks Island, Eden Landing, and Steven's Creek Caspian tern colonies at discrete times during the 2009 nesting season. Values are from the number of tags sown on-colony during the pre- (13 March to 18 March), mid- (12 May to 23 June), and post- (29 July to 20 August) nesting season periods that were subsequently recovered by researchers in substrate samples.

SUMMARY

We recovered coded wire tags (CWTs) from Caspian tern (*Hydroprogne caspia*) breeding colonies on Brooks Island, Eden Landing, and Steven's Creek in San Francisco Bay, California to evaluate predation on juvenile salmonids (*Oncorhynchus* spp.*)* originating from the Sacramento and San Joaquin rivers. A sample of colony substrate representing 7.7% of the nesting area used by terns (all three colonies combined) yielded 561 salmonid CWTs from fish released and subsequently consumed by terns in 2009. This value expands to an estimated 14,577 CWTs (95% confidence interval (c.i.) = 11,267 to 17,429 CWTs), once adjustments are made to account for tag loss and the amount of tern nesting habitat not sampled at each colony for CWTs.

The CWTs recovered from the Caspian tern colonies indicate that hatchery-raised Chinook salmon (*O. tshawytscha*) trucked to and released in San Pablo Bay were 151 times (95% c.i. = 62 to 363 times) more likely to be consumed by a Caspian tern than a Chinook salmon that migrated naturally in-river to the Bay. Fish trucked to and released in the Sacramento/San Joaquin river delta (below the confluence of the Sacramento and San Joaquin rivers but upstream of San Pablo Bay) were the next most susceptible, with delta released fish 37 times (95% c.i. = 12 to 107 times) more likely to be consumed by Caspian terns than in-river migrating Chinook salmon smolts. Data indicated that tern predation on Chinook smolts was directly correlated to the fish's release location, with predation rates highest on those groups of fish released closest to the tern colony. Fall-run Chinook salmon were particularly susceptible to tern predation relative to spring, winter, and late-fall Chinook salmon run-types. None of the approximately 290,000 wild Chinook salmon that were CWT and released in the basin in 2009 were recovered on a tern colony, suggesting impacts to survival of wild, ESA-listed Chinook salmon populations in the region were negligible. Furthermore, none of the approximately 150,000 hatchery winter-run Chinook salmon smolts (an endangered species) that were CWT and migrated in-river were subsequently recovered on a tern colony. A total of 24 CWTs from hatchery spring-run Chinook salmon smolts (a threatened species) were found on the Brooks Island tern colony. All but one or 95.8% were from spring Chinook that were trucked to and released into San Pablo Bay via net pens. Overall (all CWT Chinook run-types and release strategies combined), we estimate that ca. 0.1% of the approximately 11.2 million coded wire tagged Chinook salmon released into the basin in 2009 were subsequently consumed and the tag deposited on-colony by a Caspian tern nesting at the Brooks Island, Eden Landing, or Steven's Creek colonies.

Results from 2009 were very similar to those obtained from a comparable study conducted by our group in 2008, indicating that Caspian tern predation on salmonid smolts in the San Francisco Bay area is almost exclusively limited to hatchery-reared fall-run Chinook salmon that were trucked to and released via net pens into eastern San Pablo Bay (northern San Francisco Bay). Data from the two South Bay colonies (Eden Landing and Steven's Creek) in 2009 indicated that very few Chinook salmon smolts, regardless of the fish's release location or rear-type, were consumed by Caspian terns nesting at these two colonies. After adjusting for tag loss and the area of used substrate sampled by researchers, we estimated that just 179 (95% CI: 146 to 212) CWT Chinook salmon

smolts were consumed and their tags deposited on-colony by Caspian terns nesting at Eden Landing and Steven's Creek, a remarkably low number given the 11 million CWT Chinook salmon smolts released in the basin during 2009.

INTRODUCTION

In 2009 we continued a study initiated in 2008 to assess the impact of Caspian terns on salmonid smolts in San Francisco Bay through the recovery of salmonid coded wire tags (CWTs) on tern breeding colonies. Coded wire tags recovered on Brooks Island in 2008 were a critical component for determining the impact of Caspian terns nesting at the Brooks Island colony on ESA-listed Chinook smolts (Evans et al. in-review); these results indicated that Caspian terns were almost exclusively consuming hatchery-reared fall Chinook salmon smolts that were being trucked to and release into nearby eastern San Pablo Bay during the tern nesting season. In 2009, we expanded the study to include the recovery of CWTs from smaller Caspian tern colonies at Eden Landing and Steven's Creek, located in southern San Francisco Bay.

Each year millions of anadromous juvenile salmonids (*Oncorhynchus* spp.) are implanted with coded wire tags (CWT) in the Pacific Region of North America (RMISD 1977). Since its inception in the 1960s, coded wire tagging of juvenile salmonids in North America has been considered one of the largest fish marking programs in the world (Johnson 2005). Salmonid stocks from Alaska to California are coded wire tagged to evaluate migration histories, harvest rates, adult return rates, as well as a variety of other research and monitoring objectives (Johnson 2005). A coded wire tag is a small (ranging from 0.5 to 2.1 mm in length, 0.25 mm in diameter) piece of stainless steel wire emblazoned with a numeric code. Coded wire tags are implanted in the nasal cartilage of fish and provide a variety of information on each fish, including (but not limited to) species, stock, run, rear-type (hatchery or wild), release date, release location, and size at release (length and weight). The Regional Mark Processing Center, which is operated by the Pacific States Marine Fisheries Commission, provides coordination and maintains a centralized database for information on all salmonids marked with CWTs in the Pacific Region of North America (RMISD 1977).

Despite the large scale and geographic scope of salmonid CWT releases in North America, very few studies have focused on how the subsequent recovery of CWTs can be used to evaluate impacts of specific mortality factors, such as avian predation, on smolt survival. Numerous studies have documented the negative impact of avian predators on the survival of salmonids in the Pacific Region of North America using observational studies at foraging locations (Ruggerone 1986), analysis of stomach contents to determine food habits (York et al. 2000; Collis et al. 2002), bioenergetics modeling to estimate fish consumption (Roby et al. 2003; Antolos et al. 2005), and the recovery of fish tags on piscivorous waterbird colonies to document fish losses to avian predators (Collis et al. 2001; Ryan et al. 2001; Ryan et al. 2003; Antolos et al. 2005; Schreck et al. 2006). Studies of avian predation that utilized fish tag recoveries to estimate predation rates on juvenile salmonids have relied primarily on Passive Integrated Transponder

(PIT) tags, radio telemetry tags, or hydro-acoustic telemetry tags; all types of tags that transmit or receive a signal. Although these electronic tags have numerous advantages in fish marking and tracking studies, they tend to be expensive, require costly equipment for their detection, and require invasive procedures for implantation. Furthermore, the extent of tagging programs that utilize electronic tags are often smaller in scale and geographic scope than that of research and monitoring programs that use CWTs.

The management of piscivorous bird colonies in the Pacific Northwest is a component of regional plans to recover salmonid populations that are listed under the U.S. Endangered Species Act (ESA; NOAA Fisheries 2008). Caspian terns that nest in the Columbia River estuary on East Sand Island have been found to consume millions of juvenile salmonids annually (Lyons et al. in review). As a result, a plan entitled *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* was developed to reduce impacts on salmonids from Caspian terns nesting in the Columbia River estuary by redistributing a portion of the East Sand Island tern colony – the largest of its kind in the world – to newly created or enhanced alternative colony sites in Oregon and California (USFWS 2005, 2006). Some of the potential alternative colony sites in California are in San Francisco Bay. Caspian terns have been nesting on Brooks Island in San Francisco Bay for over 20 years (Strong et al. 2004) and Brooks Island is currently the location of the largest Caspian tern colony in the San Francisco Bay area (Collis et al. in review). The above mentioned Caspian Tern Management Plan seeks to expand the available nesting habitat for terns on Brooks Island to accommodate terns displaced from East Sand Island and too create or modify two other nesting islands in southern San Francisco Bay for terns. The potential expansion of the Caspian tern breeding population in San Francisco Bay may be controversial, however, due to the rapidly declining status of Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*) populations from the Central Valley of California that are listed under the ESA (Yoshiyama et al. 1998; Good et al. 2005).

METHODS

The number of Caspian terns nesting at Brooks Island, Eden Landing, and Steven's Creek were determined from aerial photographs taken during the peak of egg incubation in May 2009 (see Collis et al. in review for further details on the methods used to estimate colony size). Digital photos were analyzed using Arc Geographic Information System (GIS) software to estimate the number of breeding pairs, the colony area (m^2) used by nesting terns, and nesting density (number of breeding pairs per m^2). Periodic counts of Caspian terns were also conducted from an observation blind located at the periphery of the tern colonies to calibrate counts from aerial photography, determine patterns in seasonal colony attendance, and assess nesting chronology (dates of egg-laying, chick-hatching, and chick-fledging).

Samples of the nesting substrate used by Caspian terns at Brooks Island, Eden Landing, and Steven's Creek were removed and searched for coded wire tags (CWTs) in August 2009, following the tern nesting season. Plots containing nesting substrate were

haphazardly selected within the areas occupied by nesting Caspian terns in 2009. Substrate samples consisted primarily of sand, shell fragments, guano, and bones (regurgitated fish bones or bones from chicks that died during the nesting season). Substrate was removed from 55, 8, and 8 individual 1-m^2 plots (hereafter referred to as "plots") from the Brooks Island, Eden Landing, and Steven's Creek tern colonies, respectively, following the 2009 nesting season. Each individual sample included substrate to a depth of approximately 5 cm. Substrate from each plot was collected and stored in 5-gallon plastic buckets for later processing (see cover photo for an illustration of plot removal and storage).

The contents of each bucket were ground using a mortar mixer paddle and drill to break up guano and other large, compacted material. Material was then screened (3-mm mesh) to remove shell fragments, rocks, bones, and other large debris. Processed material was then placed into a 50 cm (length) x 45 cm (width) metal funnel that poured the material over a vibrating trough. The funnel ensured that substrate samples poured evenly into the trough and at a consistent rate. As the substrate moved through the trough, ferrous material was removed by a 20 cm (length) x 15 cm (width) x 5 cm (depth) ceramic and rare-earth (neodymium) magnet that was place at the end of the trough. An illuminated magnifying glass was used to locate CWTs that were stuck to the magnet. Once recovered with a pair of magnetic tweezers, CWTs were cleaned with isopropyl alcohol and the tag's numeric code read using a specially-designed MagniViewer© microscope (Northwest Marine Technology, Shaw Island, Washington).

In order to quantify the efficiency of our CWT extraction technique, we sowed CWTs with known tag codes into discrete 1-m^2 plots on each tern colony (four plots on Brooks Island, two plots on Eden Landing, and two plots on Steven's Creek) prior to the nesting season (March; hereafter referred to as "pre-season"), during the nesting season (May; hereafter referred to as "mid-season"), and after the nesting season (August; hereafter referred to as "post-season"). Equal numbers of test tags (n = 15 per plot) were sown in each plot during each release period (pre-season, mid-season, and post-season). To further assess the efficiency of our recovery efforts, test tags were also sown directly into the 5-gallon buckets containing pre-processed substrate samples. Here, too, equal numbers of test tags (n = 10 per plot) were sown into randomly-selected buckets of pre-processed substrate samples. The sowing of test tags was done under the premise that not all CWTs deposited by terns on-colony were subsequently recovered by researchers. For example, tags could be blown off the colony during wind or rain storms, buried deeper than 5 cm, washed away during high tides or other flooding events, or otherwise damaged or lost. Furthermore, it is reasonable to suspect that some of the recovered tags within the substrate samples were lost during the extraction process. Detection efficiency estimates (percentage of sown test tags subsequently recovered) were analyzed relative to the release location (on-colony versus in buckets), release date (pre-season or post-season), and tern colony (Brooks Island, Eden Landing, or Steven's Creek) to describe spatial and temporal variation in detection efficiency.

Impacts on Salmonid Survival

Data regarding the number, species, rearing-type (hatchery or wild), run-type (fall, late-fall, winter, or spring), and release location of salmonids marked with CWTs in the Sacramento and San Joaquin rivers were obtained by querying the Regional Mark Information Systems Database (RMISD 1977) on 12 January 2010. Salmonid release locations were placed in one of three categories, based on the distance from San Francisco Bay and the release strategy employed by fishery agencies in the region: (1) releases directly into the Sacramento River or a tributary of the Sacramento River (hereafter referred to as the "In-river" release group), (2) releases into the Sacramento-San Joaquin River Delta (hereafter referred to as the "Delta" release group), or (3) releases into the bay (hereafter referred to as the "Bay" release group; Figure 1). Bay released fish were released into eastern San Pablo Bay (in northern San Francisco Bay) from net pens maintained by the Fisheries Foundation of California; specifically, the fish were trucked from the hatchery, placed in a net pen for salt water acclimation, and then towed out to release points in eastern San Pablo Bay (FFC 2008).

Data Analysis

Analysis of the impacts of Caspian tern predation on survival of juvenile salmonids was limited to smolts marked with CWTs and released during the 2009 migration year (i.e., fish assumed to be out-migrating to the Pacific Ocean between December 2008 and July 2009). The numbers of CWT fish released (by species, rearing-type, and location) were compared to the numbers of CWTs recovered on each of three Caspian tern colonies in San Francisco Bay to generate minimum consumption and predation rate estimates. Chi-square tests and odds ratio comparisons (Ramsey and Schafer 1997) were used to evaluate the relative susceptibility to tern predation of fish from different run-types and release locations under the null hypothesis that fish were consumed in proportion to their availability at release. Finally, the total number of salmonid CWTs deposited by terns at each of the three colonies was estimated by calculating the density of CWTs within sampled plots and multiplying this value by the total area of nesting substrate used by Caspian terns at each colony. Estimates were then adjusted or corrected for CWT detection efficiency by dividing the number of tags recovered by the average on-colony detection efficiency value obtained for each colony based on the recovery of test tags. A measure of precision (95% confidence intervals) was obtained by applying the variation in detection efficiency (standard error of the mean) observed from test tags released on-colony to all recovered tags from that colony. This approach assumes the fate (tag loss) and detection probability of test tags was representative of salmonid tags deposited by birds during the 2009 nesting season.

RESULTS

We estimated that a total of 820 pairs of Caspian terns attempted to nest on Brooks Island (681 pairs), Eden Landing (75 pairs), and Steven's Creek (64 pairs) in 2009. At all three colonies, nesting terns arrived between late-March and mid-May, with the number of

terns peaking in early June. By late-July the majority of tern chicks had fledged and by early August the colonies had been completely abandoned. Caspian terns nesting on Brooks Island utilized a total area of 720 m^2 of nesting habitat, for an average nesting density of 0.9 breeding pairs per m^2 of nesting substrate. Caspian terns nesting at Eden Landing utilized a total area of 73 m^2 of nesting habitat, for an average nesting density of 1.0 breeding pairs per m^2 of nesting substrate. Finally, Caspian terns nesting at Steven's Creek utilized a total area of 125 m^2 of nesting habitat, for an average nesting density of 0.5 breeding pairs per m^2 of nesting substrate.

A total of 71 m^2 of nesting substrate was removed from the Brooks Island (55 m^2), Eden Landing (8 m^2), and Steven's Creek (8 m^2) colonies and sifted for salmonid CWTs in 2009 (Table 1). Samples represented 7.6%, 11.0%, and 6.4% of the available nesting habitat utilized by terns at Brooks Island, Eden Landing, and Steven's Creek colonies, respectively (Table 1). From the 71 m^2 of nesting substrate, a total of 1,086 salmonid CWTs were recovered. Of these, 561 or 51.7% were from fish tagged and released into the Sacramento or San Joaquin rivers during the 2009 migration year, while the remaining 519 tags were from older releases (prior to 2009; n = 508) of Sacramento/San Joaquin fish or from out-of-basin fish releases (e.g., Columbia River). Of 561 smolts released into the Sacramento and San Joaquin rivers in 2009, the vast majority (n = 554 or 98.8%) was recovered on the Brooks Island Caspian tern colony, with just five CWTs recovered from Eden Landing and two from Steven's Creek (Table 1). The oldest confirmed CWT recovered was from a fall-run Chinook salmon released into the Sacramento River in July of 1995. Of the out-of-basin fish recovered (n = 9), the majority were from salmonids released into the Columbia River basin from 2000 to 2009. It is unknown if these out-of-basin salmonids were captured off the California coast or whether the birds migrated from the Columbia River basin to San Francisco Bay before depositing the tags.

Detection efficiency of test tags intentionally sown on the three tern colonies prior to, during, and after the nesting season averaged 49.2% (n = 315; Table 1). Differences between pre-season (ca. 24.1%; n = 120), mid-season (ca. 41.7%; n = 90), and post-season (ca. 82.0%; n = 105) detection efficiency were observed (Figure 2), with detection efficiency positively associated with the tag's release or sow date ($r^2 = 0.7501$; $P < 0.01$ for the test that slope differs from zero). This result indicates that CWTs deposited early in the nesting season were less likely to be recovered compared to tags deposited late in the nesting season. After accounting for release date, there was no difference in detection efficiency between the three tern colonies ($P > 0.05$ for all detection efficiency comparisons between tern colonies from releases that took place during the same time period, based on a Pearson's Chi-square test), suggesting CWT loss and detection efficiency was similar amongst the three tern colonies. Detection efficiency of test tags placed in 5-gallon buckets of pre-processed substrate was high, with 91.3% (n = 300) of sown tags subsequently recovered. Consequently, most of the loss of CWTs deposited on the Brooks Island Caspian tern colony occurred prior to, or during, the sampling of nesting substrate and not as a result of processing the material (i.e., the grinding, sifting, and removal of tags with magnets).

Based on the total amount of nesting substrate searched for CWTs at each colony, average on-colony detection efficiency, and the total number of 2009 migration year salmonid tags recovered, we estimate that terns deposited a minimum of 14,577 (95% c.i. = 11,267 to 17,429) CWTs from juvenile salmonids on the Brooks Island (14,398 CWTs), Eden Landing (114 CWTs), and Steven's Creek (65 CWTs) colonies during 2009 (Table 1). Although a measure of precision is available for each colony, the estimate is still a minimum because an unknown proportion of CWTs from fish consumed by Caspian terns were deposited off-colony (e.g., at loafing or staging sites not associated with the birds' nesting site) and we have no method of estimating this proportion. As such, values presented here represent the number of tags consumed and then deposited by terns on their nesting colony, not the total number of CWT fish consumed by Caspian terns.

Impacts on Salmonid Survival

Approximately 11.2 million juvenile Chinook salmon from the Sacramento and San Joaquin rivers were marked with CWTs and released in 2009 (Table 2). The vast majority of CWT fish were from hatcheries (10.9 million or 97.4% of all CWT fish) and of the hatchery CWT fish, the majority were fall-run Chinook salmon (7.4 million or 66.3% of all CWT fish). Of the remaining marked hatchery fish, 2.0 million were spring Chinook salmon (ESA-listed fish produced by the Feather River Hatchery), 1.1 million were late-fall Chinook salmon, 0.1 million were winter Chinook salmon (ESA-listed fish produced by Coleman National Fish Hatchery; Table 2), and 0.2 million were a spring/fall hybrid Chinook salmon. In addition to hatchery fish, 0.3 million wild fall-run Chinook salmon (from Butte Creek, a tributary of the Sacramento River) were marked with CWTs and released in 2009 (Table 2). Virtually all (> 99.9%) of the hatchery spring, winter, and late-fall Chinook salmon released in 2009 were marked with CWTs. By comparison, only 29% of hatchery fall Chinook salmon released in the basin were tagged with CWTs. In addition to the approximately 18.7 million non-CWT hatchery fall Chinook released, about 0.8 million non-tagged hatchery steelhead were also released in 2009. Unfortunately, the lack of CWT steelhead precludes the use of CWT recoveries on bird colonies to evaluate impacts of Caspian tern predation on steelhead from the Sacramento River, an ESA-listed population.

Of the 561 CWTs recovered from 2009 migration year Chinook smolts, 522 or 93.0% were from fall-run Chinook salmon (Table 2), indicating a high susceptibility to Caspian tern predation for this run-type relative to the other Chinook salmon run-types (spring, winter, and late-fall) in 2009 ($P < 0.01$, based on the null hypothesis of equal susceptibility among all CWT run-types). Hybrid Chinook smolts were also susceptible, with predation rates similar to, but slightly lower than, that of fall-run Chinook. A total of 24 CWTs or 4.3% of all recovered tags were from hatchery spring Chinook salmon (Table 2). No tags from hatchery winter Chinook salmon, hatchery late-fall Chinook, or wild fall Chinook salmon were recovered on a Caspian tern colony in 2009. Overall (all run-types combined), < 0.1% of all CWT Chinook salmon released in the basin (561/11,193,248) were subsequently recovered on one of the three Caspian tern colonies sampled here. This proportion increases to ca. 0.1% (14,577/11,193,248) after

adjustments are made for detection efficiency and the proportion of the total area of the Caspian tern colonies that was sampled for CWTs.

Of the total number of CWTs from 2009 migration year smolts recovered on San Francisco Bay tern colonies, 546 CWTs or 97.3% were from fish trucked to and released into eastern San Pablo Bay from net pens, followed by just 10 CWTs or 1.8% from Delta releases, and 5 CWTs or 0.9% from In-river releases (Table 2). The odds of recovering a CWT from a Bay released Chinook salmon on a Caspian tern colony were 4 times greater (95% c.i. = 2 to 8 times greater) and 151 times greater (95% CI: 62 to 363) than recovering a CWT from a Chinook salmon released into the Delta or In-river groups, respectively ($P < 0.01$ for both comparisons). A difference between the Delta and In-river release groups were also noted, with Delta released Chinook salmon being 37 times more likely (95% c.i. = 12 to 107 more likely) than In-river released Chinook to be recovered on a tern colony. This difference in susceptibility to tern predation between release groups was also apparent within Chinook salmon run-types, with Bay released fall Chinook salmon and Bay released spring Chinook salmon 56 times (95% c.i. = 31 to 101 times) and 23 times (95% c.i. = 4 to 172 times) more likely to be recovered on a tern colony than their Delta release and In-river release counter-parts combined ($P < 0.01$ for both comparisons).

Fall Chinook salmon was the run-type most susceptible to predation from Caspian terns, even after accounting for differences in release location. Within the Bay release group, CWTs from fall Chinook salmon were 7 times (95% c.i. = 4 to 10 times) more likely to be detected on the tern colony than Bay released spring Chinook salmon ($P < 0.01$). The small numbers of CWTs recovered from In-river and Delta released Chinook ($N = 10$; all run-types combined) precludes statistical comparisons among different run-types from these two release groups.

The vast majority (98.8% or 554/561) of CWTs were found on the Brooks Island Caspian tern colony. Conversely, predation on CWT smolts by Caspian terns nesting in the South Bay was negligible, with just seven CWT smolts recovered from both Eden Landing and Steven's Creek colonies combined. All seven were from hatchery fall-run Chinook salmon and, similar to results from Brooks Island, the majority (71.4%) were from fish trucked to and released into San Pablo Bay, followed by one Delta release fish and one In-river migrant. Given the number of CWT fish released into the Sacramento and San Joaquin rivers (ca. 11.2 million), it is remarkable how few were consumed by Caspian terns nesting at colonies in the South Bay during 2009.

DISCUSSION

Results of this study demonstrate that CWTs implanted in juvenile salmonids can be recovered from Caspian tern breeding colonies and used to evaluate impacts of this avian predator on survival of juvenile salmonids. Virtually all of the CWTs recovered from the tern colonies were readable, such that the fish species, stock, run, rearing-type, release date, and release location could be determined. This finding demonstrates that CWTs are

not damaged during digestion of the tagged fish and can remain readable for several years after being deposited on a colony (as demonstrated by the CWTs found from smolts released as far back as 1998). Efforts to recover fish tags after birds have left the breeding colony avoids disturbing the birds during the breeding season, which can negatively affect nesting success and, in some cases, cause colony abandonment (Ellison and Cleary 1978; Tremblay and Ellison 1979; Burger 1984). Furthermore, the use of fish tag recoveries to assess the diet of piscivorous waterbirds avoids either lethal collection or live capture and handling of chicks or adults to collect diet samples.

Detection efficiency trials aimed at quantifying the rate of CWT loss and missed detection suggest that a large percentage (ranging from 20% to 80%) of the CWTs deposited on the tern colony were not detected by researchers. Data from test tags indicates that tag detection is associated with deposition date; tags that have been on the colony for longer periods of time are less likely to be recovered by researchers at the end of the tern nesting season. The detection efficiency of CWTs associated with the processing of substrate samples (i.e., the passing of colony substrate over magnets) was quite high (> 90% of test tags sown), suggesting that the methods used were effective at finding the vast majority of CWTs within the collected substrate. By measuring the detection efficiency of CWTs sown on-colony and by knowing the proportion of the total tern colony area that was sampled for CWTs, adjustments can be made to estimate the total number of CWTs deposited by terns on the colony during a given nesting season. Predation rates on different groups of salmonids marked with CWTs can then be estimated by dividing the estimated total number of CWTs deposited on-colony by the total number of tags released. These estimated predation rates, however, are minimum estimates because an unknown proportion of all CWTs consumed by terns nesting on the colony are either regurgitated or defecated off-colony. As such, our measure of precision (95% confidence intervals) applies to the number of CWTs deposited on-colony, not the total number consumed by Caspian terns nesting at a given site. Despite this caveat, our results regarding the relative susceptibility of CWT salmonid smolts from the Sacramento and San Joaquin rivers should not be biased due to either the loss of CWTs deposited on-colony or the off-colony deposition of ingested CWTs.

Impacts on Salmonids

Overall, a very small percentage (ca. 0.1% or 14,577/11,193,248) of the available CWTs from juvenile Chinook salmon from the Sacramento and San Joaquin rivers were estimated to be deposited by Caspian terns on their nesting colonies in San Francisco Bay during 2009. Of the fish consumed by terns, there was over-whelming evidence that smolts released directly into eastern San Pablo Bay from net pens were the most susceptible, with CWTs from this Bay release group of fish more than 50 times more likely to be recovered on the tern colony than CWTs from Delta or In-river release groups. Of the three Caspian tern colonies sampled, impacts on salmonid smolt survival were greatest for the Brooks Island colony, with 98.8% (554/561) of the CWTs found on the Brooks Island tern colony, compared to 0.9% for Eden Landing and 0.4% for Steven's Creek. The proximity of the net pen release locations in eastern Sam Pablo Bay to the Brooks Island tern colony (~ 25 km), the timing of releases (during daylight hours),

the duration of releases (April to June), and the large numbers of hatchery-reared juvenile salmonids in each net pen release are all likely contributing factors to the much higher susceptibility of the Bay release group to predation from Caspian terns nesting at Brooks Island. Previous studies have shown that Caspian terns tend to forage on the most available prey-types near the breeding colony when raising young (Lyons et al. 2005). Furthermore, hatchery-reared juvenile Chinook salmon have been shown to be more susceptible to Caspian tern predation as compared to their wild counterparts (Collis et al. 2001; Ryan et al. 2003).

Of the various run-types of CWT Chinook salmon (spring, winter, fall, and late-fall), fall-run Chinook salmon were the most susceptible to predation by Brooks Island Caspian terns; 92.0% of all recovered CWTs were from fall-run Chinook salmon. The large numbers of hatchery-reared fall Chinook salmon released into eastern San Pablo Bay from net pens is one reason for this greater susceptibility. Even after accounting for differences in release location (In-river, Delta, or Bay release groups), fall Chinook salmon were still consumed at a higher rate than spring, winter, and late-fall run Chinook salmon. For example, for Bay release group Chinook salmon, CWTs from fall Chinook were seven times more likely to be recovered on the tern colony than those of spring Chinook salmon. The timing of release and out-migration for fall Chinook smolts is likely one reason for this higher susceptibility, as fall Chinook were available to terns for at least a three-month period (April to June), while Bay released spring Chinook smolts were available for just the month of April (see Table 2). Also, the energy demands of Caspian terns nesting at colonies in the Bay Area likely peaked in June, when adults were feeding rapidly-growing chicks and colony attendance of adult terns was high.

Data presented here suggest that the impacts of Caspian terns on wild or naturally produced juvenile Chinook salmon from the Central Valley of California were minimal in 2009. This same conclusion was drawn from data collected in 2008, when nearly 97% of the CWTs recovered from the Brooks Island Caspian tern colony were hatchery fall-run Chinook released from net pens (Evans et al. In review). Similar to 2008, none of the approximately 290 wild fall-run Chinook salmon marked with CWTs and released in the Sacramento River were subsequently recovered on a Caspian tern colony in the Bay Area. Furthermore, a very small number ($N = 5$) and proportion of all Chinook salmon released in-river were recovered on a tern colony, a finding that supports the conclusion of minimal impacts to survival of wild fish because all wild Chinook salmon in the region (tagged and un-tagged) migrate in-river. Life history data on wild, ESA-listed Chinook salmon populations from the Sacramento River (i.e., winter and spring-run Chinook) indicate that the timing of smolt out-migration from stream to estuary is primarily between November and May (Yoshiyama et al. 1998), a time period that only partially over-laps with the Caspian tern nesting season on Brooks Island. Conversely, both wild and hatchery fall-run Chinook salmon out-migrate to the estuary between March and July (Yoshiyama et al. 1998; Weber and Fausch 2004), a period that completely over-laps with the tern nesting season.

Differences in fish size, density, and behavior may also limit the impact of Caspian tern predation on survival of wild Chinook salmon smolts relative to their counterparts that

are raised in hatcheries. Weber and Fausch (2004) reported that hatchery-reared Chinook salmon released into the upper Sacramento River were larger (fork length), emigrated later, and were more numerous than wild Chinook salmon of the same run-type. Data aimed at evaluating the in-river survival and timing of ocean entry – as opposed to emigration timing to the estuary – by wild and hatchery-reared smolts from the Sacramento and San Joaquin rivers would assist in quantifying and evaluating differences in susceptibility to Caspian tern predation between wild and hatchery Chinook smolts.

Unfortunately, we are unable evaluate the susceptibility of juvenile steelhead relative to the susceptibility of juvenile Chinook salmon to predation by Caspian terns, because steelhead were not marked with CWTs in 2008 or 2009. Data from Caspian tern colonies in the Columbia River basin suggest that steelhead smolts are particularly susceptible to Caspian tern predation (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005). Observations of the species of fish being delivered by Caspian terns to the Brooks Island colony (Caspian terns capture and deliver in their bills whole fish to their mates and young) in 2008 and 2009 indicated that only a small percentage of the salmonids delivered to the colony were steelhead (ca. 2.5% in 2008 and ca. 1.7% in 2009). Whether these steelhead belonged to the threatened Central Valley or Central California Coast ESUs or to several of the other non-listed steelhead ESUs in the region is unknown, but the overall impact of Caspian terns on steelhead survival in both 2008 and 2009 was likely minimal given the scarcity of steelhead in the diet of nesting terns.

Results presented here provide over-whelming evidence that Caspian terns are consuming primarily non-listed, hatchery-reared fall Chinook salmon that are being released *en masse* into eastern San Pablo Bay from net pens. Of these tern-depredated net pen fish, the majority were consumed by Caspian terns nesting on Brooks Island. Conversely, terns nesting on islands in southern San Francisco Bay were rarely observed to include salmonid smolts in their diet and consumed very few CWT salmonid smolts. The lack of CWTs from wild Chinook salmon or in-river migrating Chinook salmon supports the conclusion that impacts to the survival of naturally-produced, ESA-listed salmonid smolts by Caspian terns nesting in the Bay Area were minimal.

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Table 1: Salmonid coded wire tag (CWT) recoveries on Caspian tern breeding colonies in San Francisco Bay following the 2009 nesting season. The estimated total number of coded wire tags deposited by terns on each colony was based on the area of used nesting substrate that was sampled by researchers and the detection efficiency of test tags sown on-colony. All coded wire tags are from Chinook salmon released into the Sacramento and San Joaquin rivers as smolts in 2009. SE is the standard error of the mean average detection efficiency and CI is the 95% confidence interval.

Colony	Breeding Pairs	Total Nesting Area (m^2)	Sampled Nesting Area (m^2)	CWTs Recovered	Average Detection Efficiency (SE)	Est. Total CWTs (± CI)
Brooks Island [a]	681	720	55	554	52.7% (10.3)	14,398 (2,998)
Eden Landing	75	73	8	5	40.0% (8.6)	114 (19)
Steven's Creek	54	125	8	2	48.3% (10.9)	65 (14)
Totals	810	918	71	561	49.2%	14,577

[a] *terns nested on two different areas or sub-colonies on Brooks Island and the number of CWTs deposited by terns was independently calculated for each sub-colony and then added together for a total estimate.*

Table 2: Coded wire tagged (CWT) juvenile Chinook salmon from the Sacramento and San Joaquin rivers released and subsequently recovered on the Brooks Island, Eden Landing, and Steven's Creek Caspian tern colonies following the 2009 nesting season. In-river fish were released directly into the Sacramento River or a tributary of the Sacramento River between 135 and 615 river kilometers (Rkm) upstream of northern San Francisco Bay. Delta fish were released into sloughs below the confluence of the Sacramento and San Joaquin rivers between 80 and 95 Rkm upstream of northern San Francisco Bay. Bay fish were released directly into eastern San Pablo Bay in northern San Francisco Bay.

Salmonid Species / Run-type			Number Recovered		
by Release Strategy	Number Released	Release Month	Brooks Island	Eden Landing	Steven's Creek
Bay Releases					
Hatchery Spring Chinook	1,005,727	April	23		
Hatchery Fall Chinook	3,349,216	April to June	503	3	2
Hatchery Hybrid Chinook	204,618	April	15		
Delta Releases					
Hatchery Fall Chinook	344,222	April to June	9	1	
In-River Releases					
Hatchery Winter Chinook	146,289	January			
Hatchery Spring Chinook	1,015,717	April	1		
Hatchery Fall Chinook	3,731,785	April to June	3	1	
Wild Fall Chinook	289,830	Jan. to March			
Hatchery Late-Fall Chinook	1,105,844	January			
ALL	11,193,248		554	5	2

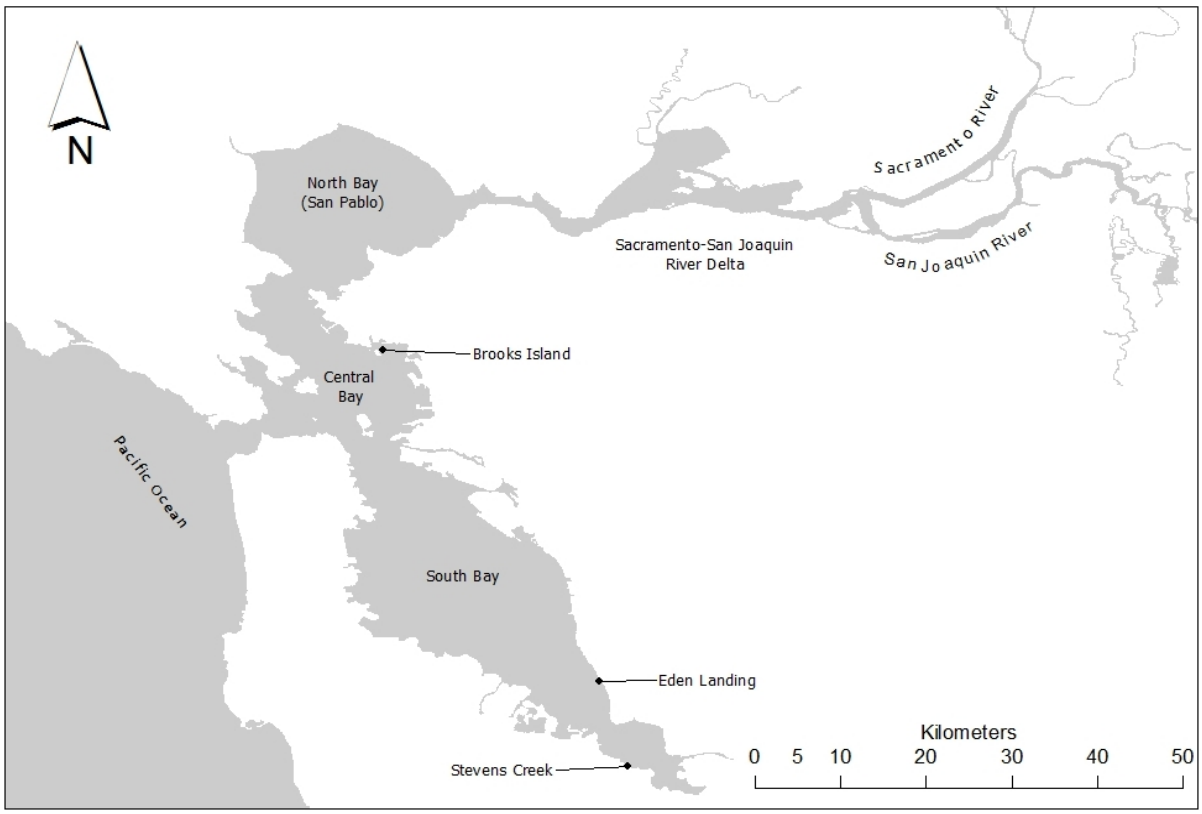

Figure 1: Map of San Francisco Bay, California. Brooks Island is located in central San Francisco Bay, with the Sacramento and San Joaquin rivers entering the Bay from the northeast. Eden Landing and Steven's Creek are located in southern San Francisco Bay.

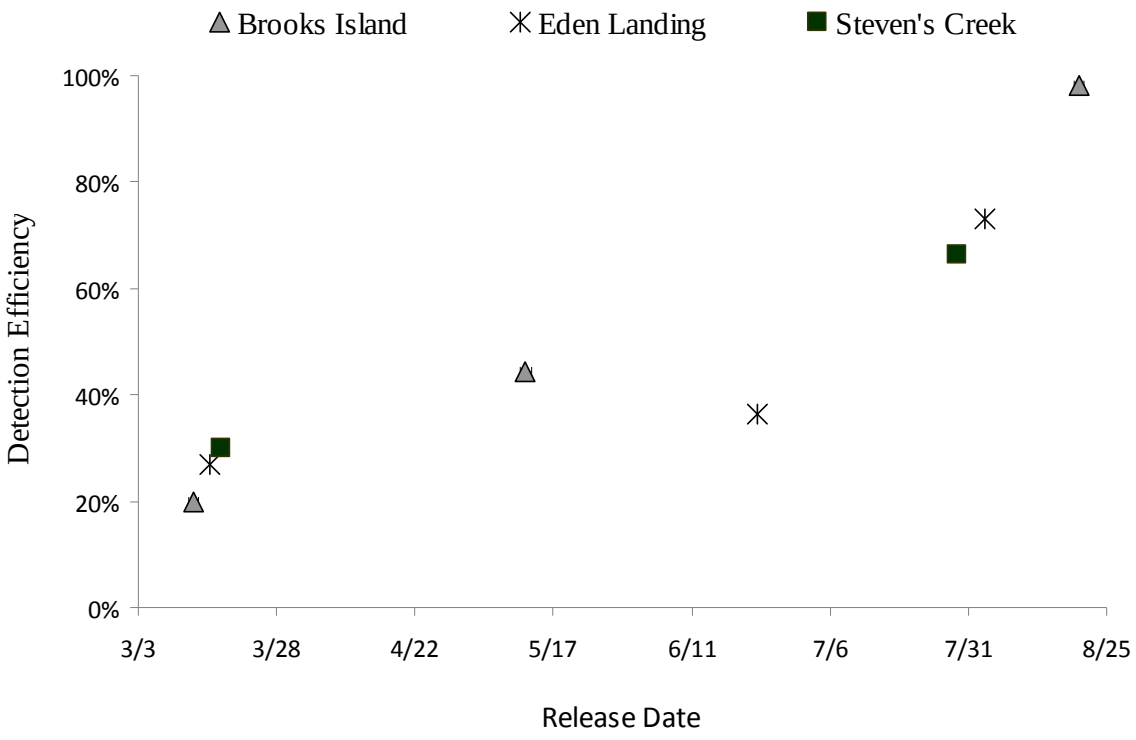

Figure 2: Average detection efficiency of coded wire tags intentionally sown on the Brooks Island, Eden Landing, and Steven's Creek Caspian tern colonies at discrete times during the 2009 nesting season. Values are from the number of tags sown on-colony during the pre- (13 March to 18 March), mid- (12 May to 23 June), and post- (29 July to 20 August) nesting season periods that were subsequently recovered by researchers in substrate samples.