Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River

Final 2009 Annual Report

This Final 2009 Annual Report has been prepared for the
Bonneville Power Administration and the U.S. Army Corps of Engineers
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EXECUTIVE SUMMARY

We conducted field studies in 2009 to assess the impact of predation by Caspian terns, double-crested cormorants, and other piscivorous colonial waterbirds on juvenile salmonids in the Columbia River Basin. The Caspian tern colony on East Sand Island in the Columbia River estuary, the largest of its kind in the world, consisted of about 9,854 breeding pairs in 2009, not significantly different from 2008. The proportion of juvenile salmonids in the diet of terns nesting on East Sand Island was 37%, somewhat higher than the average percentage over the previous decade. Caspian terns nesting at the East Sand Island colony consumed about 6.4 million juvenile salmonids (95% c.i. = 5.6 – 7.2 million) in 2009, similar to the estimate in 2008.

East Sand Island is also home to the largest double-crested cormorant colony in western North America, consisting of about 12,087 breeding pairs in 2009, about 10% larger than in 2008. Juvenile salmonids represented about 9.2% of the diet of double-crested cormorants nesting on East Sand Island in 2009, compared with 11.4% in 2008. Double-crested cormorants nesting at this colony consumed about 11.1 million juvenile salmonids (95% c.i. = 7.7 – 14.5 million) in 2009, mostly sub-yearling Chinook salmon. In 2009, smolt consumption by double-crested cormorants nesting on East Sand Island was significantly greater than smolt consumption by Caspian terns nesting on East Sand Island. Taken together, losses of juvenile salmonids to these two species of fish-eating birds nesting on East Sand Island were 15-20 million smolts, or about 15% of all juvenile salmonids estimated to reach the estuary during the 2009 out-migration.

In order to track double-crested cormorants from the East Sand Island colony during post-breeding dispersal and identify over-wintering areas, satellite tags were used to follow 39 double-crested cormorants that nested on East Sand Island during 2008 or 2009. Most satellite-tagged cormorants were tracked to over-wintering sites in either the Salish Sea region (n = 16) or the lower Columbia and Willamette rivers (n = 11), but a few cormorants roosted at sites as far north as the northern Strait of Georgia in British Columbia and as far south as the Salton Sea, CA. Only one satellite-tagged cormorant traveled east of the Cascade/Sierra Nevada range, a bird that migrated up the Columbia River to John Day Dam. These tracking data demonstrate direct connectivity between the double-crested cormorant colony at East Sand Island, which has experienced tremendous growth over the last two decades, and colonies to the north (i.e., Salish Sea region) and to the south (e.g., San Francisco Bay, CA and Salton Sea, CA) that have experienced declines over the same time period. Based on these results, double-crested cormorants from East Sand Island have the greatest connectivity with active and historical colony sites to the north in the Salish Sea region. If nesting habitat was limited on East Sand Island, most emigrants would likely search for alternative nesting habitat in the Salish Sea region.

Implementation of the federal management agencies' Caspian Tern Management Plan for the Columbia River Estuary continued, with the USACE building two new tern nesting islands prior to the 2009 nesting season. Both islands are located at Summer Lake Wildlife Area in south-central Oregon and each is a half-acre in area; one is a rock-core

island and the other a floating island. Caspian terns colonized both new islands during the 2009 breeding season, eight breeding pairs on the floating island and seven pairs on the rock-core island. Five terns that had been banded in the Columbia River estuary were re-sighted at the new Summer Lake tern islands. We continued to monitor two other tern islands that were constructed by the USACE prior to the 2008 nesting season, one on Crump Lake in the Warner Valley, Oregon, and one on Fern Ridge Reservoir near Eugene, Oregon. The Crump Lake tern island attracted nearly 700 breeding pairs of Caspian terns in 2009. Eighteen terns that had been banded in the Columbia River estuary were re-sighted on Crump Lake island. The diet of Caspian terns nesting at Crump Lake and Summer Lake consisted of > 80% tui chub, a native species that is not of conservation concern. As in 2008, no Caspian terns nested on the Fern Ridge Reservoir tern island in 2009, although at least eight different Caspian terns were seen on the island late in the nesting season.

Caspian terns and double-crested cormorants are also responsible for most losses of salmonid smolts to avian predators along the mid-Columbia River, specifically Caspian terns nesting on Crescent Island and double-crested cormorants nesting on Foundation Island, both in McNary Pool. The Caspian tern colony at Crescent Island consisted of 349 breeding pairs in 2009, the smallest the colony has been since monitoring commenced in 1997. Salmonid smolts represented 64% of the prey items for terns nesting on Crescent Island in 2009, similar to diet composition during 2000-2008. Based on bioenergetics calculations, consumption of juvenile salmonids by Crescent Island terns was about 360,000 smolts in 2009.

The largest Caspian tern colony on the Columbia Plateau in 2009 was on Goose Island in Potholes Reservoir, where about 486 pairs nested. Data on diet composition of terns nesting at the Potholes colony were limited to smolt PIT tags recovered on the colony after the nesting season. Recovered PIT tags indicated that the numbers of juvenile salmonids from the Columbia River consumed by terns nesting at this off-river colony were surprisingly high, particularly for steelhead from the endangered Upper Columbia ESU. PIT tag recoveries on the Potholes tern colony indicated that over 15.5% of Upper Columbia steelhead passing Rock Island Dam in 2009 were consumed by Caspian terns nesting at this colony.

The only active double-crested cormorant colony on the mid-Columbia River during 2009 was on Foundation Island in McNary Pool, which consisted of about 310 nesting pairs. The largest cormorant colony on the Columbia Plateau, however, consisted of about 810 pairs that nested in trees at the north end of Potholes Reservoir. Both colonies have declined somewhat over the last four years, indicating that, in the short term, the cormorant breeding population in the region is not increasing. Based on limited diet data for cormorants nesting on Foundation Island, the proportion of salmonids in the diet was similar to 2007 and 2008. Smolt PIT tag recoveries on the Foundation Island cormorant colony were also similar in 2007, 2008, and 2009. The magnitude of smolt PIT tag recoveries at the Foundation Island colony suggests that the impact of cormorants nesting at this colony on survival of juvenile salmonids is comparable to that of Caspian terns nesting at the Crescent Island colony.

Stomach contents of 35 double-crested cormorants collected along the lower Snake River during the winter of 2009-10 indicated that salmonids comprised about 12.4% of the diet; most salmonids found in cormorant stomachs were from the ESA-listed run of Snake River fall Chinook. Surveys during the 2009-10 winter indicated that less than 250 cormorants over-wintered along the lower Snake River; on average, only 20% were observed at one of the four lower Snake River dams. The highest concentrations of cormorants over-wintering along the lower Snake River during 2009-10 were observed between Ice Harbor Dam and the confluence with the Columbia River.

California and ring-billed gulls have nested in large numbers on islands on or near the mid-Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids. However, recent increases in numbers of smolt PIT tags recovered at the gull colony on Miller Rocks in The Dalles Pool, where about 4,600 pairs of gulls now nest, have raised concerns about the impact of gull predation on survival of salmonid smolts. In 2009, nearly 5,500 smolt PIT tags were deposited on the Miller Rocks colony by gulls nesting there, compared to 4,211 tags in 2008. The increase in consumption of PIT-tagged smolts by Miller Rocks gulls likely reflects both an increase in size of the gull colony (numerical response) as well as an increase in foraging intensity at nearby John Day Dam and The Dalles Dam (functional response). The magnitude of predation on salmonid smolts by Miller Rocks gulls appears to be unique among gull colonies along the mid-Columbia River.

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SECTION 1: CASPIAN TERNS

1.1. Preparation and Modification of Nesting Habitat in the Columbia River Estuary

The U.S. Army Corps of Engineers (USACE) began management of Caspian terns in 2008, actions that were described in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* (USFWS 2005, 2006). This management plan, which was developed jointly by the U.S. Fish and Wildlife Service (USFWS; lead), the USACE, and NOAA Fisheries, seeks to redistribute a portion of the Caspian tern colony on East Sand Island in the Columbia River estuary (Map 1) to alternative colony sites (islands) in interior Oregon and the San Francisco Bay area by 2015 (Map 2). Three alternative colony sites in northeastern California were added to the plan in 2008: Tule Lake NWR (1 island) and Lower Klamath NWR (2 islands). 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).

As part of this plan, the USACE restored 3.5 acres of nesting habitat for Caspian terns at East Sand Island in late March 2009. Without annual restoration of the bare sand nesting habitat that Caspian terns prefer, the East Sand Island colony would be eliminated within a few years by rapidly encroaching pioneer vegetation. The amount of Caspian tern nesting habitat prepared on East Sand Island in 2009 was a 30% reduction from the amount of nesting habitat prepared for terns in the previous year (5 acres). As stipulated in the Final Environmental Impact Statement (USFWS 2005: Chapter 2, Section 2.3.3), this 1.5-acre reduction in area of nesting habitat was allowed due to the creation of 3.0 acres of new Caspian tern nesting habitat outside the Columbia River estuary (USFWS 2005).

A camp was set up on East Sand Island on 8 April and was continuously occupied by two colony monitors throughout the tern nesting season. Although limited control of glaucous-winged/western gulls (*Larus glaucescens/occidentalis*) was performed during the 1999 and 2000 nesting seasons to enhance prospects for tern colony restoration on East Sand Island, no gull control has been conducted there since 2000.

In previous years, work crews from NOAA Fisheries, Oregon Department of Fish and Wildlife, and USACE carried out various habitat modifications on the former tern colony site on Rice Island (e.g., fencing and flagging) prior to the breeding season to discourage terns from nesting there. This was not necessary in 2009 because the former colony site on Rice Island (ca. 7 acres) has become completely vegetated and was consequently unsuitable for tern nesting. In 2009, no active hazing of terns to discourage nesting was conducted on Rice Island, but some passive measures (i.e., flagging) were deployed to discourage tern nesting at Rice Island (Map 1; see below). Active hazing or passive measures to discourage tern nesting (i.e., flagging) were not necessary at other dredged material disposal sites in the upper Columbia River estuary (i.e., Miller Sands Spit, Pillar Rock Sands, Puget Island) during the 2009 nesting season.

1.2. Nesting Chronology, Colony Size, and Productivity of Caspian Terns

1.2.1. Columbia River Estuary

Methods: The number of Caspian terns breeding on East Sand Island in the Columbia River estuary during 2009 was estimated using low-altitude, high-resolution aerial photographs of the colony taken near the end of the incubation period. The average of 3 direct counts of all adult terns on the colony in aerial photographs, corrected using ground counts of the ratio of incubating to non-incubating terns on 12 different plots within the colony area, was used to estimate the number of breeding pairs on the colony at the time of the photography. Confidence intervals for the number of breeding pairs were calculated using a Monte Carlo simulation procedure to incorporate the variance of the multiple counts from the aerial photographs and the variance in the ratios of incubating to non-incubating adults on the plots.

Nesting success (average number of young raised per breeding pair) at the East Sand Island tern colony was estimated using aerial photographs taken of the colony just prior to the fledging period. The average of 3 direct counts of all terns (adults and juveniles) on the colony in aerial photographs, corrected using ground counts of the ratio of fledglings to adults on 12 different plots within the colony area, was used to estimate the number of fledglings on the colony at the time of the photography. The total number of fledglings on-colony was then divided by the number of breeding pairs estimated from the late incubation photo census. Confidence intervals for nesting success were calculated using a Monte Carlo simulation procedure to incorporate the variance of the multiple counts from the aerial photographs and the variance of the fledgling to adult ratios on the plots.

Periodic boat-based and aerial surveys of the dredged material disposal islands in the upper estuary (i.e., Rice Island, Miller Sands Spit, Pillar Rock Sands; Map 1) were conducted during the 2009 nesting season in order to detect any early signs of nesting attempts by Caspian terns.

Results and Discussion: Nesting chronology at the East Sand Island Caspian tern colony in 2009 was delayed compared to previous years; the dates when terns first arrived on colony, when the first eggs were laid, when the first chicks hatched, and when the first tern chicks fledged in 2009 were the latest we have recorded at the East Sand Island tern colony. As was the case during 2001–2008, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2009. The colony attendance data suggest that the tern colony reached its maximum size in mid-May in 2009, slightly earlier than was observed in previous years (Figure 1). Contrary to what was observed in previous years, large numbers of terns remained on the colony throughout the month of August, with some terns observed on colony as late as mid-September (Figure 1). Based on the aerial photo census, we estimate that 9,854 breeding pairs of Caspian terns (95% c.i. = 9,509–10,199 breeding pairs) were nesting on East Sand Island at the peak of nesting activity (late May) in 2009. This estimate is lower than our comparable best estimate of peak colony size at East Sand Island in 2008 (10,668 breeding pairs, 95% c.i. = 9,923–11,413 breeding pairs), but not significantly so. During 2000-2009, the size of the East Sand Island Caspian tern colony has been relatively stable, averaging about 9,250 breeding pairs at its annual peak (Figure 2). The East Sand Island tern colony is the largest known breeding colony of Caspian terns in the world.

In 2009, unlike previous years, there were two distinct pulses of breeding activity by adult Caspian terns at the East Sand Island tern colony. The peak in egg-laying of the first and larger group of breeding terns was in early May, typical of most years. The second pulse of egg-laying occurred in mid to late June. The origin of the terns that participated in this second pulse of egg-laying is not entirely certain. Presumably at least some of these late-nesting adults were birds whose initial nesting attempt at East Sand Island in 2009 had failed and were re-nesting at the same site. It is possible; however, that most of these late-nesting birds first attempted to nest elsewhere in the region, failed there, and moved to East Sand Island to initiate a second nesting attempt. (Caspian terns have not been documented to re-nest in the same season following a successful nesting attempt.)

This second pulse of egg-laying on the East Sand Island tern colony occurred during mid to late June, and coincided with the failure of the breeding colony on Dungeness Spit, the next largest colony of Caspian terns in the Pacific coast region. The Dungeness Spit colony apparently failed due to extensive nest predation by coyotes. The size of the Dungeness Spit tern colony prior to abandonment was ca. 1,500 breeding pairs and, given the proximity of Dungeness Spit to East Sand Island (223 km straight line distance), it seems likely that terns from the Dungeness Spit colony were major contributors to the pulse of late season nesting at East Sand Island. Observations of banded terns support this conclusion; about 25% of all banded terns observed at Dungeness Spit prior to colony abandonment were later seen at East Sand Island. Other colonies in the region (e.g., Brooks Island in San Francisco Bay, Crump Lake tern island in the Warner Valley) experienced unusually high nest failure rates at this time, as well, and those individuals may have also contributed. Several thousand pairs of Caspian terns were actively incubating eggs or brooding small chicks at East Sand Island during the month of July, an unprecedented magnitude of late season nesting activity. Over 1,500 active nests were present on the East Sand Island colony as late as mid August.

Productivity of the initial, larger group of nesting Caspian terns was estimated using an aerial photo taken around the time of fledging for this cohort of chicks and we estimate that 5,944 fledglings (95% c.i. = 5,093–6,795 fledglings) were produced in this first pulse of nesting. This corresponds to an average nesting success of 0.60 young raised per breeding pair (95% c.i. = 0.52–0.69 fledglings/breeding pair), which is not significantly different from the estimate of nesting success for the East Sand Island tern colony in

2008 (0.57 fledglings/breeding pair, 95% c.i. = 0.31–0.83 fledglings/breeding pair; Figure 3).

Due to limited availability of research personnel and resources during August and September we could not precisely estimate productivity of terns nesting later in the season; however, limited counts of active nests and chicks in plots across the colony suggested that per pair productivity of this late-nesting group was poor (ca. < 0.2 fledglings/breeding pair). Given the large number of nesters still active at this time, however, it is possible that more than 1,000 late season fledglings were produced, in addition to the nearly 6,000 fledglings produced during the initial pulse of breeding.

About 220 Caspian terns were observed loafing on upland areas of Rice Island on 10 May. The behavior of these birds indicated an intention to nest at this dredged material disposal island, as evidenced by courtship displays, exchange of courtship meals, copulations, and digging of nest scrapes. Resource managers were informed of the situation and on 13 May a USACE contractor deployed stakes fixed with brightly colored flagging to dissuade terns from nesting at this incipient colony site. On 21 May, up to 300 Caspian terns were observed in another upland area on Rice Island (near an incipient ring-billed gull colony), where tern nesting again appeared to be imminent. Resources managers were notified on 23 May and once again a USACE contractor deployed stakes and flagging at the site, but not before two tern eggs were laid. These eggs were collected, under permit, by the USACE contractor to deter further nesting at the site. These efforts were effective in dissuading terns from roosting or nesting at either upland site on Rice Island after 23 May and throughout the remainder of the 2009 nesting season. No other attempts by Caspian terns to nest in upland areas at other dredged material disposal sites in the upper estuary (i.e., Miller Sands Spit, Pillar Rock Sands, Puget Island) were observed in 2009.

1.2.2. Columbia Plateau

Methods: The number of breeding pairs of Caspian terns nesting at Crescent Island (Maps 3 and 4) in 2009 was estimated by averaging six independent ground counts of all incubating terns on the colony near the end of the incubation period. These counts were made from an observation blind situated on the outskirts of the tern colony. Nesting success was estimated from ground counts of all fledglings on the colony just prior to fledging.

Periodic boat-based and aerial surveys of former Caspian tern breeding colony sites (i.e., Three Mile Canyon Island, Rock Island, Miller Rocks, Cabin Island, Sprague Lake, Banks Lake, and Potholes Reservoir) were conducted during the 2009 nesting season to determine whether these colony sites had been re-occupied (Map 3). We also flew aerial surveys of the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, the lower Snake River from its mouth to the confluence with the Clearwater River, and Potholes Reservoir searching for new or incipient Caspian tern colonies.

Results and Discussion: Colony attendance at the Crescent Island Caspian tern colony in 2009 was well below the average for 2000-2008 (Figure 4). This was associated with below average colony size (Figure 5) and nesting success (Figure 6) at the Crescent Island tern colony in 2009. About 349 breeding pairs of Caspian terns attempted to nest at the Crescent Island colony in 2009, the smallest the colony has been since monitoring commenced in 1997. Colony size at the Caspian tern colony on Crescent Island has trended downward since 2001 (Figure 5). We estimated that 152 young terns fledged from the Crescent Island colony in 2009, or 0.44 young raised per breeding pair. Nesting success at the Crescent Island Caspian tern colony in 2009 was below the average for 2000-2008, but above what was observed the previous year when nesting success was the lowest ever recorded (0.28 young raised per breeding pair; Figure 6). Since 2001, nesting success at the Crescent Island tern colony has trended downward, likely associated with declines in food availability and increased kleptoparasitism and nest predation by California gulls.

The Rock Island Caspian tern colony (located on the mid-Columbia River in the John Day Pool) consisted of about 80 breeding pairs in 2009, down from about 100 pairs in 2008. The Rock Island tern colony completely failed in 2009 due to an unknown cause(s). This is the fourth consecutive year that the Rock Island Caspian tern colony has failed or nearly failed; in 2006 due to mink predation, in 2007 due to avian predation, and in 2008 due to usually high water levels in John Day Pool during the incubation period. Tern nesting was first detected on Rock Island in 2005, when about 6 pairs of Caspian terns attempted to nest there.

We found no evidence of Caspian terns attempting to nest at colony sites along the lower and mid-Columbia River or the lower Snake River, other than Crescent Island and Rock Island, in 2009. American mink disrupted tern nesting at Three Mile Canyon Island (Map 3) in 2000 and 2001, causing the colony to fail in both years. In 2001, Caspian terns were found nesting on Miller Rocks on the lower Columbia River just upstream of the mouth of the Deschutes River (Map 3); up to 20 breeding pairs attempted to nest on the edge of a large gull colony. Cabin Island above Priest Rapids Dam (Map 3), where nesting Caspian terns have been previously recorded, was the site of a large ring-billed gull colony until the late 1990s, when USDA-Wildlife Services dispersed the colony by oiling eggs and disturbing nesting birds.

We identified three other Caspian tern colonies on the Columbia Plateau off the Columbia and Snake rivers in 2009 (Map 3): 487 pairs nested on Goose Island in Potholes Reservoir, now the largest Caspian tern colony on the Columbia Plateau; 61 pairs nested on Twining Island in Banks Lake; and 4 pairs attempted to nest on Harper Island in Sprague Lake (Table 1). Nesting success on Goose Island and Harper Island in 2009 is unknown, but at least some of the nesting terns were successful in rearing young at Goose Island. Nesting success at Twining Island was estimated to be 0.33 young raised per breeding pair. Goose Island was first used by nesting Caspian terns in 2003; previously Caspian terns nested on another island in Potholes Reservoir (Solstice Island), where tern nesting was first confirmed in 2000. Tern nesting on Banks and Sprague lakes has been sporadic since nesting at both sites was first confirmed in 1997, with colony sizes ranging between 7 and 50 breeding pairs at each site.

The total number of Caspian terns nesting throughout the Columbia Plateau Region in 2009 was approximately 980 breeding pairs (Table 1). This suggests that the number of Caspian terns nesting throughout the Columbia Plateau has remained relatively stable since 2000, when the number of breeding Caspian terns was estimated at over 1,000 breeding pairs (Figure 7).

1.2.3. Coastal Washington

Methods: Aerial surveys along the southern Washington Coast, including former Caspian tern colony sites in Willapa Bay and Grays Harbor (Map 1), were conducted on a periodic basis throughout the breeding season in order to detect formation of any new Caspian tern colonies outside the Columbia River estuary.

The number of Caspian terns breeding on Dungeness Spit (in Dungeness National Wildlife Refuge near the city of Sequim, WA; Map 3) was estimated using aerial photographs of the colony taken early in the chick-rearing period. The count of adult terns in aerial photos of Dungeness Spit was corrected to estimate the number of breeding pairs on the colony using ground counts of the ratio of brooding to non-brooding terns on a portion of the colony area. We opportunistically assessed nesting chronology, limiting factors, and potential productivity of the Dungeness Spit colony during occasional visits throughout the breeding season.

In 2008-2009, USDA-Wildlife Services, under contract from the U.S. Navy, prevented any nesting by Caspian terns at the rooftop colony site at Naval Base Kitsap, Bremerton, where an estimated 117 pairs nested in 2007.

Results and Discussion: Although Caspian terns were commonly observed foraging and roosting in Willapa Bay and Grays Harbor throughout the 2009 breeding season, no nesting attempts by terns were detected in either area. This suggests that suitable tern nesting sites (i.e., island sites that are unvegetated, above high high tide levels, not currently occupied by other colonial nesting birds, and free of mammalian predators) are not available in either Willapa Bay or Grays Harbor.

The Caspian tern colony on Dungeness Spit in Dungeness NWR during 2009 was located close to the colony site used during 2003-2008. Our best estimate of the peak size of the Caspian tern colony at Dungeness Spit in 2009 was ca. 1,500 breeding pairs, about 70% larger as compared to 2008. This colony experienced steady growth since 2003 (Roby et al. 2004, 2005, 2006, 2007) and is the second largest Caspian tern colony along the Pacific Coast of North America (after the colony on East Sand Island). Based on resightings of banded Caspian terns in earlier years, at least some of the past growth was from immigration of birds banded at colonies in the Columbia Basin (i.e., East Sand and Crescent islands) and Commencement Bay, Tacoma, WA (Roby et al. 2004, 2005, 2006). Despite repeated forays into the Dungeness Spit Caspian tern colony by mammalian predators in previous years (see below), terns have been successful in raising some young at the colony in every year until 2009, when coyotes caused complete nest failure at the colony.

Dungeness Spit was one of the alternative Caspian tern colony sites outside the Columbia River basin where managers sought to actively relocate terns from the East Sand Island colony as part the Draft EIS for Caspian tern management in the Columbia River estuary (see below). The site was dropped from the Final EIS and RODs, however, because of concerns about the potential for increased tern predation on ESA-listed Puget Sound Chinook salmon and Hood Canal chum salmon (USFWS 2005, 2006). Although no attempts will be made to improve tern nesting habitat or actively attract terns to the existing Dungeness Spit colony, it is likely that at least some of the displaced terns from East Sand Island will relocate there on their own. Alternatively, because the Dungeness Spit tern colony is located on a spit and not an island, it may continue to experience poor nesting success and disappear before the size of the East Sand Island colony is reduced and terns forced to nest elsewhere. Continued monitoring of the existing colony at Dungeness Spit is necessary to determine whether the colony survives and, if so, whether tern immigration from East Sand Island causes the colony to increase dramatically.

1.3. Diet Composition and Salmonid Consumption of Caspian Terns

1.3.1. Columbia River Estuary

Methods: Caspian terns transport single whole fish in their bills to their mates (courtship meals) and young (chick meals) at the breeding colony. Consequently, taxonomic composition of the diet can be determined by direct observation of adults as they return to the colony with fish (i.e., bill load observations). Observation blinds were set up at the periphery of the tern colony on East Sand Island so that prey items could be identified with the aid of binoculars and spotting scopes. The target sample size was 350 bill load identifications per week. Fish watches at the East Sand Island tern colony were conducted twice each day, at high tide and at low tide, to control for potential tidal and time of day effects on diet composition. Prey items were identified to the taxonomic level of family. We were confident in our ability to distinguish salmonids from non-salmonids and to distinguish among most non-salmonid taxa based on direct observations from blinds, but we did not attempt to distinguish the various salmonid species. The percent of the identifiable prey items in tern diets was calculated for each 2-week period throughout the nesting season. The diet composition of terns over the entire breeding season was based on the average of the percentages for the 2-week periods.

To assess the relative proportion of the various salmonid species in tern diets, we collected bill load fish near the East Sand Island tern colony by shooting Caspian terns returning to the colony with whole fish carried in their bills (referred to hereafter as "collected bill loads"). Salmonid bill loads were identified as either Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), or unknown based on soft tissue or morphometric analysis.

Estimates of annual smolt consumption for the East Sand Island Caspian tern colony were calculated using a bioenergetics modeling approach (see Roby et al. [2003] for a detailed description of model construction and input variables). We used a Monte Carlo simulation procedure to calculate reliable 95% confidence intervals for estimates of smolt consumption by terns.

Results and Discussion: Of the bill load fish identified at the East Sand Island Caspian tern colony during the 2009 nesting season, on average 37% were juvenile salmonids (n = 4,930 bill loads). This proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island, averaged over the entire nesting season, was higher than all previous years except 2000, when it was ca. 47% (Figure 8). As in previous years, marine forage fishes (i.e., anchovies [Engraulidae], shiner perch [Embiotocidae], herring [Clupeidae], and smelt [Osmeridae]) were prevalent, together averaging 56% of all identified bill loads in the diets of terns nesting on East Sand Island in 2009 (Figure 9). The peak in the proportion of salmonids in the diet of Caspian terns nesting on East Sand Island came later in 2009 (during mid- to late May) compared to previous years (Figure 10). The proportion of salmonids in the tern diet declined to less than 10% in July and early August, and then increased to over 20% of the diet in late August and early September (Figure 10), when primarily fall Chinook were being consumed.

Our best estimate of total smolt consumption by Caspian terns nesting on East Sand Island in 2009 was 6.4 million smolts (95% c.i. = 5.6 – 7.2 million), not significantly different than the previous year (6.7 million smolts; 95% c.i. = 5.8 – 7.6 million; Figure 11). Since 2000, the average number of smolts consumed by terns nesting on East Sand Island was 5.2 million smolts per year (Figure 11). This is less than half the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary prior to 2000, when the breeding colony was located on Rice Island in the upper Columbia River estuary.

Of the juvenile salmonids consumed in 2009, we estimate that 41% were coho salmon (best estimate = 2.7 million; 95% c.i. = 2.4 – 3.0 million), 23% were yearling Chinook salmon (best estimate = 1.5 million; 95% c.i. = 1.3 – 1.6 million), 19% were steelhead (best estimate = 1.2 million; 95% c.i. = 1.1 – 1.4 million), 16% were sub-yearling Chinook salmon (best estimate = 1.0 million; 95% c.i. = 0.9 – 1.2 million), and < 1% were sockeye salmon (best estimate = 0.03 million; 95% c.i. = 0.03 – 0.04 million; Figure 12). Most salmonids were consumed during the period from mid-April through mid-June, with the peak in smolt consumption occurring in mid-May (Figure 13). This period of high smolt consumption generally corresponds to the peak of the steelhead and yearling Chinook out-migration through the estuary.

1.3.2. Columbia Plateau

Methods: The taxonomic composition of the diet of Caspian terns nesting on Crescent Island was determined by direct observation of adults as they returned to the colony with fish (i.e., bill load observations; described above). The target sample size at Crescent Island was 150 bill load identifications per week (see above for further details on the analysis of diet composition data). Prey items were identified to the taxonomic level of family. We identified prey to species, where possible, and salmonids were identified as either steelhead or 'other salmonids' (i.e., Chinook salmon, coho salmon, or sockeye salmon). Steelhead were distinguished from 'other salmonids' by the shape of the anal and caudal fins, body shape and size, coloration and speckling patterns, shape of parr marks, or a combination of these characteristics. The percent of identifiable prey items in tern diets was calculated for each 2-week period throughout the nesting season. The diet composition of terns over the entire breeding season was based on the average of the percentages from these 2-week periods. Bill load fish were not collected at the Crescent Island tern colony due to the potential impact of lethal sampling on such a small colony.

Estimates of annual smolt consumption by Caspian terns nesting at the Crescent Island colony were calculated using a bioenergetics modeling approach (see Antolos et al. [2005] for a detailed description of model construction and input variables). We used a Monte Carlo simulation procedure to calculate reliable 95% confidence intervals for estimates of smolt consumption by terns at Crescent Island. Temporal trends in steelhead consumption by Crescent Island terns were also investigated relative to the estimated fish passage index at McNary Dam (FPC 2010), a gross measure of smolt availability near Crescent Island.

Results and Discussion: Of the bill load fish identified at the Crescent Island Caspian tern colony, on average 64% were juvenile salmonids (n = 2,055 bill loads). The annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island has been strikingly consistent (about 66%) over the last 10 years (Figure 14). Each year, millions of juvenile salmonids are released from Columbia Basin hatcheries, which provide Crescent Island terns with a reliable and relatively consistent food supply, as compared to the food supply available to terns nesting near the coast (e.g., East Sand Island). Juvenile salmonids are by far the most prevalent prey type in the diet of Caspian terns nesting on Crescent Island, followed by cyprinids (carp and minnows, 15%) and centrarchids (bass and sunfish, 12%; Figure 15). The proportion of juvenile salmonids in the diet of Crescent Island Caspian terns was highest in early May in 2009; in most years this peak came a week earlier and the proportion of salmonids in the diet declined gradually thereafter (Figure 16). Seasonal changes in the proportion of salmonids in the diet probably reflect changes in availability of hatchery-reared smolts near the Crescent Island tern colony. The proportion of salmonids in the diet of Crescent Island Caspian terns was consistently higher throughout the breeding season compared to that of terns nesting on East Sand Island (Figure 10).

We estimated that Caspian terns nesting on Crescent Island consumed 360,000 juvenile salmonids in 2009 (95% c.i. = 270,000 – 450,000), somewhat more but not significantly so compared to 2008 (best estimate = 330,000, 95% c.i. = 230,000 – 430,000). Total smolt consumption by Caspian terns nesting on Crescent Island has trended downward since 2001 (Figure 17), commensurate with downward trends in tern colony size (Figure 5) and nesting success (Figure 6). Despite this general decline in the total number of juvenile salmonids consumed by Crescent Island terns, tern consumption of steelhead smolts has not declined in recent years (Figure 18). Since 2004, total smolt consumption by Crescent island terns has declined 28%, while steelhead consumption has remained the same during this same period. In 2009, steelhead comprised an estimated 15% of the identifiable salmonid smolts, or roughly 53,000 fish. Most salmonids were consumed during the period from late-April through early-June, with the peak in smolt consumption occurring in mid-May (Figure 19).

Peak consumption of steelhead coincided with peak passage of steelhead at McNary Dam in early May 2009. Steelhead consumption by Crescent Island terns remained high through early July, despite the drop in number of steelhead passing McNary Dam during that period (Figure 20). Consumption of other salmonids (i.e., Chinook salmon, coho salmon, and sockeye salmon) also corresponded with peak passage of these species at McNary Dam in mid-May, but declined from mid-June through July despite there being another peak in passage of those species at McNary Dam in early July (Figure 20). These results provide further evidence of a preference for steelhead by Caspian terns nesting on Crescent Island.

1.4. Salmonid Predation Rates by Caspian Terns

Each spring, millions of downstream-migrating juvenile salmonids in the Columbia River basin are tagged with Passive Integrated Transponder (PIT) tags to gather information on their survival and behavior. Each tag contains a unique 14-digit alphanumeric code that provides data on the species of fish, run of fish (if known), release date, and release location, among other data. Each year, thousands of these PIT-tagged fish are consumed by piscivorous colonial waterbirds and many of the ingested tags are subsequently deposited on nesting colonies throughout the Columbia River basin. The recovery of PIT tags on bird colonies can be used to estimate predation rates on salmonid smolts, and these estimates can be used to assess the relative vulnerability of various salmonid species, stocks, and rearing types to avian predation (Collis et al. 2001, Ryan et al. 2003, Antolos et al. 2005). Furthermore, PIT tag recovery data can be used to test hypotheses on the effects of smolt morphology, condition, abundance, and origin on smolt susceptibility to avian predation (see Section 4). Data collected as part this research will help regional fishery managers determine the magnitude of avian predation on different groups of PIT-tagged smolts from the Snake and Columbia rivers, plus identify, and potentially address, those intrinsic factors that influence smolt vulnerability to avian predation.

Estimates of predation rates based on PIT tag recoveries are considered minimums because not all tags consumed by birds are deposited on their nesting colony and not all tags deposited on the colony are detected by researchers. From 2004 to 2009, we have worked collaboratively with NOAA Fisheries to generate more accurate and defensible estimates of avian predation rates based on PIT tag recoveries. This was accomplished by (1) physically removing tags from colonies where PIT tag collision is believed to significantly reduce PIT tag detection efficiency and (2) systematically sowing PIT tags with known tag codes on bird colonies in order to directly measure PIT tag detection efficiencies. From 2004 to 2006, we also conducted experiments to measure on-colony deposition rates of PIT tags ingested by Caspian terns.

1.4.1. Smolt PIT Tag Recoveries

Methods: Estimates of avian predation rate based on smolt PIT tag recoveries on piscivorous waterbird nesting colonies were corrected for the biases associated with PIT tag collision and detection efficiency. PIT tag collision (where tags in close proximity on a colony are rendered unreadable by electronic equipment) was addressed by physically removing and then individually hand scanning tags from the Crescent Island and Goose Island (Potholes Reservoir) tern colonies by passing large magnets, which gather PIT tags, over the colony surface. Detection efficiency was measured by systematically sowing PIT tags on tern colonies (Goose Island [Potholes Reservoir], Dry Falls Dam Island [Banks Lake], Crescent Island, Rock Island, and East Sand Island) throughout the nesting season and then recovering tags after the nesting season. The sowing of test tags was conducted (1) prior to the birds' arrival on colony (March), (2) during egg incubation (May), (3) during chick fledging (June), and (4) once the birds had left the colony following the nesting season (July to August). Detection efficiency estimates were then analyzed relative to the sowing date, thereby describing temporal variation in detection efficiency. Finally, not all smolt PIT tags consumed by terns are deposited on the nesting colony; some proportion of consumed PIT tags is regurgitated by terns while they are not on-colony, for example, during flight or at off-colony loafing areas.

In 2004-2006, we conducted experiments to measure on-colony deposition rates of PIT tags ingested by Caspian terns nesting on Crescent Island. First, we allowed terns to forage on PIT-tagged fish confined to net pen enclosures and then we scanned for those tag codes at the Crescent Island tern colony following the nesting season. Secondly, we captured nesting adult terns on the Crescent Island tern colony and force-fed them PIT-tagged fish and then scanned for those tag codes following the nesting season. Based on these previous studies (see BRNW 2007 for detailed methods), we estimated that the on-colony deposition rate of PIT tags consumed by Crescent Island terns was approximately 63% (± 5%). Where noted, results from the current and previous years were used to correct our predation rate estimates for terns to account for these known sources of bias.

Following the 2009 nesting season, electronic PIT tag detection equipment (antennas and transceivers) were used to detect tags *in situ* that were not physically removed using magnets. Tag recovery efforts at bird colonies in the Columbia River estuary were conducted primarily by NOAA Fisheries (POC, Scott Sebring), while recovery efforts on the Columbia Plateau (e.g., Crescent Island and Rock Island tern colonies) were conducted primarily by OSU/RTR. Personnel from the Grant County Public Utility District (POC, Behr Turner) assisted with PIT tag recovery at the Goose Island Caspian tern colony in Potholes Reservoir.

Results and Discussion: A total of approximately 118,013 unique or newly-discovered PIT tags were recovered on bird colonies in the Columbia River basin in 2009. In addition to PIT tags, 200 radio tags, 260 hydro-acoustic tags, and 22 floy or spaghetti tags were also recovered from bird colonies. Of the 118,013 newly-discovered PIT tags, 91,535 or 77.6% were from 2009 migration year salmonid smolts. All PIT tag codes recovered from bird colonies in the Columbia Basin during 2009 were uploaded to the regional smolt PIT tag database (PTAGIS 2010) and the owners of other fish tags (e.g., telemetry tags) were notified, whenever possible.

East Sand Island Caspian terns – Following the 2009 nesting season, NOAA Fisheries used specially designed electronics (for details see Sebring et al. 2008) to detect 44,635 functional, previously undetected PIT tags on the East Sand Island Caspian tern colony. Of these, 38,336 or 85.9% were from smolts tagged and released during the 2009 migration year (Table 2). Of the test tags sown on the East Sand Island tern colony in 2009 (n = 600), 549 or 91.5% were detected on-colony after the nesting season (Table 3). Detection efficiency ranged from 81.0% for tags sown during the egg incubation period to 98.0% for tags sown post-season. Similar to previous years (2004 to 2008), there was no evidence that detection efficiency increased as a linear function of the date when tags were sown on-colony ($R^2 = 0.329$, $P = 0.429$), indicating differences in detection efficiency are not related to when tags were deposited on the East Sand Island Caspian tern colony.

Crescent Island Caspian terns – Following the nesting season, we detected 8,153 PIT tags from 2009 migration year smolts using both physical and hand-held electronic detection methods (Table 2). In addition to PIT tags, 182 radio tags and 55 hydro-acoustic tags were also recovered on-colony. Of the test tags sown on the Crescent Island tern colony in 2009 (n = 400), 284 or 71.0% were detected on-colony after the nesting season (Table 3). Detection efficiency ranged from as low as 17.0% for tags sown pre-season to as high as 98.0% for tags sown post-season. Similar to data collected during 2004-2008, there was a positive association between the Julian date when test tags were sown and detection efficiency ($R^2 = 0.702$, $P < 0.01$), with tags sown late in the nesting season more likely to be detected than tags sown early in the nesting season. Detection efficiency results suggest that PIT tags from early-migrating smolts that were deposited on the Crescent Island colony by terns are less likely to be detected compared to PIT tags from late-migrating smolts.

Rock Island Caspian terns – Following the 2009 nesting season, we detected 1,268 PIT tags from smolts released during the 2009 migration year (Table 2). Of the test tags intentionally sown on the Rock Island tern colony to measure detection efficiency (n = 100), 84 or 84.0% were detected on-colony after the nesting season (Table 3). Average yearly detection efficiency on Rock Island was lower in 2009 relative to 2008 (ca. 93.0% detection efficiency), but similar to results from 2007 (ca. 88.0% detection efficiency).

Goose Island Caspian terns – Following the nesting season, we detected 2,948 PIT tags from 2009 migration year smolts using both physical and hand-held electronic detection methods (Table 2). In addition to PIT tags, 4 radio tags and 204 hydro-acoustic tags were recovered on the tern colony. Of the test tags sown on the tern colony in 2009 (n = 400), 186 or 46.5% were subsequently detected on-colony post-season (Table 3). There was no evidence of a positive association between Julian date when sown and detection efficiency (R^2 = 0.446, P = 0.332), a finding that differs somewhat from previous years, when a positive linear trend was detected (BRNW 2009). Similar to previous years, however, detection efficiency of pre-season tags was the lowest of the four individual releases, with just 16.0% (n =100) of pre-season tags recovered on-colony.

Banks Lake Caspian terns – A total of 38 PIT tags were detected from 2009 migration year smolts following the nesting season (Table 2). Of the test tags sown on the tern colony in 2009 (n = 100), 67 or 67% were recovered following the nesting season (Table 3). In addition to PIT tags, 20 floy tags were also recovered. Floy tags were from hatchery rainbow trout released into Banks Lake and nearby streams by researchers from Eastern Washington University (Candace Hultberg, pers. comm.). The small number of salmonid PIT tags recovered from the Banks Lake tern colony in 2009 is similar to the number recovered following the 2008 nesting season (52 PIT tags).

Loafing Areas (basin wide) – In addition to finding PIT tags associated with a particular tern colony, tags were also detected at one location where terns and other avian predators are known to congregate or loaf during the nesting season; the lagoon/beach associated with Crescent Island. A total of 258 PIT tags from 2009 migration year smolts were recovered in the Crescent Island lagoon. No measure of PIT tag detection efficiency was available for this loafing area and tags found in this area cannot be associated with a particular bird species (e.g., tern, gull, cormorant, or pelican). The detection of PIT tags at known loafing areas, however, provides empirical evidence of off-colony PIT tag deposition; a source of bias that decreases predation rate estimates to an unknown degree for most bird colonies and species in the Columbia River basin. Other known loafing areas in the Columbia River basin, in addition to the Crescent Island lagoon and Swallows Park (see Section 2.4.2), have been identified, but these areas had either limited bird use (e.g., southern tip of Foundation Island) or were regularly inundated by moving water (e.g., the mouth of the Walla Walla River), a process that buries and/or removes tags and makes them undetectable with conventional methods.

1.4.2. Predation Rates on Smolts

Methods: In collaboration with NOAA Fisheries, we used PIT tag recoveries on Caspian tern colonies to evaluate the relative vulnerability of various salmonid species and run-types to tern predation. PIT tag data were also used to estimate predation rates on threatened and endangered salmonid populations, when sample sizes were sufficient. Preliminary analyses of tags recovered from Caspian tern colonies in 2009, with comparisons to data collected during 2004-2008, are presented here. These data will be analyzed in greater detail – including a multi-year synthesis – in the Final Report for this project, in NOAA Fisheries' Annual Reports, and in articles published in peer-reviewed scientific journals.

We queried the regional PIT tag database (PTAGIS 2010) on 2 February 2010 to acquire data on the species of fish, run of fish (if known), origin of fish (hatchery, wild, or unknown), tagging date, tagging location, and in-river interrogation history for all PIT-tagged fish released into the Columbia River basin in 2009 (defined as 2009 migration year smolts). We calculated predation rates on different salmonid species, run types, and stocks (as defined by NOAA Fisheries' Evolutionarily Significant Units or ESUs), based on the number of released and/or interrogated (PIT-tagged fish detected passing a dam or other structure with interrogation capabilities) fish that were subsequently recovered on downstream bird colonies.

Predation rates were generated for the in-river component of the run (i.e., excludes all PIT-tagged smolts that were transported) and was generally limited to actively-migrating smolts that were last detected within the foraging range of the tern colony (hereafter referred to as "reach-specific" predation rate estimates) during the birds' nesting season (April to August). For the East Sand Island tern colony, this was done by calculating a predation rate for just those PIT-tagged smolts that were interrogated passing Bonneville Dam (located 227 Rkm up-river from East Sand Island), plus those PIT-tagged smolts that were transported and released into the Bonneville Dam tailrace or released from hatcheries below Bonneville Dam. For the Crescent Island tern colony, this was done by calculating a predation rate for just those PIT-tagged smolts that were interrogated passing Lower Monumental Dam (located on the Snake River, 80 Rkm up-river from Crescent Island), Rock Island Dam (located on the mid-Columbia River; 210 Rkm up-river from Crescent Island), and PIT-tagged smolts released into the mid-Columbia River between the confluence of the Snake and Columbia rivers (located 12 Rkm up-river from Crescent Island and including releases into the Yakima River) and McNary Dam (located on the Columbia River, 39 Rkm down-river from Crescent Island). These reach-specific estimates are still minimum predation rates because they do not account for in-river mortality between the interrogation/release site and the vicinity of the tern colony, a distance of upwards of 200 Rkm for particular ESUs and the corresponding tern colony. Reach-specific estimates also assume that predation rates based on smolts using the juvenile bypass are representative of other PIT-tagged smolts that use alternative routes to pass any particular dam (i.e., spillway, powerhouse).

Temporal trends in predation were investigated by using the interrogation date of PIT-tagged fish passing these dams relative to the recovery of PIT tags at downstream tern colonies. Temporal trends in predation by terns were also investigated relative to the estimated fish passage index at the dam, intended to be a gross measure of salmonid smolt availability to terns. Simple modeling techniques (e.g., regression analysis) were also used to evaluate various trends and associations relating to predation of PIT-tagged smolts. Per-capita consumption rates of PIT-tagged smolts were also calculated for each tern colony based on the total number of 2009 migration year smolts recovered on-colony, divided by the number of breeding adults nesting on the colony.

All predation rate estimates presented here were corrected or adjusted for on-colony PIT tag detection efficiency, based on the results of PIT tag detection efficiency studies described above (Section 1.4.1). For reach-specific predation rate estimates, we used the passage timing of smolts at each interrogation site to determine probable capture times (i.e., when the PIT-tagged smolt was likely to have been eaten) and then fit the slope or trend in the detection efficiency data to the capture time to estimate the probability a tag was consumed, but missed by researchers searching the bird colony. This approach ensured that the detection efficiencies used to correct PIT tag recovery rates for particular smolt runs were adjusted for the differences in out-migration timing among various runs. When noted, results for Crescent Island terns were also corrected for PIT tag deposition rates, based on results from a previous study (see BRNW 2007).

Results and Discussion: Approximately 2.5 million PIT-tagged juvenile salmonids were released into the Columbia River basin in 2009 (PTAGIS 2010). The majority of these fish were released into the Snake River (1.8 million), followed by the Columbia River (0.4 million) and upper Columbia River (0.2 million). As in previous years, the smallest numbers of PIT-tagged fish were released into the lower Columbia River below Bonneville Dam (0.03 million) and the Willamette River (0.03 million; PTAGIS 2010), which limits the usefulness of PIT tag recoveries on bird colonies for determining the relative vulnerability of fish originating from these two major parts of the watershed. Of the 2.5 million PIT-tagged juvenile salmonids released in the basin, 71% were Chinook salmon, 20% were steelhead, 5% were coho salmon, 4% were sockeye salmon, and the remaining (< 0.1%) were other species (e.g., sea-run cutthroat) or unknowns (PTAGIS 2010). Most of the PIT-tagged fish were raised in a hatchery environment (77.6%), although wild smolts of many different species and run-types were tagged in 2009 (PTAGIS 2010). Some important exceptions to this were wild sockeye salmon from the Snake River (n = 698), wild steelhead from the Willamette River (n = 0), and wild Chinook salmon from the lower Columbia River (n = 75); these stocks and species are listed as threatened or endangered and information regarding predation by piscivorous waterbirds is lacking. Overall, the total number of PIT-tagged fish released in 2009 was slightly smaller than the number released in 2008 (ca. 2.8 million), but was still higher than the five-year average (ca. 2.2 million during 2004 - 2008; PTAGIS 2010).

East Sand Island Caspian terns – Of the approximately 2.5 million PIT-tagged fish that were released into the Columbia River basin in 2009, 1.5% (n = 38,336) were recovered on the East Sand Island tern colony (Table 2). Of the 38,336 tags recovered, 58.6% were from steelhead, 37.9% were from Chinook salmon (including sub-yearlings and yearlings), 3.0% were from coho salmon, 0.4% were from sockeye salmon, and 0.1% were from sea-run cutthroat trout. Based on predation rates of PIT-tagged smolts, steelhead were the most susceptible salmonid species to East Sand Island tern predation in 2009, with predation rates in excess of 10% for many groups of tagged steelhead (Table 4). Predation rates on wild populations of steelhead (in-river migrants originating up-river of Bonneville Dam) in 2009 (ca. 11.6%) were slightly higher than those observed in 2008 (ca. 9.7%; BRNW 2009) but similar to the four-year average of 11.3% (BRNW 2005, 2006, 2007, 2008, 2009). Hatchery coho salmon smolts that migrated in-river were the next most susceptible to tern predation (ca. 4.7% of PIT-tagged smolts; Table 4), followed Chinook salmon (Table 4). Data from the limited numbers of PIT-tagged fish released into the lower Columbia River (down-river of Bonneville Dam) suggest that predation rates on hatchery-raised fall Chinook (ca. 4.8%) were also relatively high in 2009.

As was the case in previous years, there was evidence that predation rates differed between hatchery and wild smolts, with rates often higher among hatchery fish (Table 4 and Figure 21). Despite these differences, temporal trends in predation rates suggest that weekly predation rates on steelhead and Chinook smolts remained relatively constant throughout the nesting season (Figure 21). One small exception was predation on steelhead smolts, which decreased during the peak passage period in May (Figure 21), a trend that was observed in previous years. Although estimated predation rates on steelhead decreased as fish abundance increased, this should not be interpreted as a decrease in the number of smolts consumed in those weeks, but instead a decrease in an individual fish's probability of being consumed. Finally, the per-capita consumption rate of PIT-tagged juvenile salmonids by East Sand Island terns (2.1 tags per breeding adult) was less by a factor of ~ 8 compared to cormorants and Caspian terns that nested on the Columbia Plateau (16.2 - 16.5 tags per breeding adult; Table 5). This was also the case during 2006 - 2008, when per-capita consumption of PIT-tagged smolts was 3 to 8 times greater for cormorants and terns nesting at colonies on the Columbia Plateau compared to terns nesting at East Sand Island (BRNW 2007, 2008, 2009). This suggests that salmonid smolts comprise a larger proportion of the diet for terns and cormorants nesting up-river relative to the same two species nesting on East Sand Island; a conclusion supported by diet composition of the two species (see Sections 1.3 and 2.3).

Crescent Island Caspian terns – We estimate that a minimum of 0.6% (n = 11,483; adjusted for average on-colony detection efficiency) of in-river migrating PIT-tagged juvenile salmonids released up-river of McNary Dam in 2009 were consumed by Crescent Island terns. Similar to data collected during 2004-2008, steelhead were by far the most susceptible species to predation by Crescent Island terns, with minimum predation rate estimates of 4.8%, 1.6%, and 1.0% for wild, in-river steelhead smolts belonging to the Snake River, Upper Columbia, and Middle Columbia ESUs, respectively (Table 6). These predation rates increased to 7.6%, 2.5%, and 1.6%, respectively, for each listed ESU, once adjusted for both PIT tag detection efficiency and PIT tag deposition. Predation rates on other wild, ESA-listed species were comparatively low (ranging from 0.3%-2.5%; Table 6).

Predation rates on steelhead and Chinook salmon smolts from the Snake River (based on interrogation histories at Lower Monumental Dam) differed with both the abundance of smolts available and passage timing. As was the case in previous years, there was a negative association between predation rates on steelhead and the Lower Monumental Fish Passage Index, with predation rates by Crescent Island terns decreasing as the number of available smolts increased (Figure 22). There was also over-whelming evidence that predation rates changed throughout the season, with predation rates being higher during the later portion of the run for both steelhead and Chinook smolts (Figure 22 and Section 4). The number of smolts available, however, is a covariate with passage timing, as smolt numbers were also lowest during the later portion of the run (Figure 22). Although predation rates decreased as smolt abundance increased, this should not be interpreted as a decrease in the number of smolts consumed. In fact, consumption estimates derived from bioenergetics modeling indicated that within the season the Crescent Island tern colony consumed steelhead in proportion to their availability in-river, with peak consumption coinciding with the peak passage periods in May (see

Section 1.3). In other words, within a given year, evidence suggests that as more smolts become available, more are consumed by terns nesting on Crescent Island.

Overall, predation rates by Crescent Island terns on PIT-tagged smolts traveling through McNary pool in 2009 were similar to, but slightly lower than, those reported in 2008 (BRNW 2008). One notable exception, however, relates to predation on hatchery steelhead from the Snake River ESU, where average predation rates in 2009 (ca. 2.9%) were low relative to 2008 (ca. 4.6%). The reason for this unexpectedly low average predation rate can be tied to the large numbers of PIT-tagged hatchery steelhead released early in the migration period in 2009. For example, over 25% (11,514/43,954) of the hatchery PIT-tagged steelhead interrogated passing Lower Monumental Dam in 2009 came from just two hatcheries on the Clearwater River, and these fish passed the dam during the month of April (before the majority of Crescent Island terns had arrived to nest). The low predation rate on these large groups of early-run hatchery steelhead (ca. ~ 1.0 to 2.0%) highly influenced, and perhaps biases, the seasonal, average predation rate estimate of 2.9%. Passage index data on hatchery steelhead (both tagged and untagged) at Lower Monumental Dam suggests that the majority of hatchery steelhead passed the dam during the month of May, not April (Figure 22). Given all of this, the average hatchery predation rate of 2.9% in 2009 should be interpreted cautiously and compared to the average predation rate obtain from run-of-the-river hatchery steelhead randomly selected for tagging at LMN in 2009 (ca. 5.8% predation rate; see Section 4 for details).

In general, reach-specific predation rates on salmonid smolts by Crescent Island terns (predation on all salmonid species, run-types, and rear-types), have been in decline since 2004. For example, in 2004 predation rates on in-river steelhead were 35.5%, 6.2%, and 6.5% for steelhead smolts (hatchery and wild combined) from the Snake River, Upper Columbia, and Middle Columbia, respectively (corrected for detection efficiency and deposition rate). Comparable rates from these three river segments in 2009 were just 7.6%, 2.5%, and 1.6%, respectively. Lower predation rates in recent years are likely a result of several factors. First, the size of the Crescent Island tern colony has been steadily declining (ca. 34% reduction in number of breeding pairs since 2004). Second, evidence from research during the previous five years suggests that tern predation rates on steelhead smolts are lower in years of high river flows (Antolos et al. 2005; BRNW 2005, 2006, 2007) and/or when large numbers of steelhead migrate past Crescent Island in a relatively short period of time (BRNW 2005, 2008). Passage index data on steelhead from the Snake River in recent years (since 2007) indicates that the vast majority of the run has passed during a two- to three-week period, compared to the more protracted, bimodal run timing observed in years past (e.g., 2004). Finally, it is important to note that although predation rates have declined since peaking in 2004, this does not mean the impact to the over-all population has declined proportionately. This is because the estimates of predation rate apply to the in-river component of each species/run-type and does not include the component of the run that was transported around McNary Pool in barges and therefore not exposed to predation from Crescent Island terns. Since 2004, the number of smolts originating from the Snake River that have been left to migrate in-river has increased dramatically. For example, in 2004 an estimated 3.6% of the Snake River steelhead run remained in-river. This proportion has increased to over 50% of the run since 2007 (NOAA Fisheries, unpublished data). This change in relative availability of smolts in the Snake River helps explains why predation rates by Caspian terns have fluctuated so much from one year to the next.

Unlike juvenile salmonids from the Snake River, smolts originating from the mid- and upper Columbia are not collected above McNary Dam and transported around McNary Pool, making these salmonid runs more susceptible to avian predators in McNary Pool relative to Snake River smolts, especially in years of high transportation for Snake River stocks. Not surprisingly, predation rates on steelhead from these two non-transported ESUs have remained relatively constant compared to predation rates on Snake River stocks; average predation rates ranged from 2% to 6% for mid- and upper Columbia River stocks, compared to predation rates from 3% to 35% for Snake River stocks (BRNW 2005, 2006, 2007, 2008, 2009).

Rock Island Caspian terns – Of the PIT-tagged fish released into the Columbia River basin up-river of John Day Dam in 2009 (excluding transported fish), < 0.1% (n = 1,510 tags; adjusted for average on-colony detection efficiency) were deposited on the Rock Island Caspian tern colony during the nesting season. Similar to the Crescent Island Caspian tern colony, steelhead were the most susceptible salmonid species, with predation rates (based on interrogations of fish passing McNary Dam) averaging 0.6% and 0.5% for wild and hatchery steelhead, respectively. Predation rates on all other species and run-types were < 0.3%, with hatchery Chinook the next most susceptible species and rear-type to predation by terns nesting of Rock Island. Rock Island terns ranked third among Columbia Basin bird colonies in estimated per-capita consumption of PIT-tagged smolts in 2009 (after the Crescent Island tern colony and Foundation Island cormorant colony; Table 5), suggesting that the small size of the Rock Island colony, rather than the prevalence of salmonids in the diet, limits its impact on salmonid smolt survival. Similar low over-all impacts on salmonid survival but high per-capita consumption were documented for this tern colony during 2006 - 2008 (BRNW 2009).

Goose Island Caspian terns – Salmonid PIT tags were detected at the Potholes Reservoir tern colony on Goose Island (~ 45 km east of the Columbia River; Map 3). A total of 2,948 smolt PIT tags from the 2009 migration year were recovered. This number expanded to 6,340 PIT tags when adjusted for detection efficiency (Table 2). Of the tags deposited on-colony, the vast majority were from steelhead smolts (n = 2,077 or 70.1% of all tags). Of the steelhead tags recovered, the majority (n = 2,058 or 99.1%) were from steelhead released into the Columbia River upstream of Priest Rapids Dam. Of the remaining salmonid tags deposited on-colony, 641, 226, and 4 were from Chinook salmon, coho salmon, and sockeye salmon, respectively. We calculated reach-specific predation rates on run-of-the-river smolts captured, tagged/interrogated, and released into the tailrace of Rock Island Dam. Predation rates by Potholes Reservoir terns on PIT-tagged steelhead were far greater than on other salmonid species, with estimated predation rates (adjusted for detection efficiency) of 15.9% and 14.6% for hatchery and wild steelhead, respectively (see Section 4 for a more detailed analysis of steelhead smolts consumed by terns nesting on Potholes Reservoir in 2009). Predation rates were dramatically less for Chinook (ca. 1.3%) and sockeye smolts (ca. 0.3%). Predation rates were higher for coho smolts (ca. 2.3%) than for Chinook or sockeye smolts, but sample sizes of interrogated coho smolts were relatively small (n = 550, with 13 tags deposited on the tern colony).

Predation rates on steelhead smolts by Caspian terns nesting in Potholes Reservoir were surprisingly high and of special concern because these smolts belong to an ESU that is listed as endangered under the ESA. The predation rate estimate of 14.6% was the highest stock-specific predation rate on an ESA-listed salmonid species observed among the piscivorous bird colonies studied in 2009 (including those in the estuary). Research to better quantify the impact of the Potholes tern colony on the Upper Columbia Steelhead ESU in 2008 and 2009 (see Section 4 for details) indicated smolts were susceptible throughout the period when the run was passing Rock Island Dam. Although predation rates were consistently higher on hatchery steelhead, evidence suggests a significant proportion of the wild smolts were consumed by this relatively small, yet growing colony of Caspian terns (ca. 290 nesting pairs in 2008 and ca. 490 nesting pairs in 2009). Data presented on steelhead predation by terns nesting on Potholes Reservoir are, however, preliminary and incomplete until further research and analysis is completed. For example, data presented here are from the second year of a three-year study to investigate avian predation on steelhead from the Upper Columbia Steelhead ESU. Larger sample sizes, data sharing and collaboration (e.g., steelhead behavior and survival data being collected by Grant County and Chelan County PUDs), and study replication will be needed before study results and impacts of avian predation can be fully evaluated (see Section 4 for details).

Banks Lake Caspian terns – Salmonid PIT tags were detected at a small colony of Caspian terns (61 breeding pairs) located on Dry Falls Dam Island in Banks Lake, WA (~ 70 km southeast of the Columbia River; Map 3). A total of 38 smolt PIT tags from the 2009 migration year were recovered on-colony following the 2009 nesting season (Table 2). This number increased to 57 PIT tags when adjusted for on-colony detection efficiency (Table 3). A similar number of PIT tags (n = 52) were recovered following the 2008 nesting season. Similar to results from terns nesting on Potholes Reservoir, the majority of tags (n = 33 or 87%) were from smolts released in the Columbia River up-river of Priest Rapids Dam, with steelhead smolts being the predominant species (n = 28 or 74% of all tags recovered on the tern colony). Of the remaining tags, 8 and 2 were from Chinook and coho smolts, respectively. An estimate of per-capita consumption of PIT-tagged smolts by Banks Lake terns is just 0.5 PIT tags per adult tern, suggesting that Caspian terns nesting on Banks Lake had little impact on the survival of salmonid smolts relative to other tern colonies on the Columbia River Plateau (Table 5). This is likely a result of the distance of this colony from the Columbia River (~ 70 km) and the apparent abundance of forage fish within Banks Lake and the surrounding area.

1.5. Dispersal and Survival of Caspian Terns

Methods: Breeding adult Caspian terns were banded at East Sand Island in the Columbia River estuary and fledgling Caspian terns were banded at East Sand Island and at Crescent Island in 2009. These banding efforts are part of our continuing objective to measure survival rates, post-breeding dispersal, and movements among colonies for Caspian terns in the Pacific Coast population. Adult and fledgling terns were banded with a federal numbered metal leg band and two plastic, colored leg bands on one leg and a plastic leg band engraved with a unique alphanumeric code on the other.

As part of this study, adult terns were captured at East Sand Island (n = 55) for banding using noose mats placed around active nests. Once captured, terns were immediately transferred to holding crates until they were banded and released. Tern chicks that were near fledging were color-banded at East Sand Island (n = 406) and Crescent Island (n = 132). In addition, 37 and 20 smaller chicks were banded only with a federal numbered metal leg band at East Sand Island and Crescent Island, respectively. Tern chicks were captured on-colony by herding flightless young into holding pens. Tern banding operations were conducted only during periods of moderate temperatures to reduce the risk of heat stress for captive terns.

Terns that were color-banded in previous years (2000 – 2008) were re-sighted on various breeding colonies by researchers throughout the 2009 breeding season. Re-sightings of banded terns at other locations were reported to us through our project web page (2000-2007: www.columbiabirdresearch.org; 2008-present: www.birdresearchnw.org), by phone, or by e-mail.

Results and Discussion: In 2009, 564 and 130 previously-banded Caspian terns were re-sighted at the East Sand Island colony and the Crescent Island colony, respectively. These banded individuals were identified to banding year, age class when banded (i.e., adult or chick), and banding location. Of the 564 banded individuals that were re-sighted at East Sand Island, 509 (90%) were banded at East Sand Island (162 as adults and 347 as chicks), 35 (6%) were banded at Crescent Island (8 as adults and 27 as chicks), 9 (2%) were banded as chicks at Dungeness Spit, WA (Map 3), 6 (1%) were banded as chicks at Brooks Island in San Francisco Bay, CA, 4 (0.7%) were banded as chicks at Knight Island in San Pablo Bay (northern San Francisco Bay area; Map 2), and 1 (0.2%) was banded as an adult at the former ASARCO colony in Commencement Bay, WA (Map 3).

Of the 130 banded terns that were re-sighted at the Crescent Island colony, 127 (98%) were banded at Crescent Island (95 as adults and 32 as chicks), 2 (2%) were banded as chicks at Goose Island in Potholes Reservoir, near Moses Lake, WA (Map 3), and 1 (1%) was banded as a chick at East Sand Island.

In addition to these re-sightings, 28 banded Caspian terns were re-sighted at the colony on Dungeness Spit, WA. Of these, 24 (86%) were banded at East Sand Island (4 as adults and 20 as chicks), 2 (7%) were banded as chicks at Dungeness Spit, 1 (4%) was banded as a chick at Crescent Island, and 1 (4%) was banded as an adult at the ASARCO colony.

The age at first reproduction for Caspian terns was reported to be 3 years of age by Gill and Mewaldt (1983). The large cohorts of fledgling Caspian terns produced at the East Sand Island colony in 2001, 2002, and 2003 led to predictions that the East Sand Island colony would increase rapidly in size due to recruitment of these large cohorts into the breeding population within 3 - 4 years. The first confirmed breeding by terns banded as chicks in 2001 and 2002 was noted at East Sand Island and Goose Island in 2006, and the first breeding by a tern banded as a chick in 2003 was confirmed at East Sand Island in 2007. A tern banded as a chick in 2002 at Crescent Island was also confirmed breeding at its natal colony in 2007, the first confirmation of breeding by a tern that was banded as a chick at Crescent Island. Our observations suggest that for this population the average age of first reproduction is currently 5 years of age or older. This delayed onset of breeding, compared to what has been reported in the literature (i.e., Gill and Mewaldt 1983), may be one of the reasons that the East Sand Island tern colony has remained stable in size despite the large cohorts of fledglings produced at the colony during 2001-2003. Other potential factors responsible for the stable colony size at East Sand Island in recent years include (1) lower than expected survival rates for young terns prior to recruitment into the breeding population, (2) higher than expected adult mortality during the non-breeding season, and (3) terns fledged from the East Sand Island colony are recruiting to colonies other than their natal colony.

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, and other factors important in determining the status of the Pacific Coast population of Caspian terns, and whether current nesting success is likely to result in an increasing, stable, or declining population. Moreover, by tracking movements of breeding adult terns among colonies, either within or between years, we can better assess the consequences of various management strategies.

1.6. Implementation of the Caspian Tern Management Plan

1.6.1. Background

The Caspian Tern Management Plan called for the creation of approximately 7-8 acres of new or restored Caspian tern nesting habitat (islands) in interior Oregon (specifically Fern Ridge Lake, Crump Lake, and Summer Lake) and 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 sites. As alternative tern nesting habitat is created or restored, the available tern nesting habitat on East Sand Island would 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 was planned to occur in phases, at a ratio of two new acres of habitat provided for each acre of habitat reduction on East Sand Island. Once fully implemented, the management plan was expected to reduce the East Sand Island Caspian tern colony from its current size (approximately 10,000 nesting pairs) to about 3,125 – 4,375 nesting pairs, or a reduction in colony size of 60% - 70%. A reduction in the size of the East Sand Island Caspian tern colony to 3,125 – 4,375 pairs was 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 indicated that Caspian tern predation rates on juvenile steelhead exceeded those of other salmonid species in the Columbia Basin. The planned reduction in the size of the Caspian tern colony at East Sand Island was expected to reduce annual consumption of juvenile salmonids (smolts) from the Columbia River basin by about 3.0 million fish. Annual consumption of juvenile salmonids by Caspian terns during the period 2000-2009 has averaged approximately 5.5 million smolts per year.

The potential for reduction in Caspian tern nesting habitat at East Sand Island to 1 acre is addressed in the 2006 RODs. Before nesting habitat on East Sand Island could be reduced below 1.5 acres, however, additional alternative sites for tern nesting would need to be developed (the criteria for selection of alternative sites were 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 recently identified as part of this on-going process and environmental assessments were prepared for each site prior to island construction late in 2009 and early in 2010 (see below). A reduction in the size of the East Sand Island tern colony to 2,500 - 3,125 pairs could eventually be accomplished with development of these alternative tern colony sites.

1.6.2. Implementation of Tern Management Initiatives

The USACE and its state and federal partners have so far completed construction of eight islands (a total of 7.3 acres) specifically designed for Caspian tern nesting as part of the Caspian Tern Management Plan (Table 7, Map 2). Two one-acre islands were built prior to the 2008 breeding season (Fern Ridge Lake and Crump Lake), two half-acre islands were built prior to the 2009 breeding season (East Link Management Unit and Dutchy Lake in Summer Lake Wildlife Area), and four additional islands were built prior to the 2010 breeding season (a half-acre island at Gold Dike impoundment in Summer Lake Wildlife Area, a one-acre island at Orems Unit and a 0.8-acre island at Sheepy Lake in Lower Klamath NWR, and a two-acre island at Tule Lake Sump 1B in Tule Lake NWR). Five of the eight islands constructed to date (3.8 total acres of nesting habitat) will be available for tern nesting during the 2010 breeding season; the islands at Gold Dike (Summer Lake Wildlife Area), Orems Unit (Lower Klamath NWR), and Tule Lake Sump 1B (Tule Lake NWR) will not be surrounded by water in 2010 and therefore will be unsuitable for tern nesting during that year. As stipulated in the FEIS and RODs, the amount of habitat prepared for tern nesting on East Sand Island will be reduced from 3.5 acres in 2009 (see Section 1.1) to 3.1 acres in 2010.

In 2009, Caspian terns quickly colonized both of the new islands constructed at Summer Lake Wildlife Area; 8 pairs nested on the floating island at Dutchy Lake and 7 pairs nested at the rock core island in East Link impoundment. Five terns that had been banded in the Columbia River estuary were re-sighted at the Summer Lake tern islands. We continued to monitor two other alternative colony sites constructed by the USACE that were first available for tern nesting in 2008. The Crump Lake tern island in Warner Valley, Oregon, again attracted large numbers of Caspian terns, nearly 700 pairs. Eighteen terns that had been banded in the Columbia River estuary were re-sighted on Crump Lake island. The diet of Caspian terns nesting at Crump Lake and Summer Lake consisted of > 80% tui chub. As in 2008, no Caspian terns nested at the Fern Ridge tern island in 2009, although up to 8 Caspian terns were observed on the island at one time (see www.birdresearchnw.org for further details on the tern colony relocation efforts in 2008-2009).

1.6.3. Future Management Actions

The USACE plans to build at least one island for Caspian terns in southern San Francisco Bay prior to the 2011 nesting season. In partnership with the U.S. Fish and Wildlife Service, the USACE is planning to build a 1-acre island on a former salt pond within Don Edwards National Wildlife Refuge. In partnership with East Bay Regional Parks, the USACE also plans to enhance the habitat on two existing islands in a former salt pond at Hayward Regional Shoreline at a future date, in order to create an additional one acre of suitable nesting habitat for Caspian terns in southern San Francisco Bay. The planned restoration of Caspian tern nesting habitat at Brooks Island in central San Francisco Bay is on hold, pending further analysis of the impact of a potential expansion of the existing 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 main driver behind the plan to relocate a majority of the Caspian terns that currently nest at the colony on East Sand Island in the Columbia River estuary is to increase the survival of juvenile salmonids from throughout the Columbia River basin. There are, however, significant benefits to the Pacific Coast population of Caspian terns that may be realized by implementation of the Caspian Tern Management Plan. Currently, approximately two-thirds of all Caspian terns belonging to the Pacific Coast population nest on East Sand Island. Consequently, the tern population is more vulnerable to local catastrophes (for example, storms, disease outbreaks, oil spills, predation events, human disturbance) than it would be if it were distributed over a broader geographic area and a larger number of nesting sites. Redistributing the existing breeding population of Caspian terns to a number of smaller colonies over a larger geographic area will reduce risks to both terns and Columbia Basin salmonids. Close monitoring of this plan throughout its implementation is necessary to determine whether the intended benefits to both salmonids and terns are realized and, if not, what adaptive modifications to management actions may be warranted to achieve desired results.

SECTION 2: DOUBLE-CRESTED CORMORANTS

2.1. Nesting Distribution and Colony Size of Double-crested Cormorants

2.1.1. Columbia River Estuary

Methods: High resolution aerial photography of the double-crested cormorant colony on East Sand island was taken late in the incubation period in order to estimate the peak size of the colony. Counts of the number of stick nests within delineated boundaries of the breeding colony were conducted by staff in Geospatial Services at the Bonneville Power Administration. In addition, researchers from Oregon State University proofed the counts of stick nests in the photography to improve the precision of the estimate of numbers of breeding pairs.

Boat-based and aerial surveys of 12 navigational markers near Miller Sands Spit and Fitzpatrick Island (river km 38 and 53, respectively; Map 1) were conducted 4 - 6 times monthly from early April through late July in 2009. Because nesting chronology varied among the different channel markers, the number of nesting pairs at each marker was estimated using the greatest number of attended nests observed on each of the markers throughout the season. Any well maintained nest structure attended by an adult and/or chick was considered active. To minimize impacts to nesting cormorants (i.e., chicks jumping from nests into the water when disturbed), we did not climb the navigational markers and check nests to estimate productivity.

A boat-based survey of the Astoria-Megler Bridge (Map 1) was conducted in late May 2009. Our vantage point on the water enabled us to get an exact count of the number of attended nests on the underside of the bridge; however, visual confirmation of eggs and very small chicks was not possible. Any well maintained nest structure that was attended by an adult was considered active, along with any nests containing visible nestlings.

Frequent boat-, land-, and air-based surveys were also conducted to monitor the historical social attraction sites where double-crested cormorants formerly nested on Rice Island and Miller Sands Spit. During these surveys researchers looked for indications of nesting activity by cormorants.

Results and Discussion: Fewer than 100 pairs of double-crested cormorants nested on East Sand Island in 1989. Growth in the breeding population since 1989 has resulted in the East Sand Island colony becoming the largest known colony of double-crested cormorants in western North America (Anderson et al. 2004; L. Wires, University of Minnesota, pers. comm.; T. King, USDA-Wildlife Services, pers. comm.). We estimated that 12,087 breeding pairs (95% c.i. = 11,929 – 12,245 breeding pairs) attempted to nest at East Sand Island in 2009, compared to 10,950 breeding pairs in 2008 (95% c.i. = 10,585 – 11,315 breeding pairs). The size of the East Sand Island cormorant colony peaked in 2007, when nearly 14,000 breeding pairs were present. Although the double-crested cormorant colony on East Sand Island grew steadily and rapidly during the 1990s and the early part of this decade, there is a suggestion that the colony may be approaching an upper limit (Figure 23). The growth of the East Sand Island colony appears to be exceptional among colonies of double-crested cormorants along the coast of the Pacific Northwest, most of which are stable or declining. The available data suggest that much of the early growth of the East Sand Island colony was caused by immigration from colonies outside the Columbia River estuary. More data are needed to assess the extent to which factors limiting the size and reproductive success of colonies throughout the Pacific Northwest are influencing population trends at the East Sand Island colony.

Prior to 1999, cormorants on East Sand Island nested exclusively amongst the boulder riprap and driftwood on the southwest shore of the island. After 1999 they began nesting in satellite colonies in the adjacent low-lying habitat (see Map 5 for distribution of nesting cormorants in 2009). Based on the apparent habitat preferences of nesting cormorants, there is currently ample unoccupied habitat on East Sand Island, which could support further expansion of the colony for the foreseeable future. Despite availability of habitat to support continued colony expansion, bald eagle disturbance and predation, plus the associated nest predation by glaucous-winged/western gulls, may limit the size of the colony in the future.

In 2009, a total of 235 pairs of double-crested cormorants nested on 12 channel markers located in the upper estuary near Miller Sands Spit (n = 8 channel markers) and Fitzpatrick Island (n = 4). In 2008, a minimum of 216 cormorant pairs nested on the same channel markers. Peak nest counts on individual markers were recorded during 13 May - 29 June in 2009. The asynchrony in nesting chronology among the different channel marker colonies was likely due to differences among channel marker colonies in the incidence of disturbance and predation by bald eagles.

In 2009, we again observed double-crested cormorants nesting on the Astoria-Megler Bridge, immediately south of the established pelagic cormorant (*Phalacrocorax pelagicus*) colony on the bridge. During a boat-based census on 31 May, 24 nests were attended by double-crested cormorants. In 2008, 20 nests with attending double-crested cormorants were confirmed during a boat survey in June.

No attempt was made to attract double-crested cormorants to nest on upper estuary islands in 2009.

2.1.2. Columbia Plateau

Methods: Periodic boat-based and land-based counts of attended nest structures were used to estimate the size of the double-crested cormorant colony on Foundation Island in 2009 (Map 4). To improve nest count accuracy and our ability to monitor individual nests, we constructed an observation blind in the water, approximately 25 m off the eastern shore of the island. Nest counts and observations of nest contents were conducted each week from the observation blind in 2009.

Periodic boat- and land-based surveys were conducted at sites where cormorant nesting had been reported previously, such as the mouth of the Okanogan River (referred to as the "Okanogan colony") and in Potholes Reservoir within the North Potholes Reserve (referred to as the "North Potholes colony"; Map 3). At each site we counted attended nests to obtain a rough estimate of the number of breeding pairs at each colony. We also flew aerial surveys along the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, and along the lower Snake River from the confluence with the Clearwater River to its mouth, searching for new double-crested cormorant colonies.

Results and Discussion: In 2009, the double-crested cormorant colony on Foundation Island consisted of a minimum of 310 pairs (Figure 24), the largest cormorant colony on the mid-Columbia River. All nesting at this cormorant colony occurs in trees. During 2003-2006 the Foundation Island cormorant colony gradually grew from about 250 breeding pairs to about 360 breeding pairs, before leveling off and then declining to about 310 breeding pairs in 2009 (Figure 24). Data on colony attendance indicated that, in 2009, the Foundation Island cormorant colony reached its maximum size in early May, as was observed in previous years (Figure 25).

The largest cormorant colony in the entire Columbia Plateau Region in 2009 was on Potholes Reservoir in the North Potholes Reserve, where ca. 810 breeding pairs nested. This is a decline in colony size compared to the previous two years, when ca. 1,000 breeding pairs nested at this colony. As with the Foundation Island colony, cormorants at the North Potholes colony nest in trees, and at North Potholes the trees are flooded for much of the nesting season. Although this colony is the largest of its kind in the region, there is little evidence that these birds commute to the Columbia River to forage on juvenile salmonids, based on the scarcity of salmonid PIT tags beneath the colony.

Based on our counts of cormorant nests at the Okanogan colony, we estimate that there was a minimum of 36 nesting pairs at the colony in 2009, similar to 2008 (33 nesting pairs).

We estimated that 42 breeding pairs of cormorants nested at the colony on Harper Island in Sprague Lake in 2009 (Map 3). This colony apparently first formed in 2008 when an estimated 38 breeding pairs nested on the island. Harper Island is also home to a large California and ring-billed gull colony and a small Caspian tern colony.

Aerial surveys of the lower and mid-Columbia River and lower Snake River revealed no other double-crested cormorant colonies in 2009.

2.1.3. Coastal Washington

Methods: In 2009, we counted cormorant nests on channel markers in Grays Harbor, WA during three aerial survey flights between early May and mid-June. No boat-based surveys of cormorant nesting success were conducted in Grays Harbor during 2009.

Results and Discussion: We counted a total of 90 cormorant nests on six different channel markers during aerial surveys in Grays Harbor.

2.2. Nesting Chronology and Productivity of Double-crested Cormorants

2.2.1. Columbia River Estuary

Methods: Two elevated blinds located in the East Sand Island cormorant colony were used to observe nesting cormorants in 2009 (Map 5). The blinds were accessed via above-ground tunnels to prevent disturbance to nesting cormorants and gulls, as well as roosting California brown pelicans (*Pelecanus occidentalis californicus*), listed as an endangered subspecies until late 2009. In 2009, 162 individual cormorant nests in 6 separate plots were monitored for productivity. Visual observations of nest contents were recorded each week from mid-April through July to determine nesting chronology and monitor nesting success. Productivity was measured as the number of nestlings in each monitored nest at 28 days post-hatching. Cormorant chicks older than 28 days are capable of leaving their nests.

Monitoring of nesting cormorants on channel markers in the upper estuary and on the Astoria-Megler Bridge was conducted periodically (1 – 8 times each month) from a boat.

Results and Discussion: We estimate that 33,844 fledglings (95% c.i. = 31,598 – 36,090 fledglings) were produced at the East Sand Island colony in 2009. This corresponds to an average productivity of 2.80 young raised per breeding pair (95% c.i. = 2.60 – 3.00 fledglings/breeding pair), the highest productivity ever recorded at East Sand Island (Figure 26). Recent improvements in ocean conditions may have contributed to above average nesting success at the East Sand Island cormorant colony. Nevertheless, these results indicate that the size of the East Sand Island cormorant colony is not currently limited by food supply.

Confirmation of eggs in cormorant nests on channel markers and on the Astoria-Megler Bridge was not possible from our vantage on the water, but small chicks (7-14 days post-hatch) were observed on 13 June and 16 June on the channel markers and Astoria-Megler Bridge, respectively, during the 2009 nesting season. These data suggest that nesting chronology was similar at these two sites, and within the range observed at the East Sand Island cormorant colony in 2009. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for either the nests on the upper estuary channel markers or on the Astoria Bridge.

2.2.2. Columbia Plateau

Methods: We monitored 72 cormorant nests at the Foundation Island colony from the observation blind in 2009, employing weekly visits (Map 4). Productivity was estimated from the number of chicks in monitored nests at 28 days post-hatching. Because of the distance of the blind from the colony and our vantage below the elevation of the nests, we assumed that chicks were approximately 10 days old when first observed.

Results and Discussion: Productivity on Foundation Island was moderately high in 2009 (2.13 fledglings/nest), within the range observed in previous years (Figure 27).

2.3. Diet Composition and Salmonid Consumption of Double-crested Cormorants

2.3.1. Columbia River Estuary

Methods: Lethal sampling techniques were necessary to assess the diet composition of double-crested cormorants nesting on East Sand Island. The best method to obtain a random sample of the diet is to collect adult birds commuting toward the colony from foraging areas throughout the breeding season. The target sample size for collections was 5-20 adult fore-gut (stomach and esophagus) samples per week. Immediately after collection, the cormorant's abdominal cavity was opened, the fore-gut removed, and the contents of the fore-gut emptied into a whirl-pak. Each fore-gut sample was weighed, labeled, and stored frozen for later sorting and analysis in the laboratory.

Laboratory analysis of semi-digested diet samples was conducted at Oregon State University. Samples were partially thawed, removed from whirl-paks, re-weighed, and separated into identifiable and unidentifiable fish soft tissues. Fish in fore-gut samples were identified to genus and species, whenever possible. Intact salmonids in fore-gut samples were identified as Chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on otolith[1] and/or genetics[2] analyses. Unidentifiable fish soft tissue samples were artificially digested (work that is ongoing) according to the methods of Petersen et al. (1990, 1991). Once digested, diagnostic bones (i.e., otoliths, cleithra, dentaries, and pharyngeal arches) were removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish soft tissue samples that did not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) were excluded in diet composition analysis. Taxonomic composition of double-crested cormorant diets was expressed as % of identifiable prey biomass. The prey composition of cormorant diets was calculated for each 2-week period throughout the nesting season. The diet composition of cormorants over the entire breeding season was based on the average of these 2-week percentages.

Estimates of annual smolt consumption by double-crested cormorants nesting at the East Sand Island colony were calculated using a bioenergetics modeling approach (after the Caspian tern model described in Roby et al. 2003). We used a Monte Carlo simulation procedure to estimate 95% confidence intervals for estimates of smolt consumption by cormorants.

A major source of uncertainty in past bioenergetics estimates of smolt consumption by East Sand Island cormorants has been colony size across the breeding season (at times other than late incubation, when the colony is censused from aerial photography). In previous years we used estimates of colony size made from blinds or from boats just off shore. Such estimates are limited due to poor visibility of birds behind vegetation, debris, and other birds. In 2008 we implemented a new approach to estimating colony size across the breeding season by expanding the use of aerial photography. In addition to the

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[1] Susan Crockford and staff at Pacific Identifications, Inc. (Victoria, B.C.) conducted the otolith analysis used to identify salmonid species found in diets of piscivorous waterbirds.

[2] Genetic analyses were conducted by NOAA Fisheries (POC: David Kuligowski) at the Manchester Field Station genetics laboratory. Species identifications were carried out by amplifying (PCR) the mitochondrial DNA fragment COIII/ND3 as outlined in Purcell et al. (2004). Samples identified as Chinook salmon were genotyped with 13 standardized microsatellite DNA markers (Seeb et al. 2007). Stock origins of individual Chinook salmon were estimated using standard genetic assignment methods (Van Doornik et al. 2007).

photography taken during late incubation (early June), high resolution aerial photography of the colony was taken approximately every 2 weeks throughout the season, beginning in early May and concluding in early September. In total, aerial photography of the entire cormorant colony was taken nine times (including the late incubation photography). To count active nests in these additional aerial photographs of the East Sand Island cormorant colony (as well as count aerial photography of other colonies of terns, gulls, etc.), we developed a GIS-equipped computer workstation where digitized photos could be viewed and birds counted. Counts of birds in these photos are pending and will be presented in a subsequent report.

Results and Discussion: Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 9% of double-crested cormorant diets (by mass) at East Sand Island in 2009 (n = 133 adult fore-gut samples or a total of 21,830 grams of identifiable fish tissue). The annual proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island has remained relatively stable (ca. 10%) over the last four years (Figure 28). The proportion of salmonids in the diet of East Sand Island cormorants was highest in 1999 (about 25%) and lowest in 2005 (about 2%; Figure 28). The diet of double-crested cormorants, which forage by pursuit diving throughout the water column, at the East Sand Island colony is more diverse (Figure 29) than that of Caspian terns nesting on the same island (Figure 9). On average, anchovy is the single most prevalent prey type for cormorants, followed by various marine and freshwater taxa. In 2009, the prey category "other" consisted of nine different taxa, all less than 6% of the diet, with the exception of stickleback, which was 9% of the diet. The peak in the proportion of salmonids in the diet of double-crested cormorants nesting on East Sand Island in 2009 was in late May, later in the season compared to previous years, and remained relatively high in late June and early July (Figure 30), when primarily subyearling Chinook were being consumed.

Our best estimate of total smolt consumption by double-crested cormorants nesting on East Sand Island in 2009 was 11.1 million smolts (95% c.i. = 7.7 – 14.5 million), the highest annual smolt consumption by cormorants nesting on East Sand Island in the last decade (Figure 31). Annual smolt consumption by double-crested cormorants nesting on East Sand Island has been trending upward since 2003, with the exception of 2005 when smolt consumption was at the lowest level observed since 2003 (Figure 31). For the first time since 2000, estimates of smolt consumption by East Sand Island cormorants are significantly higher than that of Caspian terns nesting on East Sand Island (best estimate = 6.4 million smolts; 95% c.i. = 5.6 – 7.2 million). Of the juvenile salmonids consumed in 2009, we estimate that 74% were sub-yearling Chinook salmon (best estimate = 8.3 million; 95% c.i. = 5.1 – 11.4 million), 12% were coho salmon (best estimate = 1.4 million; 95% c.i. = 1.0 – 1.7 million), 7% were steelhead (best estimate = 0.8 million; 95% c.i. = 0.6 – 1.0 million), 6% were yearling Chinook salmon (best estimate = 0.7 million; 95% c.i. = 0.5 – 0.8 million), and < 1% were sockeye salmon (best estimate = 0.02 million; 95% c.i. = 0.01 – 0.03 million; Figure 32).

Forty-one individual salmonids that were removed from the stomachs of 14 cormorants collected at East Sand Island during 2008 were identified to species and, for Chinook salmon, stock of origin. Steelhead were the most frequent salmonid in the cormorant stomach samples (61% of identified salmonids), followed by Chinook salmon (34%). One Coho salmon and one sockeye salmon were also identified. The Chinook salmon from cormorant stomachs that were identified to stock included Snake River Spring Chinook and Upper Columbia Summer/Fall Chinook. Ongoing collaboration with David Kuligowski at NOAA Fisheries will allow us to more precisely identify the salmonid portion of cormorant diets by processing samples from additional years, as well as samples with genetic materials extracted from bone. This analysis will include the East Sand Island colony site, in addition to other cormorant colonies on the Columbia River (i.e., Foundation Island). These more precise breakdowns of the taxonomic composition of the salmonid portion of the diet will enhance our ability to estimate the numbers of salmonids consumed by species and type using the bioenergetics modeling approach.

2.3.2. Columbia Plateau

Methods: During the breeding season for double-crested cormorants nesting on Foundation Island, we lethally sampled small numbers of adult cormorants commuting back to the colony from a foraging bout during 2005-2009. Because of small sample sizes of collected fore-gut samples and uneven distribution of collected samples across the breeding season within any particular sample year, samples were pooled across years. During 2005-2009, a total of 103 adult cormorants were sampled in five different time periods (n = 14 in late April, n = 37 in early May, n = 17 in late May, n = 20 in early June, and n = 15 in late June). Contents of these collected fore-guts were removed and other tissues were sampled as well. All diet samples were analyzed in our laboratory at Oregon State University to estimate diet composition of cormorants nesting on Foundation Island during 2005-2009 (see section 2.3.1 for description of diet analysis). Taxonomic composition of double-crested cormorant diets was expressed as percent of identifiable prey biomass. The prey composition of cormorant diets was calculated for five 2-week periods during the nesting season. The diet composition of cormorants over the entire 10-week period was based on the average of these 2-week percentages collected during 2005-2009. Bioenergetics estimates of smolt consumption by double-crested cormorants nesting on Foundation Island during 2005-2009 are not yet available and will be presented in a subsequent report.

Results and Discussion: During 2005-2009, a total of 122 fore-gut samples were collected from double-crested cormorants nesting at Foundation Island. The peak in the proportion of salmonids in the diet of double-crested cormorants nesting on Foundation Island apparently occurred in early May and declined thereafter (Figure 33). These diet composition results should be interpreted cautiously, however, because they are based on relatively small sample sizes and pooled across years.

More comprehensive diet composition results and bioenergetics estimates of smolt consumption by Foundation Island double-crested cormorants during 2005-2009 are not yet available and will be presented in a subsequent report.

2.4. Salmonid Predation Rates by Double-crested Cormorants

The same general methods used to calculate predation rates on smolts by Caspian terns (see Section 1.4.2) were used to estimate predation rates by double-crested cormorants. The recovery/detection of smolt PIT tags on cormorant colonies, however, is more difficult than on Caspian tern colonies. Unlike Caspian terns, which nest primarily on bare sand, cormorants nest in a wide array of habitat types, such as in trees, on the ground amongst vegetation and woody debris, on rip-rap, on bridges, and on channel markers. This poses challenges for the on-colony recovery or detection of PIT tags egested by nesting cormorants. To address these challenges, more intensive PIT tag recovery efforts – in regards to sampling effort, the use of newer electronics, and the use of additional test tags to quantify detection efficiency – were used in 2009.

2.4.1. Columbia River Estuary

Methods: Test tags to measure detection efficiency were sown on two different habitat types used by cormorants nesting on East Sand Island: boulder rip-rap (n = 400) and bare sand (n = 600). Tags were sown haphazardly within the two different habitat types, with tags sown at two different times: before nest building (6 April) and immediately following fledging (17 September). Aerial photos of the colony were used to determine what proportion of nesting birds used the two different habitat types (rip-rap vs. sand) during the nesting season. PIT tags were recovered following the nesting season by NOAA Fisheries using hand-held electronic scanners (see Sebring et al. 2008 for details). Estimates of predation rates were generated using the methods described in Section 1.4.2. Predation rates based on PIT tag recoveries were adjusted for detection efficiency, but not deposition rate, and therefore are minimum estimates.

Results and Discussion: The detection efficiency of sown test tags on the cormorant colony averaged 70.4% (Table 3), based on tags sown on rip-rap and bare sand nesting habitats. This value is weighted to account for differences in nesting density in and area of the two different habitat types. This is the highest detection efficiency value recorded for double-crested cormorants on East Sand Island since PIT tag recovery efforts were first initiated in 2000, eclipsing last year's high of 57.0% (BRNW 2009).

A total of 25,270 salmonid PIT tags from 2009 migration year smolts were recovered from the double-crested cormorant colony on East Sand Island by NOAA Fisheries in 2009 (Table 2). Of these tags, 57% were from Chinook salmon (including both sub-yearlings and yearlings), 37% from steelhead, 4% from coho salmon, and 2% from sockeye salmon. As observed in previous years, the relative proportions of PIT tags from different salmonid species recovered on the East Sand Island cormorant colony were similar to the relative proportions of different salmonids PIT-tagged and released throughout the Columbia Basin in 2009 (ca. 71% Chinook, 20% steelhead, 5% coho, and 4% sockeye), suggesting that cormorants consume salmonids in similar proportions to their relative abundance. Some preference towards steelhead is evident in 2009, but due to uncertainties regarding the relative survival of various species and groups of PIT-tagged smolts from their release location to the estuary, the relative proportions of PIT-tagged smolts at release are only rough approximations of relative abundance in the estuary. Nonetheless, the data suggest that cormorants are less selective and more generalist predators compared to Caspian terns, which consume steelhead smolts in much greater proportion to their relative abundance (see Section 1.4.2).

Per capita PIT tag consumption by East Sand Island cormorants was estimated to be 1.5 tags per breeding adult (Table 5), a slight decrease relative to the 1.8 tags per breeding adult observed in 2008, but still dramatically higher than the 0.6 tags per breeding adult observed in 2007 (BRNW 2009). Annual fluctuations in the number of PIT tags detected on bird colonies are due mostly to variation in three factors: (1) the number of PIT-tagged fish available, (2) colony size and productivity, and (3) the preponderance of juvenile salmonids in the diet of avian predators. In 2009 the number of PIT-tagged fish available to cormorants in the estuary was much higher (due to higher release numbers and high in-river survival of tagged fish to the estuary; FPC 2010) than in 2007. This, in conjunction with higher prevalence of juvenile salmonids in the diet, explains the higher per capita consumption of PIT-tagged fish in 2009 and 2008 compared to 2007.

Estimates of predation rates based on PIT-tagged smolts released from barges below Bonneville Dam or detected passing Bonneville Dam (interrogated at the dam's bypass or corner collector) indicate that steelhead, fall Chinook, and sockeye salmon smolts were the most vulnerable to predation from East Sand Island cormorants (Table 4). Results for sockeye salmon, particularly wild smolts, however, are limited by small sample sizes (Table 4). Data from the limited number of PIT-tagged fish that were released downstream of Bonneville Dam indicated predation rates were generally higher on those stocks relative to inland stocks last detected passing Bonneville Dam. For example, predation rates of 15.5% (n = 6,129) and 17.5% (n = 13,722) were observed for hatchery coho and hatchery fall-run Chinook smolts released into rivers within 40 Rkm of the mouth of the Columbia River. Similar data from wild, ESA-listed smolts from the lower Columbia or Willamette rivers are generally lacking because of the very small number of smolts PIT-tagged in these runs.

2.4.2. Columbia Plateau

Methods: In 2009, PIT tags were recovered at the Foundation Island double-crested cormorant colony in order to estimate smolt predation rates. The methods used to generate these estimates were similar to those described for Crescent Island terns (see Section 1.4.2). Double-crested cormorants on Foundation Island nest in trees and test tags (n = 400) to quantify detection efficiency were sown haphazardly under nesting trees on four different occasions: (1) prior to arrival of birds on the colony (12 March), (2) early in the chick-rearing period (21 April), (3) during fledging (8 June), and (4) after the birds had left the colony following nesting (21 July). Predation rates based on recovered PIT tags were corrected for PIT tag detection efficiency, but not deposition rate; consequently, these estimated predation rates are minimums. Furthermore, an unknown proportion of smolt PIT tags are likely retained within the arboreal nests (primarily from small chicks being unable to regurgitate castings outside the nest), a phenomenon that further reduces tag recovery and thus underestimates predation rates for this particular colony.

To address the concern that tag recovery is reduced by tags being retained in arboreal nests, we initiated a study whereby an artificial nesting platform was constructed on Foundation Island to improve our ability to recover PIT tags at this colony. Prior to the 2009 nesting season, we constructed a platform elevated 14 feet above ground level, measuring 6 m x 6 m x 6 m, at the north end of the Foundation Island cormorant colony. The platform, which was covered with sand, contained 30 old tires filled with fine woody debris, and was surrounded by a 10-cm high side wall to prevent PIT tags from blowing or washing off the platform during the nesting season. Large woody debris was added to the platform structure in 2009 in an attempt to provide cover and perching sites for nesting cormorants. Cormorant decoys and two audio playback systems broadcasting sounds from a cormorant colony were used to attract nesting pairs to the platform. PIT tags (n = 50) were spread on the platform to measure detection efficiency.

Results and Discussion: Of the 400 test tags sown under nesting trees on Foundation Island in 2009, 291 or 72.8% were subsequently recovered on-colony after the nesting season (Table 3). Detection efficiency ranged from a low of 65.0% for tags sown during the egg incubation period to a high of 87.0% for tags sown during the pre-season period. For the fifth consecutive year, there was no evidence of a correlation between the Julian date when test tags were sown and detection efficiency ($R^2 = 0.319$, $P = 0.435$), indicating that test tags sown early in the nesting season were just as likely to be recovered as test tags sown late in the nesting season.

For the third consecutive year, no cormorants were attracted to nest on the artificial platform on Foundation Island in 2009. Although it is still unclear why the platform was unsuccessful in attracting nesting pairs, the height of active cormorant nests on the Foundation Island colony in 2009 were slightly higher (ranging from 8 to 20 meters agl) than nests on the platform (all 6 meters agl). Furthermore, arboreal nesting habitat on Foundation Island was not limited, as several unoccupied trees were available to nesting cormorants during the 2009 nesting season. Finally, we know that similar social attraction experiments in the Columbia River estuary (see Section 2.5.1) have demonstrated that it may take several years for cormorants to colonize a new site where habitat enhancement and social attraction have been deployed. There are no plans to repeat this experiment on Foundation Island in 2010.

A total of 7,288 PIT tags from 2009 migration year smolts were recovered on the Foundation Island cormorant colony following the nesting season. These tags represent 0.4% of the in-river PIT-tagged smolts released upstream of McNary Dam. This proportion increased to 0.5% (10,011 PIT tags) once the correction was made for PIT tag detection efficiency. Foundation Island cormorants consumed an estimated 1.2% (1,348/109,643) of the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July 2009. Like Crescent Island Caspian terns, predation rates were higher for Snake River and Middle Columbia Steelhead ESUs (ca. 1.7% for wild fish and as high as 4.0% for groups of hatchery fish) relative to other species and run-types originating up-river of McNary Dam (Table 6). In addition to steelhead, predation was also relatively high on hatchery sockeye from the Snake River ESU (ca. 2.1%) and on Chinook from the Middle Columbia River ESU (ca. 2.3%; Table 6). Of fish originating from mid-Columbia River, most predation was targeted on fish from the Walla Walla River, with predation rates as high as 3.7% for steelhead and 7.3% for Chinook. Predation rates on all other salmonid species and run-types were generally around 1.0% (Table 6). Predation rates on smolts originating from the upper Columbia River, however, were surprisingly low (≤ 0.2% average for all species and run-types) relative to smolts originating from the mid-Columbia River downstream of the confluence with the Snake River.

Despite large seasonal fluctuations in smolt abundance in the lower Snake River, weekly predation rates on steelhead and Chinook salmon smolts (based on interrogation histories at Lower Monumental Dam) remained relatively constant throughout the cormorant nesting season (Figure 22), a trend observed in previous years (BRNW 2009). Weekly predation rates on PIT-tagged steelhead ranged between ~ 2% and 4% throughout the 13-week nesting period (Figure 22), while weekly predation rates on Chinook salmon ranged from ~1% to 2% for most weeks (although predation dropped off to less than 1% for the latter half of the run; Figure 22). Although predation rates on steelhead and Chinook smolts remained relatively constant throughout the nesting season, this should not be interpreted as steady consumption throughout the nesting season. In fact, diet data collected from Foundation Island cormorants indicates that the proportion of salmonids in the diet peaked during the peak period of salmonid out-migration in May (Figure 33), indicating that Foundation Island cormorants consumed more smolts during the peak out-migration period. Seasonal differences in the relative susceptibility of hatchery and wild PIT-tagged fish to cormorant predation were observed, with hatchery smolts often (but not always) preyed upon at higher rates relative to their wild counterparts (Figure 22 and Table 6).

Similar numbers of salmonid PIT tags were deposited on the Foundation Island cormorant colony (10,011 salmonid PIT tags) and the Crescent Island tern colony (11,483 salmonid PIT tags) in 2009, and the two colonies were roughly equal in size (ca. 349 pairs and 309 pairs, respectively). Consequently, estimated per capita consumption of PIT-tagged smolts was very similar for the two breeding colonies: 16.2 PIT-tagged smolts per nesting individual for Foundation Island cormorants and 16.5 PIT-tagged smolts for Crescent Island terns. Similar to results from both 2007 and 2008, per capita consumption rates for PIT-tagged smolts by Crescent Island terns and Foundation Island cormorants were the highest of all bird colonies scanned for PIT tags in the Columbia River basin in 2009 (Table 5). The number of PIT tags recovered and the resultant estimates of predation rates by Foundation Island cormorants are now similar to those of Crescent Island Caspian terns. Prior to the 2007 nesting season, the number of smolt PIT tags recovered on the Foundation Island cormorant colony was 50% to 80% less than the number recovered on the Crescent Island tern colony. The relatively recent increase in the impact of the Foundation Island cormorant colony on survival of PIT-tagged smolts relative to the impact of the Crescent Island tern colony is likely associated with the slow but steady decline in the size of the tern colony (Figure 5) and the relatively stable size of the Foundation Island cormorant colony (Figure 24). Finally, it should also be noted that the proportion of Snake River smolts allowed to migrate in-river was substantially higher from 2007 to 2009 (ca. ~ 50% to 75% of the population) relative to 2004 to 2006 (ca. ~ 3% to 25% of the population).

For the second consecutive year, PIT tags from bull trout (*Salvelinus confluentus*) were found on the Foundation Island cormorant colony. In total, 11 newly discovered bull trout PIT tags were recovered in 2009. In 2008, five bull trout PIT tags were recovered on-colony. All of the tags recovered in 2009 were from bull trout captured, tagged, and released in the Walla Walla River basin. Of the 11 recovered tags from 2009, one fish was released in 2006, two fish were from releases in 2007, seven were released in 2008, and one was released in 2009. In total, 7,502 PIT-tagged bull trout were captured and released into the Walla Walla River basin from 2006 to 2009 (PTAGIS 2010), resulting in a minimum estimate of predation rate of 0.2% (corrected for detection efficiency and assumes 100% annual bull trout survivorship). PIT-tagged bull trout recovered on the cormorant colony ranged from 13 to 30 cm (fork length) at the time of tagging and release. It is unknown, however, how large the fish were when they were actually consumed or where within the river they were consumed (e.g., in the mainstem Walla Walla River, in a tributary of the Walla Walla River, or in the Columbia River).

North Potholes Reservoir Double-crested Cormorant Colony: In 2009, salmonid PIT tags were also recovered from an arboreal colony in Potholes Reservoir, the largest known breeding colony of cormorants in the Columbia Plateau Region (see Section 2.1.2). No test tags were sown at this site; therefore, no measure of detection efficiency exists, although a detection efficiency value of 62% was recorded at this colony in 2007 (BRNW 2008). Following the nesting season, PIT tags were recovered using hand-held electronic scanners and transceivers. The nesting area under which tag recovery occurred contained an estimated 118 nests (a sub-sample of the estimated 809 active nests present in 2009), based on counts of nests after the breeding season. A total 20 tags from 2009 migration year smolts were recovered, including smolts released into the upper Columbia (n = 5), Snake (n = 10), and Yakima (n = 5) rivers. If tags deposited by the 118 pairs scanned are representative of all breeding adults at the colony, a minimum 137 PIT-tagged salmonid smolts were consumed by cormorants at this colony in 2009. This finding suggests that cormorants nesting on Potholes Reservoir had very little impact on survival of anadromous salmonids from the Columbia River basin. Similar results were found in 2007, when only six salmonid tags were detected from a sub-sample of 167 nests.

Swallows Park Double-crested Cormorant Roost: A double-crested cormorant roost located in eastern Washington was scanned for PIT tags in August of 2009. The Swallows Park roost is on the Snake River (Rkm 228) upstream from the confluence with the Clearwater River. Cormorants roost on several large trees that are located on a near-shore island near the Swallows Park boat ramp. In total, 555 PIT tags from 2009 migration year smolts were recovered on the ground beneath the trees used by cormorants. The vast majority (528 or 95.1%) of the tags recovered were from hatchery Chinook salmon. Of these, 103 were from Snake River fall-run Chinook salmon, an ESA-listed species. In addition to smolt PIT tags, one bull trout originating from the

Walla Walla River basin was also detected. No detection efficiency tags were sown on the island; therefore, recovery numbers represent minimums. Counts of cormorants at the Swallows Park roost from November 2009 to February 2010 – a period following the 2009 PIT tag recovery effort– numbered between 89 and 118 individuals. How many cormorants utilized this roost during the winter/spring of 2009, however, is unknown.

2.5. Dispersal and Survival of Double-crested Cormorants

Methods: In 2009, pre-fledging double-crested cormorants were banded at East Sand Island in the Columbia River estuary with a federal numbered metal leg band on one leg and a field-readable plastic leg band engraved with a unique alphanumeric code on the other. This was the first year of a prospective long-term effort to collect information on the survival and movements of double-crested cormorants from the East Sand Island colony and to study dispersal patterns and recruitment of cormorants to other colonies using re-sighting of plastic-banded individuals.

Prior to 2009, double-crested cormorants at East Sand Island had never been banded with field-readable plastic leg bands. Metal banding of pre-fledging cormorants had not been conducted at East Sand Island since 2000, when the US Fish and Wildlife Service discontinued their nighttime banding efforts due to concerns of potential impacts to roosting California brown pelicans, an ESA-listed species (recently de-listed in November 2009. Our banding efforts in 2009 were conducted during daylight to minimize disturbance to California brown pelicans that continue to use East Sand Island as a major night-time roost site.

Cormorant chicks that were near fledging were captured on-colony by herding flightless young into an off-colony holding pen. Once contained in the holding pen, cormorants were individually removed from the pen and banded before being released back onto the colony. Cormorant banding operations were conducted during periods of moderate temperatures to reduce the risk of heat stress for captive cormorants.

Results and Discussion: A total of 82 pre-fledged cormorants were captured, banded, and released at the East Sand Island colony in 2009. In the first year of this effort we established and refined methods for capturing and banding pre-fledging cormorants that will facilitate larger-scale banding efforts in future years. By marking pre-fledging cormorants with field-readable alphanumeric plastic leg bands, we will be better able to track movements and monitor recruitment into the breeding population and recruitment of cormorants to other colonies. Through tracking movements of fledgling cormorants (and adults in future years) among colonies, either within or between years, we can better assess the effect of various potential management strategies, should they be deemed necessary.

2.6. Management Feasibility Studies for Double-crested Cormorants

2.6.1. Techniques to Encourage Nesting

Methods: In 2009, we continued studies to test the feasibility of potential management techniques for reducing losses of juvenile salmonids to cormorant predation in the Columbia River estuary. This study seeks to determine whether habitat enhancement and social attraction techniques can be used to induce double-crested cormorants to nest at alternative colony sites outside the Columbia River estuary where they have not previously nested and, if so, whether these techniques can be used to redistribute some of the double-crested cormorants nesting in the Columbia River estuary to alternative colony sites outside the estuary, if deemed necessary by resource management agencies.

We continued using habitat enhancement (i.e., placement of old tires filled with nesting material) and social attraction techniques (i.e., decoys and audio playback systems; Kress 2000, Kress 2002, Roby et al. 2002) on a floating platform in Fern Ridge Wildlife Area adjacent to Fern Ridge Reservoir, near Eugene, OR (Maps 2 and 3) in 2009. In 2007, we selected Fern Ridge Wildlife Area for this study because it supported significant numbers of cormorants during the non-breeding season and we were able to obtain permission to use a floating platform launched and anchored in the Fisher Butte impoundment cell #2, where public access was limited. A floating platform, about 30 feet long by 15 feet wide, was assembled in 2007 from sections of floating dock material. Plywood sideboards about 30-cm high were attached to the sides of the floating platform to retain material on the platform. Forty-eight old tires were placed on the platform, and sticks and other fine woody debris were placed in each tire for nesting material. The floating platform was anchored in about 1 m of water, about 150 m from the nearest dike. The platform and tires with sticks were left in place after the 2008 season for the third year of the feasibility study in 2009. In late March 2009, 38 hand-painted double-crested cormorant decoys were secured on the platform and two audio playback systems, each with two speakers, were placed on the platform, along with the solar panels and deep cycle batteries necessary to power the audio systems. The platform was checked from the dike once or twice a week until mid-April and weekly or every other week thereafter throughout the season for any signs of cormorant nesting.

Results and Discussion: Cormorants did not attempt to nest on the floating platform and cormorants were not observed perching on the floating platform during the nesting season in 2009. Although small numbers of double-crested cormorants were observed in Fisher Butte cell #2 in late March and April, larger numbers of cormorants (approximately 100 individuals) were only observed in Kirk Pond at the north end of Fern Ridge Lake, and mainly in March and April. Bald eagles were observed in the vicinity of the floating platform in Fisher Butte, and may have deterred prospecting adult cormorants from using the platform. Although public access to the area was largely restricted during the nesting season, human disturbance may have deterred prospecting cormorants from using the floating platform.

Conclusions: Habitat improvements and social attraction (i.e., decoys, audio playback systems) have been shown to be highly effective in inducing Caspian terns to nest at sites where they have not nested previously (Kress 2000, Kress and Hall 2002, Roby et al. 2002, Collis et al. 2002b). Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction to relocate nesting cormorants have shown some promise; cormorants were attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper Columbia River estuary where no previous successful cormorant nesting was known (Miller Sands Spit) or nesting had not occurred in recent years (Rice Island). Although habitat enhancement and social attraction techniques appear effective in establishing double-crested cormorant breeding colonies at sites where nesting attempts have previously occurred, results from the three-year study at Fern Ridge Wildlife Area suggest that habitat enhancement and social attraction techniques may require longer periods to successfully attract cormorants to nest at sites with no prior history of cormorant nesting, especially if no well-established breeding colonies exist nearby.

The efficacy of habitat enhancement and social attraction techniques to establish new double-crested cormorant colonies outside the Columbia River basin remains uncertain. Additional study will be required to fully evaluate this methodology as a means to reduce cormorant predation rates on juvenile salmonids in the Columbia River estuary. Developing methodologies to enhance the size of existing double-crested cormorant colonies, along with reestablishing colonies using habitat enhancement and social attraction techniques at sites where cormorants have historically nested, may be necessary to shift cormorants from the large and growing colony on East Sand Island to alternative colony sites where ESA-listed salmonids are not as susceptible to cormorant predation.

2.6.2. Techniques to Discourage Nesting

Methods: In 2008, we investigated two techniques to dissuade nesting by double-crested cormorants on East Sand Island. The first technique, human disturbance, was used on a discrete portion of the breeding colony and only prior to the onset of egg-laying. The second technique, hazing with a green laser, was used on cormorants that were roosting on beaches adjacent to the colony, and not necessarily nesting. In 2009 we once again tested the efficacy of these two active nest dissuasion techniques, and added a passive technique in the form of habitat modification (i.e., covering a discrete area previously used by nesting cormorants with pond liner). These dissuasion experiments are part of a continuing study to identify effective methods for deterrence of cormorant nesting, should managers decide to limit the number of double-crested cormorants nesting on East Sand Island.

Modifications to last season's efforts to use human disturbance to dissuade cormorant nesting were implemented in 2009. Prior to the initiation of cormorant nesting, a observation blind (see Map 5) was built at the terminus of an above ground tunnel that allowed researchers to access the colony without detection by nesting cormorants. The blind was constructed with one east-facing and one west-facing window, allowing views of the nesting colony in either direction. A visual barrier (a fence of black plastic fabric, 1.5-m tall) was erected in front of the blind, effectively isolating a small section of the eastern-most end of the double-crested cormorant colony, comprising approximately 1,000 cormorant nests in 2007 (ca. 7% of the 2007 colony size). Beginning on 14 April researchers entered the blind daily to actively disturb birds on the eastern-most section of the colony. Prior to each disturbance the number of cormorants that occupied the area near the blind was counted and photos were taken to evaluate the affects of the disturbance on cormorants that occupied both the targeted area of the disturbance and areas nearby (i.e., non-targeted area). Before, during, and immediately following the disturbance the behavior of all cormorants was noted, both in the targeted area and non-targeted area.

The targeted area on the cormorant colony was disturbed when a researcher exited the blind through a hatch at the bottom and emerged onto the cormorant colony. Upon entering the colony the researcher noted the time, the number of birds disturbed, and their initial reaction to the disturbance. The researcher remained on the colony for five minutes, and then re-entered the blind. In order to quantify the effectiveness of human disturbance on the colony, researchers would note the length of time the dissuasion area was abandoned by all cormorants, as well as the time elapsed until 50% and 100% of the birds returned to the dissuasion area. Five minutes after the first cormorant returned to the dissuasion area, a researcher entered the colony once again as described above. In each successive emergence onto the colony, the researcher would increase the time spent on colony. This daily procedure was terminated once cormorants remained off the targeted area for over one hour. Researchers remained in the blind to conduct post dissuasion observations in an attempt to determine the most effective temporal and visual dissuasion methods. In an attempt to keep birds from nesting in the dissuasion area, protocols were altered to focus on techniques that were determined to be most effective. Over the course of the study, the daily frequency and temporal intensity of the disturbances increased in response to the cormorants' apparent habituation to our methods of dissuasion. Disturbances ceased as soon as evidence of egg-laying was detected in the targeted dissuasion area.

In addition to human disturbance, we tested the efficacy of a green laser (LEM50 laser torch) as another form of active dissuasion of nesting double-crested cormorants at selected locations on East Sand Island. Prior to the initiation of any breeding, another observation blind (different from the one mentioned above; Map 5) was built at the terminus of an above-ground tunnel that would allow researchers access to the designated hazing area without detection by nesting cormorants. The blind was constructed with a single large window made of one way glass. Under the window was a 3 inch by 6 inch slot that allowed us to operate the green laser from within the blind and direct it towards the discrete areas within the cormorant colony chosen for this experiment. We targeted an area where ca. 110 cormorant nests were counted in 2008. This area was selected adjacent to other nesting cormorants so that the effectiveness of the laser to dissuade selected individuals could be tested. Beginning on April 15, twice daily (one hour prior to sunrise and civil twilight, respectively), researchers would enter the blind. Upon entering, researchers would record the number of cormorants in the area and note their behavior using a Bushnell Night Vision 26-4050 – Monocular 4 x 50, when necessary.

Thirty minutes prior to sunrise and civil twilight researchers would direct the laser onto the colony and sweep back and forth at the feet of the targeted birds, until the maximum number of birds in the targeted area were flushed. The researcher would record the amount of time the laser was directed on the colony, the number of targeted and non-targeted birds that were disturbed, and their initial reaction. As birds started to return to the area, the researcher recorded the time elapsed before the first bird returned, when 50% of the birds had returned, and when 100% of the birds had returned. Five minutes after the first bird returned, the laser was swept across the target area again. This process was repeated until the area remained free of birds for one hour (or, in the case of the pre-sunrise dissuasion, until daylight prevented the laser from effectively dissuading any birds from the area). Disturbances ceased as soon as evidence of egg-laying was detected in the immediate area.

In 2009, we also tested the feasibility of a passive method to dissuade cormorants from nesting in a specific section of the colony. We selected an area of rip-rap approximately 50 feet by 30 feet in area and covered it with rubber pond liner material (Map 5) in an attempt to dissuade cormorants from nesting by eliminating the structure that cormorants seem to prefer for nest building. In 2008, ca. 80 pairs of cormorants nested in the area where the pond liner was installed. Using two 45-mm thick strips of pond liner measuring approximately 15 feet wide by 60 feet long we were able to essentially "smooth out" a section of the rip-rap previously used by nesting cormorants. In an attempt to smooth out the area, we removed nesting structures, small pieces of driftwood and used a chainsaw to trim the larger driftwood. Large gaps between rocks were filled in so that the area was as level as possible before deploying the pond liner. The two sheets of liner were then laid down, one on top of the other. Sections of 2"x4"s were placed above and below the edge of the two sheets and screwed together using 3-inch wood screws. A 6-inch deep trench was dug along the northern edge of the pond liner, where it was draped down onto the sandy area of the colony, with the edge buried to secure it. The remaining three edges were secured using 10-inch spikes and washers hammered through the material into the larger logs wedged into the rocks. When possible, these logs were set flush with the edge of the pond liner to discourage cormorants from nesting on these undulations. In an effort to further stabilize the pond liner, and to prevent gaps that wind could enter, rocks were piled along the edges for added weight. Additional 10-inch spikes and washers were driven into other areas all over the pond liner to insure it was securely held down. Once securely in place, the pond liner effectively smoothed out the rocky area that was previously prime cormorant nesting habitat. The habitat modification was completed on 2 April, before cormorants arrived on the colony.

Results and discussion: The human disturbance experiment proved to be an effective method of delaying, but not preventing, cormorants from nesting in the targeted area and caused little apparent disturbance to cormorants nesting in areas nearby (i.e., non-targeted areas). Time invested in dissuading birds from the targeted area seemed to be the limiting factor that eventually resulted in cormorants laying eggs in the experimental area on May 15. Although the efforts to disturb nesting cormorants in the targeted area were carried out daily, there was evidence of habituation by targeted cormorant to this disturbance. Also, blind access was limited by the tides (i.e., researchers could not enter or leave the blind during high tide without disturbing large numbers of nesting cormorants and roosting California brown pelicans). This constraint prevented us from disturbing nesting cormorants in the experimental area frequently enough to prevent the onset of egg-laying.

Following the initial appearance of a researcher on the colony the displaced cormorants would circle overhead between one and four times before landing in the water or on a roost further to the west on East Sand Island. We found that the time that it took cormorants to return to the dissuasion area after the researcher re-entered the blind was not associated with the length of time the researcher remained on the colony (5-30 minutes). The disturbance to cormorants nesting in non-targeted areas was minimal. Most disturbances to non-targeted areas were recorded in the initial weeks of the experiment, when cormorants were just beginning to prospect in the areas surrounding the blind. As nesting progressed and birds became more committed to their sites, the number of cormorants that flushed from non-targeted areas declined as a result of our disturbances to the targeted area. Cormorants nesting within 10 meters of the blind on the west side (non-targeted area) were observed to have eggs in early of May (prior to 15 May, when eggs were first laid in the targeted area). This chronology was consistent with the nesting chronology of the rest of the double-crested cormorant colony.

The green laser was effective at flushing cormorants from the targeted areas while used in low light conditions, primarily at dusk, but the effectiveness dropped considerably as light levels increased after sunrise and eventually failed completely to flush cormorants. When using the laser in the evenings it had to be directed at the targeted area between 3-6 times for it to be successful in flushing cormorants. All 14 night disturbances using the green laser were successful at keeping birds off the targeted area for greater than one hour. It was noted that on at least two occasions the targeted area remained clear of birds until the next morning. Although partially successful in flushing cormorants, none of the 13 morning disturbances using the green laser were successful at keeping birds off the focal area for more than one hour. Although the laser was effective at disturbing the birds in low light conditions, there was on average 14 hours and 20 minutes of daylight each day when the birds were not disturbed. The experiment was terminated on 28 April, when an egg was observed in the targeted area, seven days after the first cormorant egg was observed on the colony.

The area of rip-rap covered by pond liner remained free of nesting cormorants for the entire 2009 breeding season. The pond liner was compromised once, however, when a wind storm picked up the southern edge and folded it over on itself, exposing approximately 20 m^2 of rip-rap. The pond liner was quickly re-secured by researchers who entered the colony, and stayed in place for the remainder of the nesting season. It proved a popular place for roosting gulls, Canada geese, and cormorants, but proved unsuitable for nesting. Cormorants did nest up against the edges of the pond liner, and in some cases on the anchoring logs. The lack of nesting structure was apparently the most important factor inhibiting cormorants from nesting on the pond liner. Contributing factors included billowing during south winds and the slippery surface when wet. Birds were seen slipping and falling on the pond liner during wet conditions.

Conclusions: Both of the active disturbance measures that we tested were effective at flushing cormorants, but ultimately failed to prevent nesting. Human disturbance may be an option for effectively deterring cormorants from nesting on part of the colony, if the frequency and intensity of disturbances can be increased. Ultimately, time and resources might limit this method as a cost-effective management strategy for selective dissuasion of nesting cormorants. As expected, the green laser was most effective in low light conditions, but proved ineffective during daylight. The green laser may be effective in dissuading nesting cormorants on East Sand Island if coupled with other methods of dissuasion, but was ineffective when used alone. The passive habitat modification in the form of pond liner was successful at deterring cormorants from nesting in a small area of the cormorant colony throughout the 2009 breeding season.

2.7. Distribution and Diet of Double-crested Cormorants Over-wintering on the Lower Snake River

Unlike Caspian terns, which depart the Columbia Basin during the non-breeding season, some double-crested cormorants over-winter on the Columbia and Snake rivers. Over-wintering cormorants could potentially affect the survival of hold-over fall Chinook salmon smolts, particularly in the lower Snake River. Genetic analysis of salmonid tissues found in cormorant stomachs sampled in 2007 and 2008 confirmed that fall Chinook salmon were present, although they were not the most frequently identified salmonid species and run-type in cormorant diets.

Methods: In 2009 we continued a study initiated in 2008 to determine the distribution, behavior, and diet composition of double-crested cormorants along the lower Snake River during winter. Research in 2008 indicated that several hundred cormorants were over-wintering on the lower Snake River and could potentially be reducing the survival of hold-over fall Chinook salmon in this section of the river. To assess potential impacts, we conducted monthly boat surveys to determine the number, location, and behavior (roosting, foraging, or in-flight) of cormorants on the lower Snake River from November 2009 to February 2010. Boat surveys were conducted on the Snake River from Clarkston, WA to its confluence with the Columbia River near Pasco, WA. This entire 229-km river segment was delineated into five river reaches separated by the four hydroelectric dams on the lower Snake River. At the end of each monthly river survey, approximately 10 cormorants were lethally collected between Lower Monumental and Lower Granite dams (the river reach with the highest numbers of over-wintering cormorants in 2008) in order to assess diet composition. Cormorants were collected returning to two roost sites near Lyons Ferry and Central Ferry, or near loafing areas in the vicinity of these roosts. Fore-gut samples collected from these cormorants were processed and analyzed as described in Section 2.3 of this report.

Results and Discussion: Double-crested cormorants were observed in all five river reaches during the four-month study (Table 8). A seasonal average of 222 cormorants was observed on the lower Snake River, with the highest concentrations of cormorants observed below Ice Harbor Dam, and above Lower Granite Dam (Table 8). Overall, the number of cormorants observed decreased as the winter progressed, followed by an increase in the number of cormorants observed during the last survey in February. The highest number of cormorants was counted on the lower Snake River during the November survey (n = 272) and the lowest number was counted during the January survey (n = 159; Table 8).

At the dams, cormorants used the navigation lock walls, log booms, trash-shear walls, and spillway guide walls to roost and stage before foraging. The maximum number of cormorants counted at each dam varied both spatially (i.e., forebay versus tailrace) and temporally. No cormorants were observed in the Lower Granite Dam forebay and 0 – 9 were observed in the tailrace (based on counts conducted during monthly river surveys). At Little Goose Dam, counts of cormorants ranged from 0 – 14 in the forebay and from 1 – 3 in the tailrace. At Lower Monumental Dam, counts ranged from 0 – 4 in the forebay and from 3 – 17 in the tailrace. Cormorants were most numerous at Ice Harbor Dam, where counts ranged from 1-2 in the forebay, and from 8-70 in the tailrace. More cormorants were observed in the forebay of dams early in the season. The distribution of cormorants at dams relative to areas away from dams also changed as the season progressed, with fewer cormorants observed in close proximity (within 2 Rkm) of the dams later in the winter (Table 9). The majority of cormorants observed during the surveys were several kilometers from the dams, regardless of month (Table 9). Cormorants commonly used bridges, channel markers, trees, and other semi-submerged woody debris in areas away from dams to roost and stage before foraging.

In addition to collecting data on double-crested cormorants, we also enumerated the abundance of other piscivorous waterbirds during each river survey. The most commonly observed piscivorous waterbird species were California and ring-billed gulls (seasonal average = 427), followed by western and Clark's grebes (seasonal average = 232), and double-crested cormorants (seasonal average = 222; Table 10). Smaller numbers of American white pelicans and common mergansers were also observed throughout the course of the study (Table 10).

Based on identifiable fish tissue in foregut samples (n = 35), juvenile salmonids comprised 12.4% by mass of the diet of double-crested cormorants foraging between Lower Monumental and Lower Granite dams during the winter of 2009-10 (Table 11). Centrarchids (sunfish and smallmouth bass) were the most abundant fish type found in foregut samples, representing 29.8% of prey biomass, followed by Catostomids (suckers) at 12.9%, clupeids (juvenile shad) at 12.8%, and salmonids at 12.4% (Table 11). The proportions of different prey types in the diet varied greatly across months in 2009-2010. November and December yielded similar results, with salmonids (ca. 24.1% by mass; Table 11) and clupeids (ca. 25.7% by mass) being the most prevalent prey types. The most prevalent prey types in the January sample were dramatically different, however, with centrarchids (66.6% by mass) the most prevalent prey type, while in the February sample Catostomids (30.7% by mass) were the most prevalent prey type. Spatial differences, however, were not as distinct as temporal differences; similar numbers of salmonids were found in samples collected from cormorants returning to roost sites at both Lyons Ferry and Central Ferry.

The proportion of salmonid smolts found in the diet of cormorants in 2009-2010 was similar to that found in 2008-2009 (ca. 12.5% salmonids by mass; BRNW 2009). In 2008-2009, centrarchids were the most prevalent prey type found in foregut samples (ca. 28.8% of prey biomass; BRNW 2009), which was similar to 2009-2010 (ca. 29.8% of prey biomass). To date, genetic analysis of 14 salmonid smolts found in cormorant fore-gut samples collected in 2007-2008 and 2008-2009 has confirmed that nine of the smolts were fall-run Chinook salmon. All of the Chinook salmon also exhibited a "hold-over" life history, meaning the smolts did not migrate as sub-yearlings and were either going to migrate next spring or were currently spawning as mini-jack adults. In 2009-2010, a total of 17 salmonid smolts were found in cormorant fore-gut samples. Tissue samples from these smolts have been submitted for genetic analysis and results are pending.

In addition to the evidence from soft tissue of salmonid smolts in the diet of cormorants in the 2009-10 samples, several PIT tags and coded wire tags were recovered from fore-gut samples. Of the 15 PIT tags recovered, 14 had reported interrogation histories. Detection data for these tag codes were retrieved from the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fisheries Commission (PSMFC, Gladstone, Oregon; retrieved on 02 March 2010). The majority of the PIT tags were from 2009 migration year hatchery reared fall-Chinook salmon (n = 10). Based on downstream interrogations from September to December of these fish at Lower Granite and Little Goose dams, these ten fish were confirmed as hold-over fall-run Chinook. PIT tags from 2009 migration year Chinook salmon of unknown rear and run were also recovered (n = 3); however, based on the tagging and interrogation history of these fish, they were likely hold-over fall-run Chinook salmon as well. One additional PIT tag from a 2010 migration year spring Chinook was also recovered. Interrogation histories from the tags recovered indicated 10 smolts were detected in the Little Goose juvenile fish bypass system the day prior to or the same day the cormorant was collected. In addition to the recovery of PIT tags, six coded wire tags were found in fore-gut samples, three of which were confirmed fall Chinook salmon. In total, of the 21 salmonid smolts identified, 16 were confirmed fall-run Chinook salmon, and 13 were verified as hold-over fall-run Chinook salmon.

Results from 2007-2010 suggest that moderate numbers of cormorants over-winter in the lower Snake River, and their abundance varies both spatially and temporally. Diet data suggests that salmonids make up a small proportion (< 15%) of cormorant diets, with the majority being fall-run Chinook salmon. In 2009-2010, the proportion of salmonids in the diet of over-wintering double-crested cormorants varied temporally, with salmonids comprising ca. 24% of the diet in November and December and ca. 1% of the diet in January and February.

2.8. Post-breeding Movements and Over-winter Distribution of Double-crested Cormorants nesting on East Sand Island

A two-year satellite-tracking study was conducted in order to investigate post-breeding season dispersal of double-crested cormorants nesting on East Sand Island, the largest breeding colony on the Pacific Coast, and to better understand over-winter distribution of cormorants nesting at East Sand Island and connectivity between cormorant breeding colony sites. During June-July 2008 and 2009, double-crested cormorants that were attending active nests were captured at East Sand Island and equipped with satellite-transmitters.

Methods: During 2008, the initial year of the study, four types of satellite tags and attachment configurations were tested. Battery-powered tags attached using a harness made of Teflon ribbon (Dunstan 1972), and modified by King et al. (2000), proved to be the most reliable technique for tracking double-crested cormorants over-winter (see BRNW 2009 for further details). Thirty-five of these transmitters, with an expected battery life of 12 months, were scheduled to be deployed during the 2009 breeding season. In addition, 3 solar-powered tags with manufacturer modifications to the 2008 design, which yielded poor tracking results, were scheduled for deployment. All satellite-tags deployed in 2009, including attachment materials, weighed approximately 60 grams and were deployed using the same harness design successfully used in 2008. Battery- and solar-powered tags were duty-cycled to collect nighttime roosting locations one and three nights weekly, respectively.

After 30 battery-powered tags had been deployed, a manufacturing defect in the harness loops was found to be causing early harness breakage. Once the defect was discovered, all possible efforts were made to recover the defective tags and replace them with refurbished tags with functioning harness loops. However, not all defective tags could be recovered. The expected harness life and therefore tracking duration of the defective tags could not be predicted, as harnesses on recovered tags showed varying levels of degradation. By the end of the 2009 breeding season, a total of 47 cormorants were equipped with satellite tags (refurbished, $n = 30$; faulty harness loops, $n = 14$; solar, $n = 3$). Combining cormorants tagged in 2008 and 2009, data on post-breeding season dispersal (July- November) were collected from 51 birds (2008: $n = 14$, 2009: $n = 37$) and data on over-winter distribution (November-January) were collected from 39 birds (2008: $n = 6$, 2009: $n = 33$).

Results and Discussion: Satellite-tracked cormorants dispersed during the post-breeding season to use over-winter roost sites near the northern and southern extremes of the range of the Western Population of double-crested cormorants ($n = 51$). Tracking data collected through January 2010 revealed that tagged individuals traveled to roosting locations as far north as the mouth of the Powell River in the northern Strait of Georgia, British Columbia, Canada and as far south as the mouth of the Colorado River, Baja California, Mexico (Map 6). More than 75 roost sites in British Columbia, Washington, Oregon, California, and Baja California were used by tagged cormorants during the post-breeding season, including at least 19 current or historical nesting sites (Map 6). Satellite-tagged cormorants did not travel to interior states (Map 6) and only one individual was recorded east of the Cascade-Sierra Nevada mountain range.

Cormorants began to disperse from the Columbia River estuary in mid-August. All tagged cormorants had left the region by mid-December, with the exception of two individuals that remained resident in the estuary. The most commonly used roost sites outside of the Columbia River estuary were the two estuaries to the north, Willapa Bay and Grays Harbor, which are within 75 km of East Sand Island, (Map 6). At least 76% (39/51) of tagged cormorants used one of these two estuaries as a stopover location for up to 10 weeks before dispersing to other over-winter locations. Nearly half of the tracked cormorants (47%) used interior roosting sites in addition to coastal sites. The majority (95%) of cormorants tracked through the winter (n = 39) traveled to a region and made only local movements within the region (< 20 km) for three or more months during September through January. Cormorants arrived at these over-wintering areas between mid-September and early November. A small proportion of individuals (2/39 (5%)) remained transients during the winter period. One transient individual roosted at multiple locations in the Salish Sea region, including the northernmost roosting location identified (Powell River mouth in the northern Strait of Georgia); the second transient individual traveled south to multiple roost sites in California and Baja California, including the southernmost roosting location of any tagged cormorant (Colorado River mouth in Baja California, Mexico; Map 6).

Double-crested cormorants tagged at East Sand Island mostly over-wintered in one of two regions, (1) the Salish Sea region in northern Washington and southern British Columbia that encompasses the coastal areas and islands from the north end of the Strait of Georgia to the west end of the Strait of Juan de Fuca to the south end of Puget Sound, and (2) interior Oregon and Washington west of the Cascade Mountains, primarily near Portland, Oregon along the Columbia and Willamette Rivers. The Salish Sea and interior regions were used by 41% (16/39) and 28% (11/39) of over-wintering cormorants, respectively. In 2009, one cormorant over-wintered at Tenmile Lake on the southern Oregon coast. In northern California, interior and coastal regions were used by 8% and 5% of over-wintering birds, respectively. Two individuals (5%) remained resident in the Columbia River estuary and one individual over-wintered in the Willapa Bay in southern Washington. Mullet Island at the Salton Sea in southern California was utilized by one cormorant that arrived at this southernmost over-wintering location in late October while nesting activity was on-going at this year-round, but ephemeral, colony.

For double-crested cormorants satellite-tagged in 2008 and 2009, the most commonly used roost site, outside of the two southern Washington estuaries, was Sauvie Island in Portland, Oregon; at least 14% (7/51) of individuals utilized this interior location (which is not a known breeding site) for one or more nights. Regionally, however, the Salish Sea was used by the greatest number of cormorants; at least 41% (21/51) of birds roosted at sites throughout this region during dispersal or overwintering. Cormorants that utilized the Salish Sea region roosted at Bird Rocks (n = 4), Mandarte Island (n = 1), and Drayton Harbor (n = 1), sites that were active breeding colonies during 2008 and 2009, in addition to roosting at historical colony locations such as Viti Rocks (n = 5) and

Westshore Terminal (n = 3). Before reaching the Salish Sea region, one individual roosted near Dahodaalah [rock] and Seal Rock and another individual roosted at Gunsight Rock, locations that are historical double-crested cormorant colony sites along the outer Olympic Peninsula on the northern Washington coast. Tenmile Lake, used by one over-wintering cormorant in 2009, was the only location on the Oregon coast to be identified as a roosting site utilized by cormorants dispersing from East Sand Island. In northern California active breeding sites in San Francisco and Arcata bays were utilized by dispersing and over-wintering cormorants. Additionally, Clear Lake (Lake County) in interior California, an active breeding site when last surveyed in 1999, was used by two individuals. In interior southern California, Mullet Island at the Salton Sea was visited by at least two individuals, one of which over-wintered at this location, while the other continued southward to roost at multiple sites along the Colorado River in Baja California, Mexico.

Conclusions: These tracking data demonstrate direct connectivity between the double-crested cormorant colony at East Sand Island, which has experienced tremendous growth over the last two decades, and colonies to the north (several coastal Washington and Puget Sound colonies) and to the south (several San Francisco Bay colonies and Mullet Island in Salton Sea) that have experienced declines over the same time period. Based on the observed dispersal of satellite-tagged individuals following the 2008 and 2009 breeding seasons, double-crested cormorants from East Sand Island had the greatest connectivity with active and historical colony sites to the north in the Salish Sea region, followed by colonies to the south in northern California. Similar to our satellite-tracking observations, Clark et al. (2006) found the greatest concentration of band recoveries during the migration-winter periods in the greater Puget Sound region. These preliminary tracking results support the suggestion by Clark et al. (2006) that double-crested cormorants from the Columbia River estuary infrequently travel beyond the Cascade-Sierra Nevada Range, resulting in minimal intermixing with interior North American populations. Our data also support the hypothesis that some double-crested cormorants nesting on East Sand Island originated from breeding colonies to the north, which is thought to have contributed to the rapid growth of the double-crested cormorant colony at East Sand Island, at least in the early 1990's, early in colony formation (Carter et al. 1995, Anderson et al. 2004).

SECTION 3: OTHER PISCIVOROUS COLONIAL WATERBIRDS

3.1. Distribution

<u>3.1.1. Columbia River Estuary</u>

Gulls: During land-based, boat-based, and aerial surveys in 2009, breeding colonies of glaucous-winged/western gulls (*Larus glaucescens/occidentalis*) and ring-billed gulls (*L. delawarensis*) were confirmed at several sites in the Columbia River estuary (Table 1). Glaucous-winged/western gulls nested on East Sand Island (ca. 6,200 adults on colony), Rice Island (ca. 1,750 adults on colony), and Miller Sands Spit (ca. 160 adults on colony) in 2009. Ring-billed gulls, which previously nested on Miller Sands Spit (Collis et al. 2002a), are now nesting on East Sand Island (ca. 2,250 adults on colony) and Rice Island (ca. 310 adults on colony) within the Columbia River estuary (Table 1). In total, there were ca. 8,100 adult glaucous-winged/western gulls counted on colonies in the Columbia River estuary in 2009, which is a 15% increase in the number of glaucous-winged/western gulls nesting in the Columbia River estuary compared to 1998 (ca. 7,050) when the last comprehensive survey of gull colonies in the estuary was conducted (Table 1, Collis et al. 2002a). There has been a major increase in the number of ring-billed gulls nesting in the Columbia River estuary since 1998; 2,550 ring-billed gulls were counted in 2009 compared to less than 100 in 1998 (Collis et al. 2002a).

California Brown Pelicans: East Sand Island is the largest known post-breeding night-time roost site for California brown pelicans (*Pelecanus occidentalis californicus*), and the only known night roost for this ESA-listed endangered species in the Columbia River estuary (Wright 2005). In 2009, the first California brown pelicans were observed roosting on East Sand Island on 10 April. The number of brown pelicans roosting on East Sand Island peaked at about 16,850 on 22 July, the largest number of brown pelicans counted on East Sand Island to date. This was also the earliest seasonal peak in pelican numbers roosting on East Sand Island. We observed breeding behavior by brown pelicans roosting on East Sand Island (i.e., courtship displays, nest-building, attempted copulations), but there was no evidence of egg-laying. Bald eagle activity was the most common source of non-researcher related disturbance to brown pelicans roosting on East Sand Island in 2009.

Brandt's and Pelagic Cormorants: A small colony of Brandt's cormorants (*P. penicillatus*) consisting of 44 breeding pairs became established on East Sand Island amidst the double-crested cormorant colony in 2006. This colony grew to 288 and 508 breeding nesting pairs in 2007 and 2008, respectively. In 2009, the East Sand Island Brandt's cormorant colony continued to grow and was estimated at 684 breeding pairs (Table 1). Formerly, a small breeding colony of Brandt's cormorants existed on a pile dike at the western end of East Sand Island, but this site was abandoned in 2006 because of storm damage to the pile dike during the severe winter of 2005-2006. Brandt's cormorants were first documented to nest on that pile dike in 1997, when a few pairs were found nesting there (Couch and Lance 2004).

About 130 breeding pairs of pelagic cormorants (*P. pelagicus*) nested on the Astoria–Megler Bridge in 2009 (Table 1). This is the only site in the Columbia River estuary where pelagic cormorants are known to nest. Pelagic cormorants have been observed nesting on the underside of the southern portion of the Astoria-Megler Bridge since we began surveying the structure in 1999.

3.1.2. Columbia Plateau

Gulls: Based on aerial, boat-based, and land-based surveys along the mid-Columbia and lower Snake rivers during the 2009 nesting season, California or ring-billed gulls were confirmed nesting on six different islands on the Columbia River between The Dalles

Dam and Rock Island Dam: Miller Rocks (river km 333), Three Mile Canyon Island (river km 413), Blalock Island (river km 445), Rock Island (river km 445), Crescent Island (river km 510), and Island 20 (river km 545; Map 3 and Table 1). The large gull colony on Island 18 (river km 553) was abandoned in 2008, due apparently to a combination of coyote predation and human disturbance, and was not re-colonized in 2009. In total, there were ca. 41,700 adult gulls counted on colonies on the mid-Columbia River from The Dalles Dam to Rock Island Dam in 2009, which is a 22% reduction in the number of gulls counted at colonies on the mid-Columbia River compared to 1998 (ca. 53,200), when the last comprehensive survey of gull colonies was conducted (Table 1, Collis et al. 2002a). This decline was largely driven by the reduction in the number of gulls nesting on islands in the Tri-Cities area (Islands 18, 19, and 20; ca. 35,000 gulls and ca. 19,000 gulls counted at colonies on these islands in 1998 and 2009, respectively) and Three Mile Canyon Island (ca. 11,100 gulls and ca. 6,200 gulls counted at this colony in 1998 and 2009, respectively; Table 1, Collis et al. 2002a). Despite this overall decline in the number of gulls nesting on the mid-Columbia River from 1998 to 2009, three colonies increased in size during this time period (Miller Rocks: ca. 2,200 gulls and ca. 6,000 gulls counted on-colony in 1998 and 2009, respectively; Blalock Islands: 0 gulls and ca. 1,600 gulls counted on-colony in 1998 and 2009, respectively; Crescent Island: ca. 4,600 gulls and ca. 8,600 gulls counted on-colony in 1998 and 2009, respectively; Table 1, Collis et al. 2002a). The near doubling in the size of the California gull colony on Crescent Island over the last decade is particularly interesting because there has been a concurrent decline in the size of the Crescent Island Caspian tern colony by about 50%. No gull colonies were detected on the lower Snake River in 2009, nor has there been any confirmed breeding by gulls on the lower Snake River since our research began in 1997 (Collis et al. 2002a). The total number of gulls nesting on the mid-Columbia River in 2009 was nearly equally divided between California gulls and ring-billed gulls (Table 1).

Ring-billed and California gulls were also confirmed to be nesting on Goose Island in Potholes Reservoir, on Harper Island in Sprague Lake, and on Twining and Goose islands in Banks Lake during 2009 (Map 3 and Table 1). In total, ca. 21,500 gulls were counted at these off-river colonies in 2009, which is roughly half the number of gulls counted on colonies located on the mid-Columbia River (Table 1).

American White Pelicans: We conducted boat-based counts of American white pelicans (*Pelecanus erythrorhynchos*) at the colony on Badger Island in the mid-Columbia River each week during the 2009 nesting season (Map 4). Badger Island is the site of the only known nesting colony of American white pelicans in the State of Washington, and the species is listed as endangered by the State. Consequently, the island is closed to both the public and researchers in order to avoid human disturbance to nesting pelicans that might cause pelicans to abandon the colony. Aerial photography was taken of the colony on 18 May during the incubation period in order to estimate colony size. Complete counts of the number of active pelican nests on Badger Island are not possible from the water because most nests are concealed by the thick, brushy vegetation on the island. Most, but probably not all, pelicans present on the island were visible in the aerial photography; however, we could not correct counts from aerial photography to estimate the number of breeding pairs (as with Caspian terns) because we were unable to obtain representative counts of incubating and non-incubating pelicans from the water. Thus counts of adult pelicans from the aerial photos are an index to the number of breeding pairs utilizing Badger Island, rather than a count of nesting pairs. In 2008 we refined the photo count process by using an in-house GIS workstation and conducted 3 independent counts of pelicans at the colony; we continued to use this methodology in 2009. As it was only possible to obtain index counts of adults and juveniles at the Badger Island pelican colony; it was not possible to estimate nesting success (number of young raised per breeding pair).

A mean of 1,754 adult American white pelicans (SE = 19.4) were counted in the aerial photography taken on 18 May. This is a minimum count of adults present on the colony at the time of the photography. The pelicans were divided among three main nesting areas on the island: approximately one third were counted near the middle of the eastern shore of the island, the area of the island where pelicans have nested the longest, another third were scattered among 5 groups to the interior of this area in approximately the middle of the island, and the remaining third were at the nesting area on the upstream end of the island along the eastern bank. The count of 1,754 adult white pelicans recorded in 2009 was the highest total ever recorded at Badger Island; exceeding the count of 1,327 white pelicans in 2008 by 30% (aerial photography was initiated in 2001, when 263 white pelicans were counted on the island; Figure 34). Annual counts of adults in photographs have increased in all years since 2001 with the exception of 2007 (Figure 34).

Our boat-based counts resulted in a maximum count of 260 adults on 8 June, and a maximum count of 144 juveniles on 22 July. Annual maximum counts of juvenile pelicans during boat-based surveys have ranged from 141 – 329 during the period 2002 – 2008.

3.2. Diet Composition

3.2.1. Columbia River Estuary

Gulls: We have not collected diet composition data for gulls nesting in the Columbia River estuary for several years. Our previous research indicated that, in contrast to the gulls nesting at up-river locations (see below), glaucous-winged/western gulls nesting in the Columbia River estuary consumed primarily fish (Collis et al. 2002a). In general, gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. At least some of these fish had been kleptoparasitized (i.e., stolen) from Caspian terns, which nested at the nearby colony on Rice Island throughout the 1990s (Collis et al. 2002a). In 2009, kleptoparasitism rates (proportion of fish delivered by terns to the colony that were subsequently stolen by gulls) for salmonid smolts delivered to the East Sand Island tern colony averaged 8.8%; steelhead smolts were kleptoparasitized at a higher rate (15.4%) than salmon smolts (7.4%). These data indicate that gulls nesting in close proximity to Caspian terns on East Sand Island have an impact on survival of juvenile salmonids by reducing the number of salmonid smolts successfully delivered to the tern colony.

California Brown Pelicans: Brown pelicans feed primarily on schooling marine forage fishes and, near their breeding grounds in southern California, the diet of brown pelicans consists almost entirely of anchovies (Engraulidae) and sardines (Clupeidae; Tyler et al. 1993). There is an abundance of these and other schooling marine forage fishes near East Sand Island (Emmett et al. 2006), and presumably these fish species comprise the majority of the diet of brown pelicans that roost on East Sand Island.

Brandt's and Pelagic Cormorants: As part of this study, we did not collect diet data on Brandt's or pelagic cormorants nesting in the Columbia River estuary. Based on a study conducted in 2000, the frequency of occurrence of juvenile salmonids in the diet of Brandt's cormorants nesting in the Columbia River estuary was estimated at 7.4% (Couch and Lance 2004). Very little is known about the diet of pelagic cormorants along the Oregon Coast (Hodder 2003), but they are believed to forage primarily on marine and estuarine fishes. Due to small colony sizes and the previously-documented diet preferences of Brandt's and pelagic cormorants, the impacts of these birds on survival of juvenile salmonids from the Columbia River basin are expected to be negligible.

<u>3.2.2. Columbia Plateau</u>

Gulls: We have not collected diet composition data from gulls nesting on islands in the lower and middle Columbia River for several years. Our previous research indicated that there were small amounts of fish in general, and salmonids in particular, in the diets of California and ring-billed gulls nesting at up-river colonies in the late 1990's. The only up-river gull colonies where juvenile salmonids were found in diet samples were the California gull colonies on Little Memaloose Island (15% of total biomass from stomachs; this colony is no longer extant) and Miller Rocks (3% of total biomass). Gulls from these colonies were known to prey on juvenile salmonids in the tailrace of The Dalles Dam (J. Snelling, OSU, pers. comm.). Gulls from other up-river colonies may occasionally prey on juvenile salmonids when available in shallow pools or near dams (Ruggerone 1986; Jones et al 1996), but our results in the late 1990's suggested that at the level of the breeding colony, juvenile salmonids were a minor component of the diet.

California gulls that nest at the periphery of the Caspian tern colony on Crescent Island may have a negative effect on survival of juvenile salmonids because some individuals kleptoparasitize (i.e., steal) juvenile salmonids from terns as they return to the colony to feed their mates and young. Breeding adult terns may catch one to several fish on a successful foraging trip. Of these fish, the majority are consumed by the adult away from the colony in order to meet the adult's own energy requirements. A minority of the fish captured by a breeding adult tern is brought back to the colony to feed its mate (pre-chick rearing) or young. These fish are subject to kleptoparasitism by gulls. In 2009 kleptoparasitism rates on salmonid smolts delivered by terns to the Crescent Island colony averaged 17.5%. As was observed at East Sand Island, kleptoparasitism rates were higher on steelhead smolts (23.3%) than on salmon smolts (13.5%), suggesting that gulls prefer, or find it easier, to steal larger fish. These rates are useful in evaluating the relative vulnerability of different smolts to gull kleptoparasitism, but they are not representative of the proportion of all smolts caught by terns that were stolen by gulls. Therefore, empirical data on the cumulative impacts on smolt survival associated with gull kleptoparasitism are not available. Given that (1) California gulls nesting at Crescent Island significantly out-number Caspian terns nesting there, and (2) gulls kleptoparasitize only a small portion of the smolts captured by adult terns nesting at the colony (most smolts captured by terns are immediately consumed by the tern and thus not available for gulls to steal), it is unlikely that smolts kleptoparasitized by gulls fulfill more than a small fraction of the food and energy requirements of the Crescent Island gull colony.

Finally, smolt PIT tags that were recovered from several gull colonies on the Columbia Plateau in 2009 corroborate our conclusion that the majority of gulls nesting at up-river locations pose little risk to salmonid survival (Collis et al. 2002a), with the possible exception of the California gulls nesting on Miller Rocks and Crescent Island (Table 5; see Section 3.3).

American White Pelicans: We do not collect data on diet composition of American white pelicans nesting on Badger Island because of the conservation status of this species in Washington. Based on smolt PIT tag detections on the white pelican colony, however, pelicans do not appear to be a significant source of smolt mortality (Table 5; see Section 3.3). Despite this, the Badger Island white pelican colony appears to be growing and there is an increasing number of non-breeding white pelicans along the Columbia and Snake rivers, where they are often observed foraging below mainstem hydroelectric dams (Tiller et al. 2003, author's unpublished data) and at sites in the Yakima River basin (A. Stephenson, Yakima Klickitat Fisheries Project, pers. comm.), presumably foraging on out-migrating juvenile salmonids. The total impacts of breeding and non-breeding white pelicans on survival of juvenile salmonids from some runs are not well understood.

3.3. Salmonid Predation Rates

Gulls: Salmonid PIT tags were recovered from five different gull colonies in the Columbia River basin in 2009: (1) Crescent Island (Rkm 510 in the McNary Pool; Map 4), (2) Three Mile Canyon Island (Rkm 414 in the John Day Pool), (3) Miller Rocks (Rkm 333 in The Dalles Pool; Map 3), (4) Rice Island (Rkm 34 in the Columbia River estuary), and (5) East Sand Island (Rkm 8 in the Columbia River estuary; Map 1). These gull colonies were scanned for PIT tags because prior research indicated they were relative large, stable breeding colonies, known to consume juvenile salmonids (Collis et al. 2001). Tag recovery at Rice, East Sand, and Three Mile Canyon islands was limited to plots or sub-sections of the colony, while tag recovery efforts at the other colonies were colony-wide (i.e., the entire surface area occupied by birds during the nesting season was scanned). With the exception of Three Mile Canyon Island, test PIT tags were sown (n = 200 per colony) prior to and immediately following the nesting season to measure detection efficiency. In addition to nesting colonies, one previously un-scanned gull loafing area on the Clearwater River in western Idaho (Lower Hog Island) was also visited. Similar to the analytical approach used for Foundation Island cormorants, estimates of predation by gull colonies were adjusted for bias due to PIT tag detection efficiency, but not for deposition. As such, estimates of predation rates from PIT tag recoveries are minimums.

Results and Discussion: In total, 9,610 PIT tags (adjusted for detection efficiency) from 2009 migration year smolts were deposited on the five different gull colonies 2009 (Table 2). The largest number (n = 5,509) was found on the Miller Rocks gull colony in The Dalles pool (Table 2). Of the tags recovered on Miller Rocks, 96% were attributed to nesting California gulls (ca. 5,272 adults) and the remainder to a smaller colony of ring-billed gulls (ca. 744 adults). The second largest number of tags was recovered from the Crescent Island gull colony (n = 2,531; Table 2). A sub-sample of the Three Mile Canyon Island gull colony (57% of the colony) yielded 188 PIT tags from 2009 migration year smolts. If the sub-sampled area was representative of the colony at large, a minimum of 330 salmonid PIT tags were deposited by the entire colony during the nesting season. Scanning a small sub-sample of the Rice Island and East Sand Island gull colonies yielded 13 and 4 tags, respectively (Table 2). Tags from these two colonies, however, were from relative small plots (< 5% of the colony), so the small number is not indicative of colony-wide impacts on smolt survival. Finally, only five 2009 migration year smolt tags were recovered from the Lower Hog Island gull loafing area on the Snake River, near Clarkston, WA.

Estimates of per capita consumption of smolt PIT tags were three times higher for gulls nesting on Miller Rocks (ca. 0.6 tags per adult) compared to gulls nesting on Crescent Island (ca. 0.2 tag per adult) and ≥ 10 times higher than for gulls nesting on Three Mile Canyon Island (ca. 0.04 tags per adult; Table 5), a colony located just 81 Rkm upstream of Miller Rocks in the John Day Pool (Map 3). Comparisons of per capita consumption rates for gulls nesting on the Columbia Plateau suggest that gulls consume far fewer PIT-tagged fish per capita compared to nearby tern and cormorant colonies (Table 5). The overall number of nesting gulls on these colonies, however, far exceeds that of terns and cormorants on the Columbia Plateau, and this should be taken into account when evaluating impacts on the survival of juvenile salmonids. Counts of the total number of gulls that nested on Rice Island and East Sand Island were not available, but counts of nesting gulls were made within the plots or sub-sections of the colony to generate per capita consumption estimates. Estimates of per capita PIT tag consumption were 0.2 (second highest of the five gull colonies examined in 2009) and 0.1 for Rice Island and East Sand Island gulls, respectively (Table 5). In 2008, a per capita PIT tag consumption rate of 0.9 tags per adult was recorded for gulls on Rice Island, indicating that gulls in the estuary are consuming some salmonid smolts. The small number of gull nests scanned in the estuary, however, prohibits a more in-depth analysis.

Of the gull colonies studied in this region in previous years (see Collis et al. 2001), both Miller Rocks and Crescent Island gull colonies were identified as colonies that consumed salmonid smolts in relatively high numbers compared to other gull colonies in the region (e.g., Three Mile Canyon and Island 20). Predation of juvenile salmonids by Crescent Island gulls is associated with nesting Caspian terns, from which the gulls kleptoparasitize fish, while smolt predation by Miller Rocks gulls is solely from the gulls foraging on smolts themselves. Data from 2009 suggests that California gulls, not ring-billed gulls, are consuming the most smolts; per capita consumption rates by California gulls were 3.5 times higher than that of ring-billed gulls on Miller Rocks. For the third consecutive year, the number of smolt PIT tag found on Miller Rocks has increased. These data suggest that the Miller Rocks colony may have a significant negative effect on survival of salmonid smolts, especially when compared to other gull colonies in the region. None-the-less, the impacts are far less compared to those of the Caspian tern and double-crested cormorant colonies in the region.

American White Pelicans: Smolt PIT tags were recovered from the Badger Island American white pelican colony in order to estimate impacts to salmonid smolts in 2009. The methods used to generate these estimates were similar to those described for Crescent Island terns (see Section 1.4.2) and Foundation Island cormorants (see Section 2.4.2). Test PIT tags (n = 200) were sown on both the southern and northern nesting areas on 12 March (prior to the nesting season) and on 11 November (several months after the nesting season). Test tags could not be sown on Badger Island during the nesting season, as white pelicans are very sensitive to human disturbance on the colony. PIT tags were recovered in November 2009, after birds had completely left the island following the breeding season. Similar to the analytical approach used for Foundation Island cormorants, predation rate estimates from the Badger Island pelican colony were adjusted for bias due to PIT tag detection efficiency, but not for deposition rate. Consequently, estimates of fish consumption and predation rates from PIT tag recoveries are minimums.

Results and Discussion: Of the 200 test tags sown on the Badger Island pelican colony in 2009, 85.0% were subsequently recovered on-colony (Table 3). There was some evidence of a difference between detection rates of tags sown pre-season (ca. 76.0%) and post-season (ca. 94.0%), although eight months elapsed between the two release periods which reduces the influence of time because smolts were only available to pelicans on Badger Island for roughly four of the eight months (April to July).

An estimated 2,061 PIT tags (corrected for detection efficiency) from 2009 migration year smolts were deposited by pelicans on Badger Island during the nesting season (Table 2). These tags represent < 0.1% of all the PIT-tagged fish released into the Columbia River basin upstream of McNary Dam (excluding transported fish). Overall, Badger Island pelicans consumed just 204 (0.2%) of the PIT-tagged smolts interrogated passing Lower Monumental Dam on the lower Snake River from 1 April to 31 July. Estimated predation rates by Badger Island pelicans were similar to those of gulls on Crescent Island and the second lowest rate among bird colonies studied in McNary Pool during 2009 (Table 6). Data suggest that sub-yearling Chinook salmon from the Middle Columbia River ESU (not listed) were the most vulnerable (ca. 1.1% predation rate) to white pelicans nesting on Badger Island, followed by spring/summer Chinook from the Middle Columbia River (ca. 0.6%; Table 6). The estimated per capita consumption rate of PIT-tagged salmonid smolts by Badger Island pelicans (ca. 0.7 tags per adult) also suggested that the effects of white pelicans on survival of juvenile salmonids are very low compared to most other piscivorous waterbirds investigated as part of this study (Table

5). Similar results and conclusions were drawn from the analysis of PIT tag recovery data from the white pelican colony during 2004-2008 (BRNW 2009), although it should be noted that the number of PIT tags recovered on the colony continues to increase each year in concert with the growing size of the breeding colony of American white pelicans on Badger Island (Figure 34).

In addition to smolt PIT tags, at least 13 tags from adult salmonids were deposited by pelicans on Badger Island in 2009. Three adult sockeye (tagged at the Bonneville fishway in June 2009), two jack Chinook (tagged at the Bonneville fishway in May and June 2009), two pre-spawn, adult steelhead (tagged at the Bonneville fishway in June 2009), and six post-spawn (kelt) adult steelhead (tagged at the Lower Granite Dam bypass or Roza Dam from April to June) were recovered on-colony. The largest tagged adult salmonid consumed was a 680 mm wild steelhead kelt. Also of note were three PIT tags from bull trout tagged in the Walla Wall River basin that were detected on Badger Island in 2009. To our knowledge, this is the first time a bull trout PIT tag has been recovered on a pelican colony in the Columbia River basin (to date, bull trout PIT tags have only been found in double-crested cormorant colonies).

Brandt's Cormorants: PIT tags were recovered at the East Sand Island Brandt's cormorant colony in order to estimate impacts on juvenile salmonids. The methods used to generate these estimates were similar to those described for double-crested cormorants nesting on East Sand Island (see Section 2.4.1). Test PIT tags (n = 100) were spread on 6 April (prior to the nesting season) and on 17 September (following the nesting season). Electronic scanning for PIT tags during the post-season was guided by aerial photographs of the Brandt's cormorant colony taken during the nesting season and by an examination of individual nest contents taken during scanning. Brandt's cormorants use grasses and other small materials to build their nests, while double-crested cormorants use sticks and larger woody debris, thereby making it possible to visually determine which species used a particular nest. Similar to the analytical approach used for East Sand Island double-crested cormorants, estimates of salmonid predation rate from Brandt's cormorants were adjusted for bias due to PIT tag detection efficiency, but not for off-colony deposition. As such, estimates of predation rates from PIT tag recoveries are minimums.

Results and Discussion: A total of 176 PIT tags (corrected for a detection efficiency of 83.0%; Table 3) from 2009 migration year smolts were deposited by Brandt's cormorants on East Sand Island in 2009. Per capita PIT tag consumption estimates were just 0.1 tags per adult cormorant (Table 5), one of the lowest per capita estimates from an avian colony scanned in 2009. By comparison, per capita consumption of PIT-tagged smolts by double-crested cormorants on East Sand Island was 1.5 tags per adult (Table 5). After accounting for differences in colony size, PIT-tagged salmonid smolts were 11.6 times more likely to be consumed by a double-crested cormorant compared to a Brandt's cormorant nesting on East Sand Island in 2009.

The results presented here provide evidence that Brandt's cormorants consumed far fewer salmonid smolts than Caspian terns and double-crested cormorants nesting on East Sand Island in 2009. Both the number of PIT-tagged smolts consumed and per capita PIT tag consumption rates were substantially lower for Brandt's cormorants relative to other piscivorous waterbirds in the estuary and in the Columbia River basin as a whole (Table 5). Several factors may account for this. First, with just 684 nesting pairs, the Brandt's cormorant colony is a relatively small breeding colony, especially in the context of other waterbirds nesting on East Sand Island. Secondly, the nesting chronology of Brandt's cormorants differs from that of Caspian terns and double-crested cormorants in the estuary, with colony attendance peaking in late June, compared to mid May for Caspian terns and early June for double-crested cormorants. This difference in nesting chronology may be important because by late June the peak of the smolt run has passed, especially for large groups of PIT-tagged steelhead and yearling Chinook (Figure 21). Thirdly, differences in salmonid smolt consumption between Brandt's cormorants and other piscivorous waterbirds nesting on East Sand Island may be attributed to differences in foraging behavior and diet composition. Brandt's cormorants are considered a truly pelagic seabird that readily forages for prey in the open ocean, a location where non-salmonid prey types (e.g., anchovy, Pacific herring, smelt, and others) are common. Consequently, it is likely that salmonid prey types make up a smaller proportion of the diet of Brandt's cormorants compared to that of Caspian terns and double-crested cormorants, although empirical data to support this hypothesis are lacking. Finally, relative to double-crested cormorants, Brandt's cormorants are a smaller (by weight) cormorant, with a lower daily energy requirement.

SECTION 4: STEELHEAD SUSCEPTIBILITY STUDY

In 2009 we continued a study initiated in 2007 to investigate how smolt morphology, condition, and origin might influence smolt susceptibility to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with decreasing physical condition of the fish. We also hypothesized that river conditions and dam operations may be linked in some way to smolt susceptibility to avian predators. Data collected as part of this research will help regional fishery managers identify and potentially address those intrinsic and extrinsic factors that influence smolt susceptibility to avian predators. Steelhead were selected as the model species for this study because prior research has shown that they are the most susceptible to predation by birds nesting on the Columbia River (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005). The benefits of using steelhead for this study are three-fold: (1) we were likely to recover a sufficient number of PIT tags from steelhead on bird colonies along the Columbia River to address a multitude of predation-related questions (more so than any other salmonid species or run), (2) the incidence of morphological abnormalities (e.g., external symptoms of disease, de-scaling, parasites, body injuries, etc.) tends to be greater in steelhead relative to other salmonid species (USACE, unpublished data), and (3) a better understanding of those factors responsible for the higher susceptibility of steelhead to avian predation will help resource managers implement measures to reduce avian predation on ESA-listed steelhead ESUs, if warranted and feasible. In addition, the tagging of steelhead as part of this study has the benefit of refining estimates of smolt predation rates (see Sections 1.4, 2.4, and 3.3) on run-of-the-river fish, including fish of varying conditions, origins, and stocks that constitute the Snake River and Upper Columbia River Steelhead ESUs.

Data presented for 2009 are preliminary and incomplete until further analysis is completed. For example, we are still compiling and analyzing environmental data regarding river conditions and dam operational strategies. Additionally, we have only completed the second year of a three-year study on the Upper Columbia River Steelhead ESU. Results from this study should be considered preliminary at this time and will be fully analyzed in the project's final comprehensive report (tentative completion date of January 2011) and in peer-reviewed journal publications.

Methods: From 5 April through 4 July 2009, run-of-the-river steelhead smolts were collected and PIT-tagged at juvenile fish collection facilities located at Rock Island Dam, Lower Monumental Dam, and Ice Harbor Dam. At the Rock Island Dam juvenile fish facility, steelhead were sampled 6-7 days per week for 11 weeks starting in early April and ending in mid-June. At the Lower Monumental Dam juvenile fish facility, steelhead were sampled 5-7 days per week for 13 weeks starting in early April and ending in early July. Steelhead were sampled 1-2 days per week at Ice Harbor Dam, from mid-April to mid-June. Sampling at all locations was terminated when steelhead numbers were too low for productive sampling.

Steelhead were PIT-tagged, measured (mm, fork length), weighed (g), photographed, and placed in a recovery tank, where they were held up to 20 hours before being released into the dam's tailrace. Two general release times, morning and night, were used at each of the three release locations to account for possible circadian effects on passage and predation susceptibility. To reduce handling time, digital photographs were taken of each side of the steelhead, which allowed for a subsequent detailed classification of external conditions by type and severity. We assessed the incidence and severity of different anomalies (e.g., externally visible physical damage, disease, and parasite load) for each tagged fish. In addition, each fish was assigned to one of three overall condition ranks: good, fair, or poor. These condition rankings were based on the presence, prevalence, and severity of all the various anomalies observed in each fish and are defined as follows: good = no noticeable external damage, de-scaling < 10%; fair = minor external damage, de-scaling 10% – 50%; poor = open body injuries, external symptoms of disease (fungal, bacterial, or viral infections), parasite infestations, or de-scaling > 50%.

As described in Section 1.4.1, piscivorous waterbird colonies were scanned for PIT tags following the breeding season. Recoveries of PIT tags on bird colonies above McNary Dam were used to determine if susceptibility to avian predation varied by external condition of steelhead tagged in this study. We focused on testing for associations between the external condition of fish and susceptibility to avian predation from birds nesting at colonies closest downstream from release locations (above McNary Dam), as we were not able to track potential changes in smolt condition later in out-migration. Logistic regression was used to evaluate whether the probability of recovering a particular steelhead PIT tag on a bird colony was associated with individual fish characteristics, including external condition. In-river survival of steelhead from release to the vicinity of downstream bird colonies was calculated by using downstream detections of fish at McNary Dam, John Day Dam, Bonneville Dam, and a net-mounted detector deployed by pair-trawlers in the Columbia River estuary. Survival estimates to McNary Dam, John Day Dam, and Bonneville Dam were generated using the Cormack-Jolly-Seber models in Program MARK (White and Burnham 1999). Predation rates were adjusted for bias due to PIT tag detection efficiency, but not for deposition rate; therefore, estimates of predation rates presented here are minimums.

Results and Discussion: A total of 16,810 steelhead were tagged and released from Lower Monumental Dam (n = 6,990 hatchery-raised smolts and n = 1,295 wild smolts), Ice Harbor Dam (n = 1,258 hatchery and n = 158 wild), and Rock Island Dam (n = 5,148 hatchery and n = 1,961 wild) in 2009. Sampling efforts were conducted in concert with the run-at-large, with the largest numbers of fish tagged (n = 8,729 or 51.9% of all tagged fish) during the peak migration period of 10 May to 2 June (a period encompassing 81.0% of the run enumerated while passing Lower Monumental and Rock Island dams in 2009). Overall (all release sites combined), 65.6% of the steelhead PIT-tagged as part of the study were classified as in good condition, 22.0% were in fair condition, and 12.4% were in poor condition. A variety of external anomalies were evident in steelhead ranked in poor condition, including body injuries (55.6%), de-scaling (24.0%), and external symptoms of disease (16.6%). Steelhead ranked in fair condition primarily suffered from superficial body abrasions (62.5%) and moderate de-scaling (51.0%). Conversely, external damage among fish in good condition was limited to minor patches of de-scaling (6.4%).

Of the 7,109 steelhead tagged and released from Rock Island Dam on the mid-Columbia River, 1,127 (15.9%) were subsequently recovered on a bird colony in the Columbia River basin. This number increased to 1,804 (26.7%) when corrected for detection efficiency. Avian predators consumed a minimum of 27.9% of the hatchery-reared steelhead and 23.8% of the wild steelhead that we tagged and released from Rock Island Dam in 2009 (Table 12). Impacts from avian predation were evident from the large numbers of smolt PIT tags recovered on the East Sand Island tern colony in the Columbia River estuary, the Crescent Island tern colony in McNary Pool, and the Goose Island tern colony in Potholes Reservoir (Table 12). Recoveries of steelhead on the Goose Island Caspian tern colony at Potholes Reservoir (an off-river colony) were notable, with estimated predation rates of 15.9% and 14.6% for hatchery-reared and wild steelhead smolts, respectively (Table 12). Additionally, predation rates by Goose Island terns in 2009 (15.5% of PIT-tagged steelhead released at Rock Island Dam) were higher than 2008 estimates (7.7% of PIT-tagged steelhead; Figure 35). The higher predation rates by Goose Island terns in 2009 corresponded with an increase in the size of the Caspian tern colony at Goose Island, with an estimated increase of 197 breeding pairs compared to 2008. Overall, the magnitude of predation rates by Goose Island terns surprising because of the small size of the Goose Island Caspian tern colony (487 breeding pairs) and the distance of this colony from the Columbia River (nearest distance = 45 km). After accounting for changes in the numbers of PIT-tagged steelhead available to avian predators within a given reach or segment (based on estimated mortality of steelhead during in-river out-migration), however, the greatest impact from avian predation on

Upper Columbia River steelhead occurred in the Columbia River estuary, where an estimated 18.3% of steelhead that survived to the estuary was consumed (Figure 36). Conversely, predation by gulls and American white pelicans nesting on islands in McNary Pool was relatively minor (ranging from 0.1% to 1.2%) in comparison to that by Caspian terns and double-crested cormorants nesting in the same reach (Figure 36). For steelhead PIT-tagged and released into the tailrace of Rock Island Dam, survival-adjusted (or reach specific) estimates of predation rates by piscivorous colonial waterbirds were 18.3% by waterbirds from colonies in the Columbia River estuary, 15.5% by waterbirds nesting at Potholes Reservoir, 4.6% by waterbirds from colonies in McNary Pool, and 0.8% by waterbirds from colonies in The Dalles and John Day pools (Figure 36).

Of the 9,701 steelhead tagged and released from Lower Monumental and Ice Harbor dams on the lower Snake River, 1,553 (16.0%) were subsequently recovered on a bird colony in the Columbia River basin. This number increased to 1,970 (19.7%) when corrected for detection efficiency. Avian predators consumed a minimum of 19.8% of the hatchery-reared steelhead and 19.5% of the wild steelhead released from Lower Monumental and Ice Harbor dams in 2009 (Table 12). Similar to steelhead smolts from the Upper Columbia ESU, avian predation on Snake River steelhead was much higher for Caspian terns and double-crested cormorants nesting at McNary Pool colonies relative to gull and pelican colonies (Table 12). Survival-adjusted estimates of avian predation rates indicated that 15.7%, 9.1%, and 1.9% of steelhead released below Lower Monumental Dam were consumed by colonial waterbirds nesting in the Columbia River estuary, in McNary Pool, and in John Day/The Dalles pools, respectively (Figure 36). Caspian terns nesting on East Sand Island consumed the largest percentage of available Snake River steelhead (11.5%), followed by Caspian terns on Crescent Island (6.1%), and cormorants on East Sand Island (4.3%; Figure 36). Weekly estimates of avian predation on Snake River steelhead indicated within-season susceptibilities across the three years of this study were similar. For example, estimated weekly predation rates on Snake River steelhead by Crescent Island Caspian terns indicated that steelhead migrating in June and July were more susceptible to tern predation compared to steelhead migrating earlier in the season (Figure 35). Increased susceptibility of late season migrants was also evident in weekly predation rates on Upper Columbia River steelhead by Goose Island Caspian terns (Figure 35).

Preliminary results from 2009 indicated that susceptibility of smolts to avian predation was associated with external condition and morphology of steelhead smolts. PIT tag detections on bird colonies located up-river of McNary Dam indicated that avian predation was partially condition dependent, with diseased or injured steelhead more likely to be consumed than steelhead with little or no external evidence of injuries or disease (Figure 37). For example, steelhead in fair condition were 1.2 times (95% c.i.: 1.0 – 1.3 times; $P = 0.02$) more likely to be detected on bird colonies located above McNary Dam than steelhead in good condition. Similarly, steelhead in poor condition were 1.3 times (95% c.i.: 1.1 – 1.5 times; $P < 0.01$) more likely to be consumed by an avian predator above McNary Dam than steelhead in good condition. Specific external symptoms associated with increased avian predation susceptibility included body injury severity ($P = 0.001$, df = 2), external symptoms of disease (fungal, viral, or bacterial infections; $P = 0.06$, df = 2), and severity of de-scaling ($P = 0.15$, df = 2; Figure 37). In addition to condition-dependent susceptibility to avian predation, there was also evidence of an association between fish size and susceptibility to avian predation. Steelhead fork length, specifically a quadratic function of fork length, was associated with steelhead susceptibility to tern predation (all tern colonies in the Basin). This result indicates that steelhead susceptibility to tern predation was greatest for steelhead with fork lengths of 190-210 mm, but decreased for longer or shorter smolts ($P < 0.01$, based on a simple least squares regression; Figure 38). This quadratic relationship between fork length and susceptibility was also detected for double-crested cormorants. Results from 2009 indicated susceptibility to cormorant predation was greatest for steelhead with fork lengths of 220-230 mm, but decreased for longer or shorter steelhead ($P < 0.01$, based on a simple least squares regression; Figure 38). Although this quadratic relationship was significant in 2009, in previous years of this study cormorants demonstrated the ability to consume steelhead smolts across the entire range of available fork lengths, including some of the largest steelhead smolts tagged in this study (> 340 mm). Conversely, no steelhead tagged by this study that was > 300 mm has ever been recovered on a Caspian tern colony.

A comparison of avian predation rates on steelhead ESUs from the Snake River vs. the Upper Columbia River indicates similar susceptibilities between groups once they reach McNary Dam, with predation rates very similar for tern, cormorant, and gull colonies downstream of McNary Dam (Figure 36). This result suggests that these two steelhead ESUs (Snake River and Upper Columbia) experience similar predation intensities from downstream bird colonies. Conversely, large differences in avian predation rates were observed between Snake River and Upper Columbia steelhead ESUs by avian predators nesting up-river from McNary Dam (Figure 36). These differences were primarily associated with the unexpectedly high predation rate on Upper Columbia steelhead by Caspian terns nesting on Potholes Reservoir (Table 12 and Figure 36) and by high predation rates on Snake River steelhead by terns and cormorants nesting on islands in McNary Pool (Table 12 and Figure 36). Interestingly, only one of the steelhead released from Lower Monumental or Ice Harbor dams was recovered on the Potholes tern colony and only six of the steelhead released from Rock Island Dam were deposited on the Foundation Island cormorant colony (Table 12).

Detections of returning adult steelhead at Bonneville Dam indicated that 397 or 1.7% of the 23,524 PIT-tagged steelhead smolts released in 2007 and 2008 have returned as adults. Preliminary results suggest that the probability of returning as an adult is associated with external conditions during smolt out-migration. PIT tag detections of returning adult steelhead at Bonneville Dam in 2008 and 2009 indicated that steelhead smolts released in good condition were 1.8 times (95% c.i.: 1.4 – 2.3 times; $P < 0.001$) and 2.2 times (95% c.i.: 1.5 – 3.2 times; $P < 0.001$) more likely to return as adults compared to steelhead smolts released in fair or poor condition, respectively. Inter-annual differences in adult returns were also detected in Snake River steelhead. Steelhead smolts PIT-tagged and released at Lower Monumental and Ice Harbor dams in 2008 were 4.0 times more likely to return as adults compared to steelhead released in 2007 (95% c.i.: 2.9 – 5.6 times; $P < 0.001$). This inter-annual difference may become even more pronounced after the 2010 migration year, because steelhead released in 2007 have returned in 2008 (n = 24 one-salt adults) and 2009 (n = 16 two-salt adults), while steelhead released in 2008 have so far only returned in 2009 (n = 204 one-salt adults). Additionally, we found no differences in adult returns between Upper Columbia and Snake River steelhead released in 2008 ($P = 0.61$), with 2.1% (n = 153) of Upper Columbia and 2.2% (n = 204) of Snake River steelhead returning as adults in 2009. Additional adult returns of steelhead evaluated by this study will enhance our understanding of how individual smolt characteristics and condition are associated with mortality factors and adult returns of ESA-listed steelhead ESU's.

SECTION 5: SYSTEM-WIDE OVERVIEW

5.1. Population Trajectories for Colonial Piscivorous Waterbirds

The numbers of Caspian terns nesting in the Columbia River basin have remained fairly stable over the past decade. In contrast, the numbers of double-crested cormorants nesting on East Sand Island have nearly doubled during the same period to ca. 12,100 breeding pairs by 2009, the largest known breeding colony of double-crested cormorants in western North America (Figure 23). Despite apparently ample unused nesting habitat for double-crested cormorants on East Sand Island, the size of the colony in 2008 and 2009 has not equaled or exceeded colony size in 2007. Productivity at the East Sand Island cormorant colony has been high the last few years (Figure 26), suggesting that some other factor(s) has limited the increase in size of this cormorant colony. Similarly, the size of the double-crested cormorant breeding population on the Columbia Plateau has stabilized or even declined in the last few years, despite unused suitable nesting habitat and good nesting success at both the Foundation Island and North Potholes colonies. Productivity at both the East Sand Island and Foundation Island cormorant colonies has been consistently higher than productivity at Caspian tern colonies, whether in the estuary or on the Columbia Plateau.

In 2008, the U.S. Army Corps of Engineers began implementing the management actions outlined in the Final EIS (FEIS) and the Records of Decision (RODs) for Caspian tern management in the Columbia River estuary, a plan to redistribute a portion of the East Sand Island Caspian tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California by 2015 (USFWS 2005, 2006). A substantial increase in the numbers of nesting Caspian terns along the mid-Columbia River as a result of management to reduce the numbers of Caspian terns nesting in the estuary is unlikely due to the paucity of suitable nesting habitat for terns in that region.

Based on recent nesting success and the apparent availability of suitable habitat at a number of colony sites in the Columbia River basin, it is possible that the double-crested cormorant breeding population will resume the expansion that was observed during the early part of this decade, while numbers of Caspian terns nesting in the estuary and up-river will decline as management is implemented on East Sand Island. The trajectories of the American white pelican colony on Badger Island and the California brown pelican night-time roost on East Sand Island seem to steadily increasing, although neither species appears to be a significant mortality factor for juvenile salmonids from the Columbia River basin. The trajectories of the various gull colonies along the Columbia River are variable, with some increasing dramatically over the last decade (e.g., Miller Rocks and Crescent Island) and others declining just as dramatically (e.g., Richland islands, Three Mile Canyon Island). Overall, the breeding populations of ring-billed gulls and California gulls on the Columbia Plateau appear to have declined somewhat in the last decade. In contrast, the population of glaucous-winged/western gulls in the Columbia River estuary has increased slightly in the last decade.

5.2. Relative Impact of Avian Predators on Salmonid Smolt Survival

Caspian terns that nest on Crescent Island in the mid-Columbia River had the highest proportion of juvenile salmonids in their diet, much higher than Caspian terns or double-crested cormorants that nest at the much larger colonies on East Sand Island in the Columbia River estuary. Nevertheless, a system-wide assessment indicates that the most significant impacts of avian predation on survival of juvenile salmonids from the Columbia River basin occur in the estuary. Caspian terns and double-crested cormorants nesting on East Sand Island together consumed ca. 6-18 million smolts annually during 2003 – 2009 (based on the sum of the best estimates of total smolt consumption in each year). The magnitude of avian predation in the Columbia River estuary represents about 5-15% of all juvenile salmonids that reach the estuary during out-migration. Estimated smolt losses to piscivorous colonial waterbirds that nest further up-river are more than an order of magnitude less than losses due to avian predation in the estuary. Additionally, when compared to the impact of avian predation on smolt survival further up-river, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids from every ESA-listed stock in the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary. For these reasons, management of Caspian terns and double-cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other colonies of piscivorous waterbirds. The Caspian tern colonies on Crescent Island and on Goose Island (Potholes Reservoir) and the double-crested cormorant colony on Foundation Island may be exceptions to this rule; management of these small, up-river colonies may benefit certain salmonid stocks, particularly the Snake River and Upper Columbia ESUs of steelhead.

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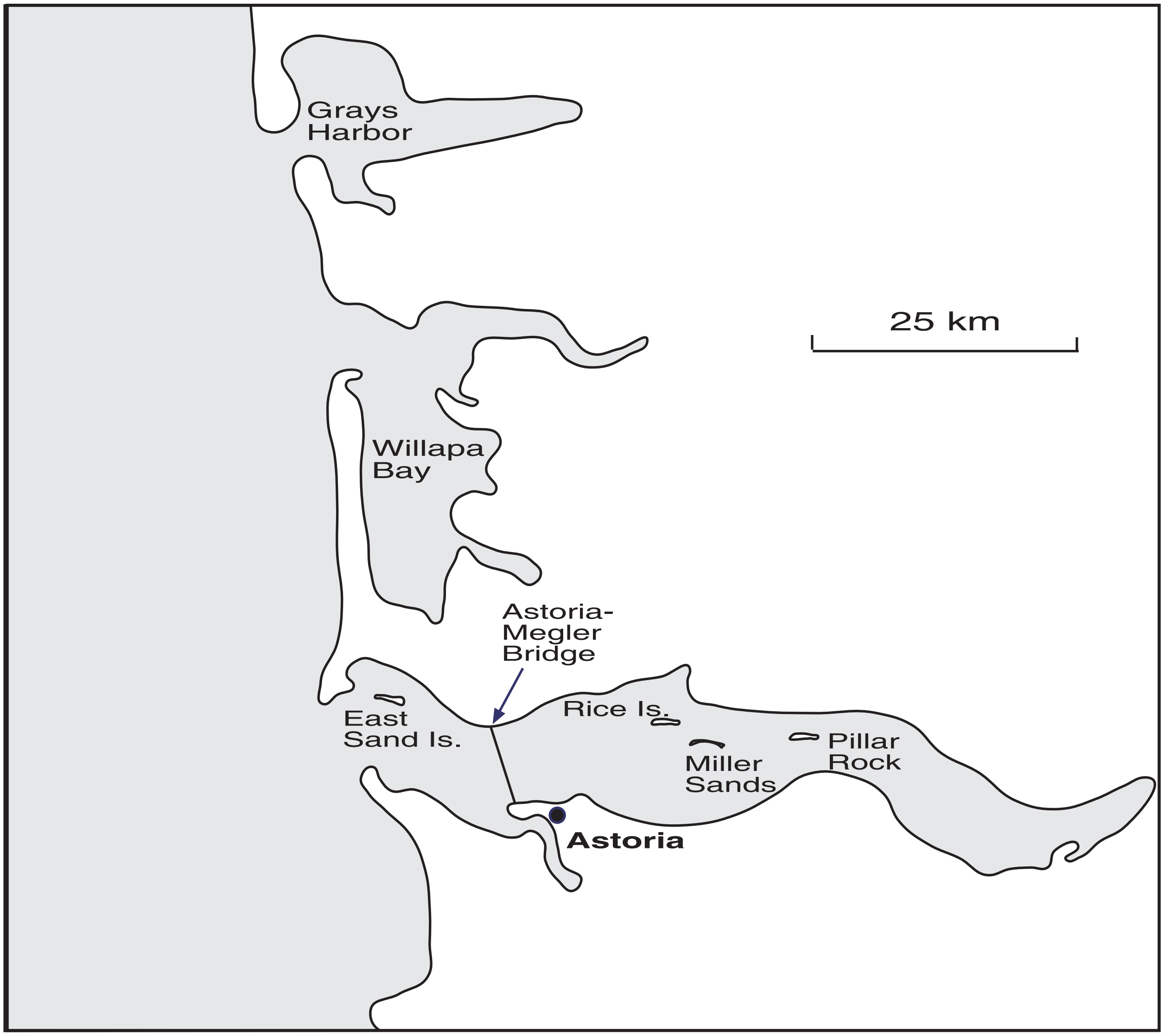
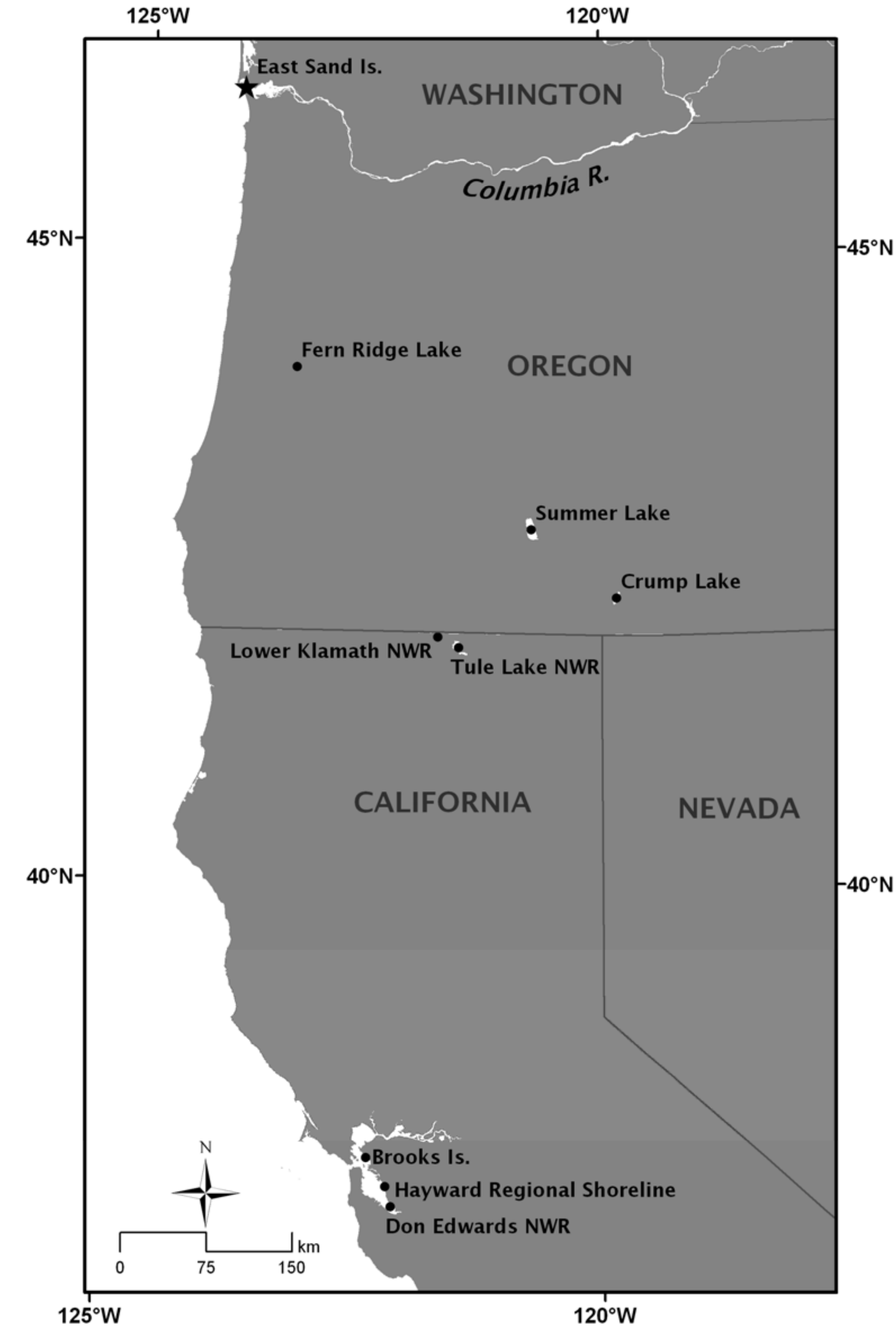
	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian terns			
1.1. Preparation and Modification of Nesting Habitat in the CRE		x	
1.2. Nesting Chronology, Colony Size, and Productivity			
1.2.1. Columbia River Estuary	x	x	
1.2.2. Columbia Plateau	x		x
1.2.3. Coastal Washington		x	
1.3. Diet Composition and Salmonid Consumption			
1.3.1. Columbia River Estuary	x		
1.3.2. Columbia Plateau	x		x
1.4. Salmonid Predation Rates			
1.4.1. Smolt PIT Tag Recoveries	x		x
1.4.2. Avian Predation Rates on Smolts	x		x
1.5. Dispersal and Survival	x	x	
1.6. Caspian Tern Management Plan			
1.6.1. Background	x	x	
1.6.2. Management Initiative Implemented in 2008		x	
1.6.3. Future Management Actions		x	

	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Double-crested Cormorants			
2.1. Nesting Distribution and Colony Size			
2.1.1. Columbia River Estuary	x	x	
2.1.2. Columbia Plateau			x
2.1.3. Coastal Washington		x	
2.2. Nesting Chronology and Productivity			
2.2.1. Columbia River Estuary	x		
2.2.2. Columbia Plateau			x
2.3. Diet Composition and Salmonid Consumption			
2.3.1. Columbia River Estuary	x	x	
2.3.2. Columbia Plateau			x
2.4. Salmonid Predation Rates			
2.4.1. Columbia River Estuary	x		
2.4.2. Columbia Plateau			x
2.5. Dispersal and Survival		x	
2.6. Management Feasibility Studies			
2.6.1. Techniques to Encourage Nesting		x	
2.6.2. Techniques to Discourage Nesting		x	
2.7. Distribution and Diet of Double-crested Cormorants Over-wintering on the Lower Snake River			x
2.8. Post-breeding Dispersal and Over-winter Distribution of Double-Crested Cormorants on East Sand Island		x	

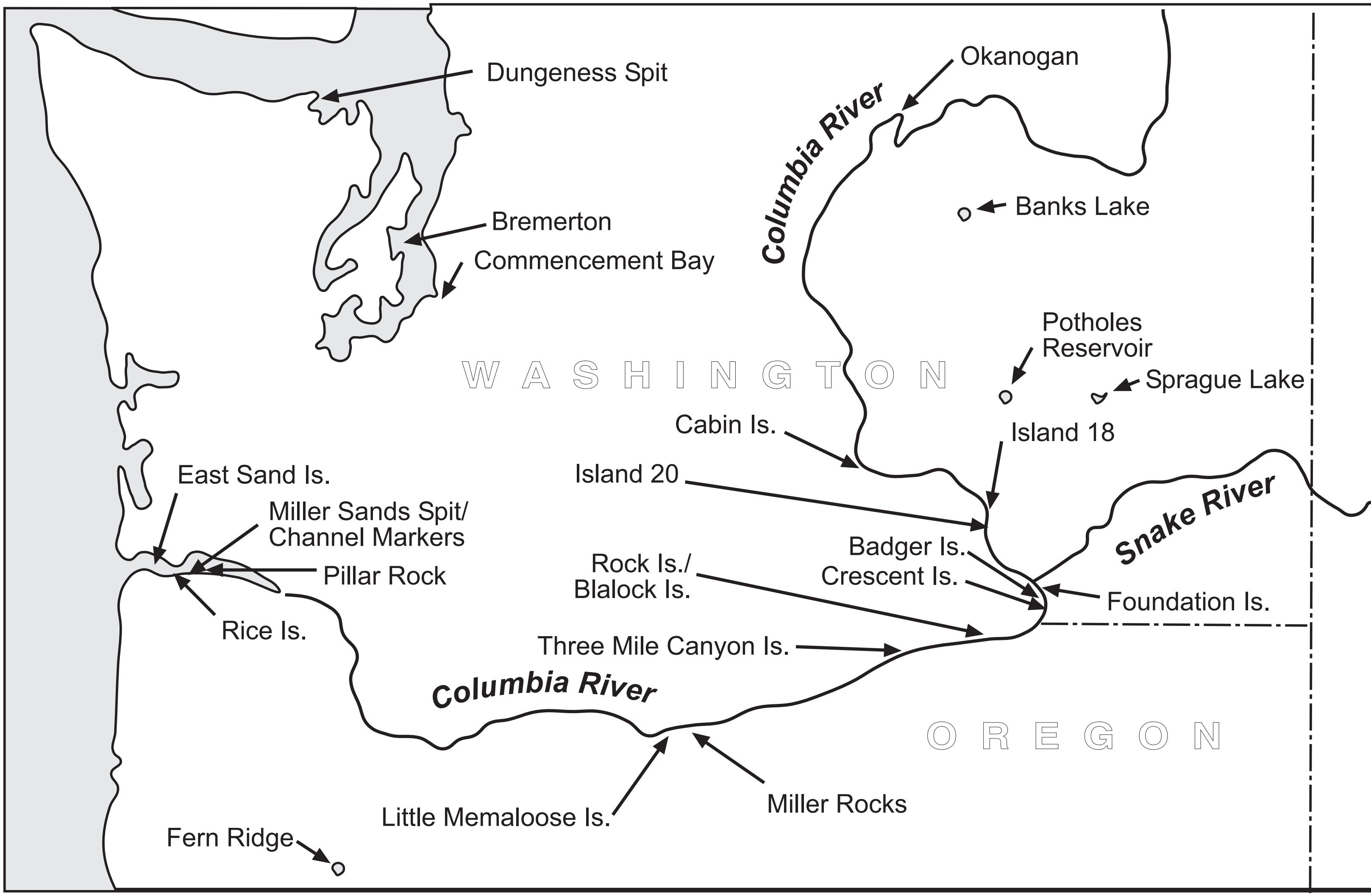
	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Other Piscivorous Colonial Waterbirds			
3.1. Distribution			
3.1.1. Columbia River Estuary	x		
3.1.2. Columbia Plateau			x
3.2. Diet Composition			
3.2.1. Columbia River Estuary	x		
3.2.2. Columbia Plateau			x
3.3. Salmonid Predation Rates			x
Steelhead Vulnerability Study			x



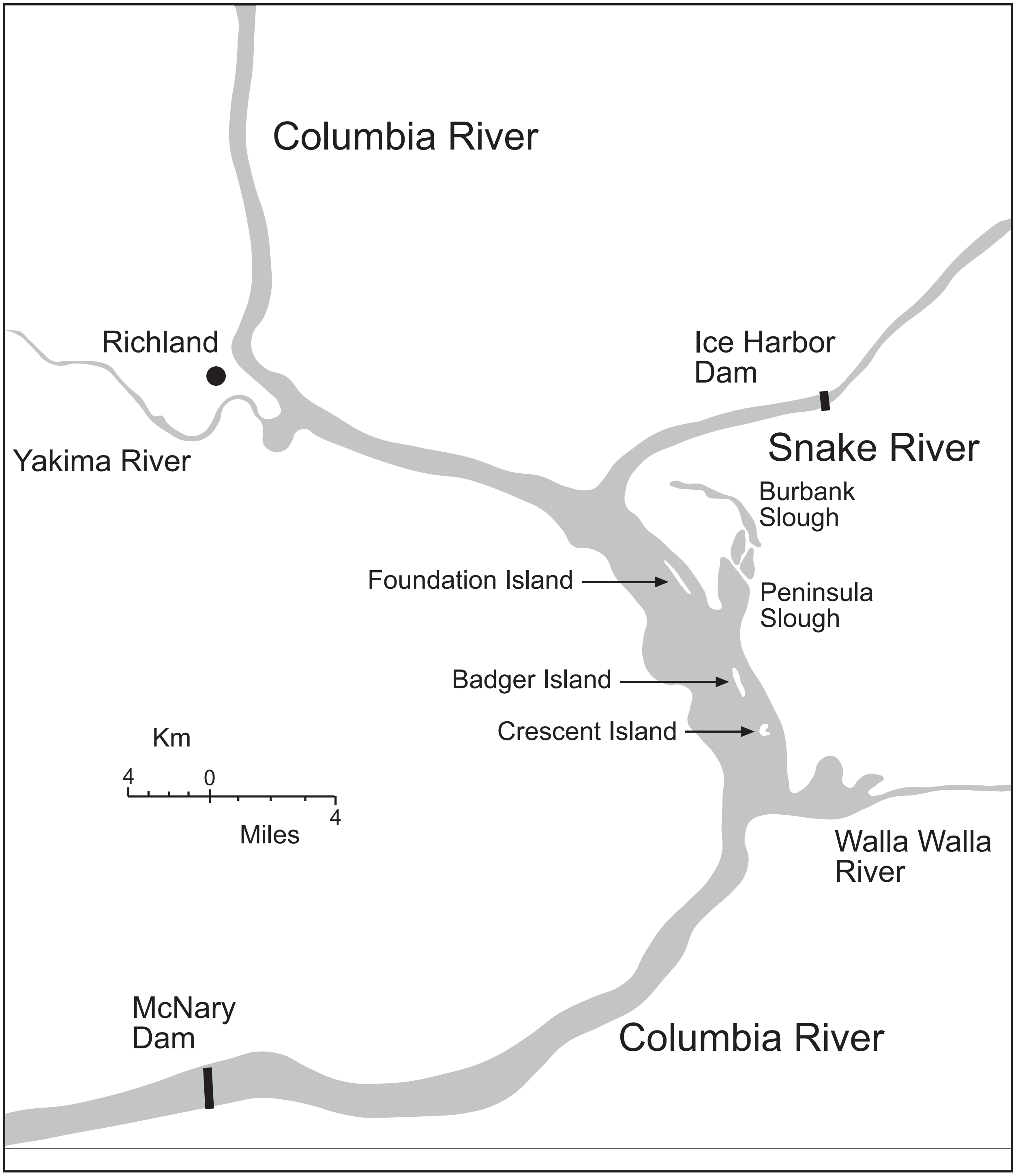
Map 1. Study area in the Columbia River estuary and along the southwest coast of Washington.



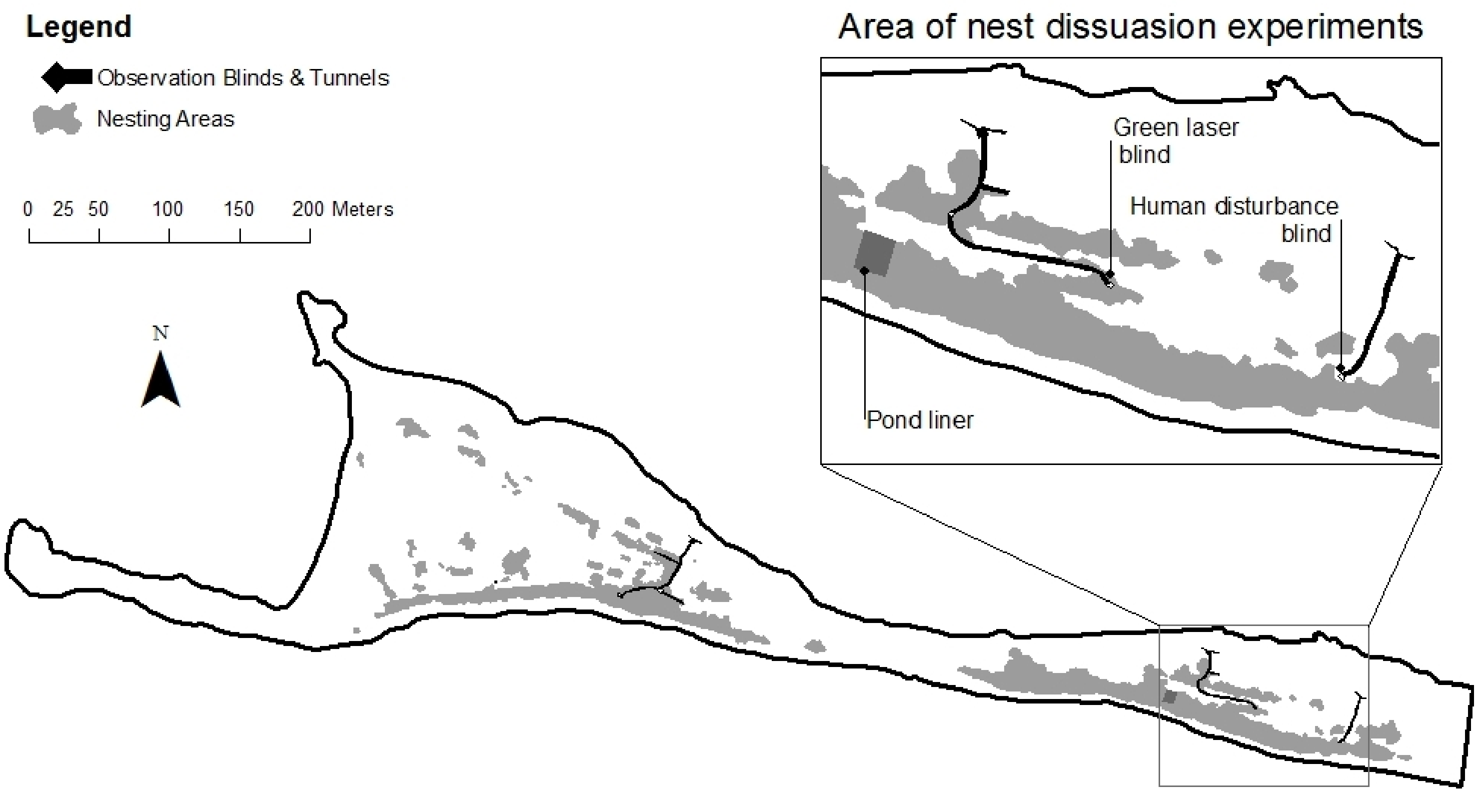
Map 2. Locations of existing, newly built, and proposed islands designated for Caspian tern nesting as part of the federal agencies' Caspian Tern Management Plan (USFWS 2005, 2006).



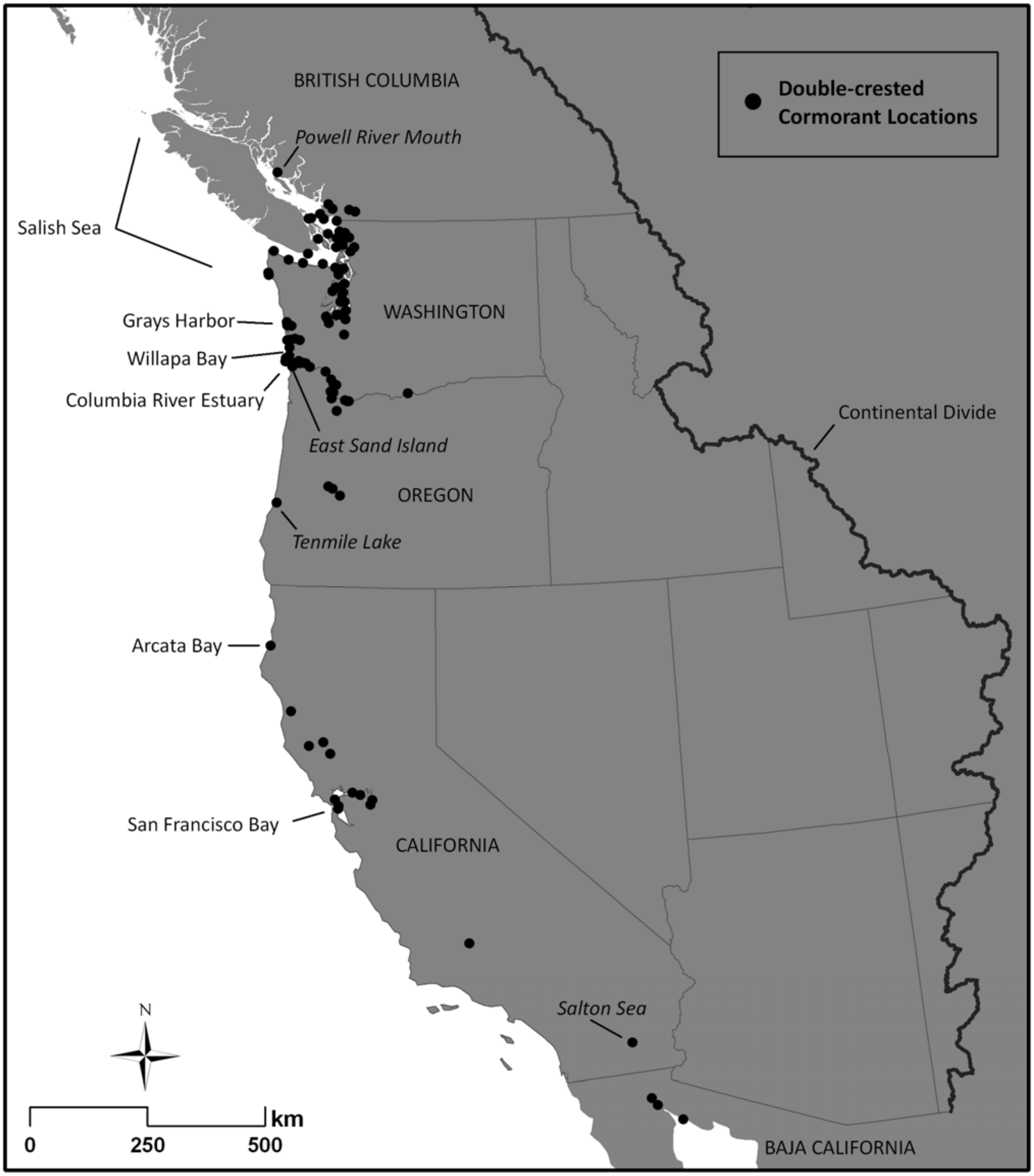
Map 3. Study areas along the Columbia River and the locations of active and historic bird colonies mentioned in this report.



Map 4. Study area in the middle Columbia River.



Map 5. Distribution of double-crested cormorant nests on East Sand Island in 2009. Also shown are the locations of observation blinds and tunnels, plus the area used for nest dissuasion experiments (see text for details). In 2009, cormorants nested only on the western half of East Sand Island (shown here) and not elsewhere on the island.



Map 6. Roosting locations of 51 satellite-tagged double-crested cormorants during the winters of 2008-2009 and 2009-2010. Cormorants were satellite-tagged as breeders at the East Sand Island colony during June and July, 2008-2009.

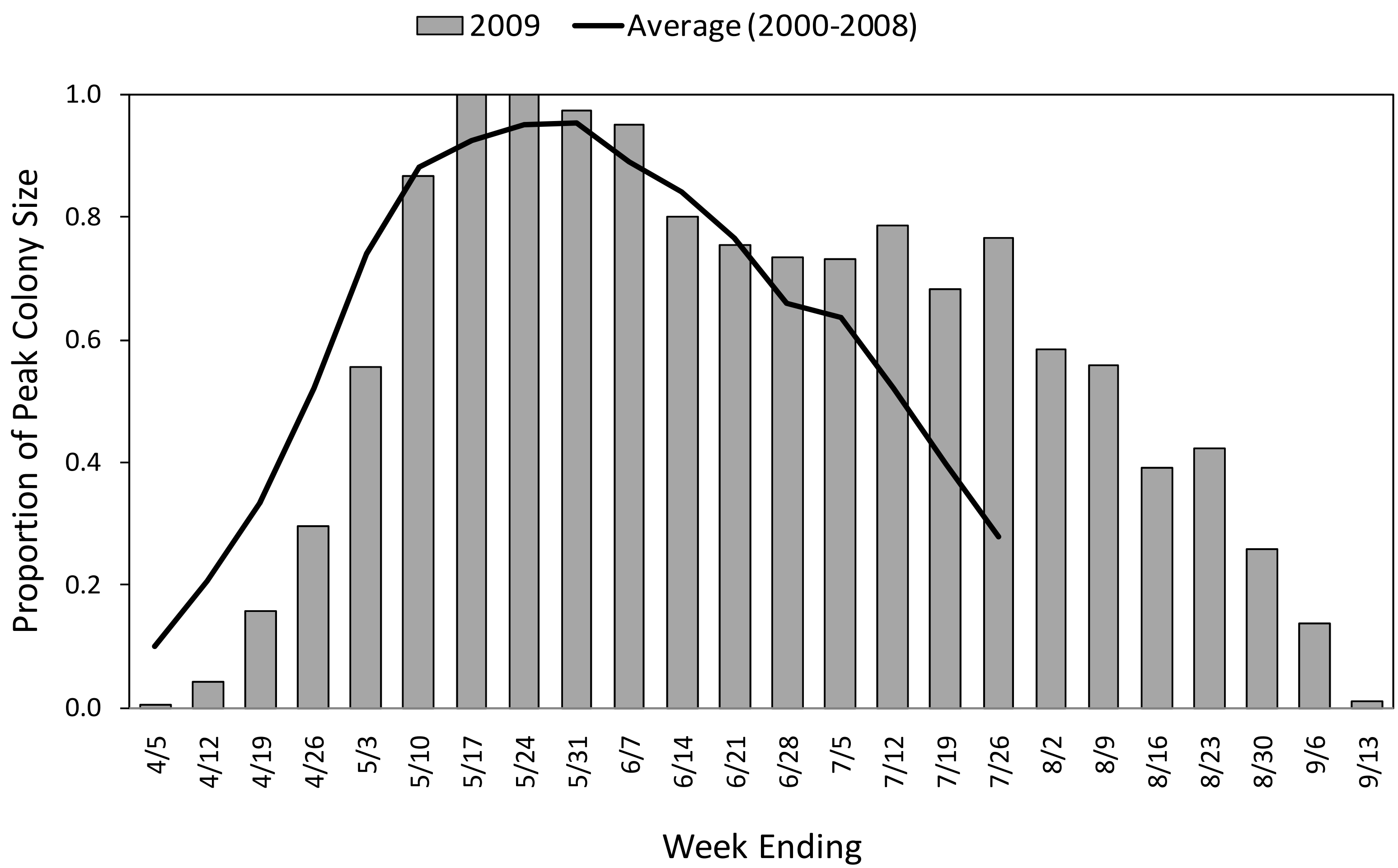


Figure 1. Weekly estimates from the ground of the number of adult Caspian terns on the East Sand Island colony during 2009, relative to peak colony attendance determined from aerial photography late in incubation.

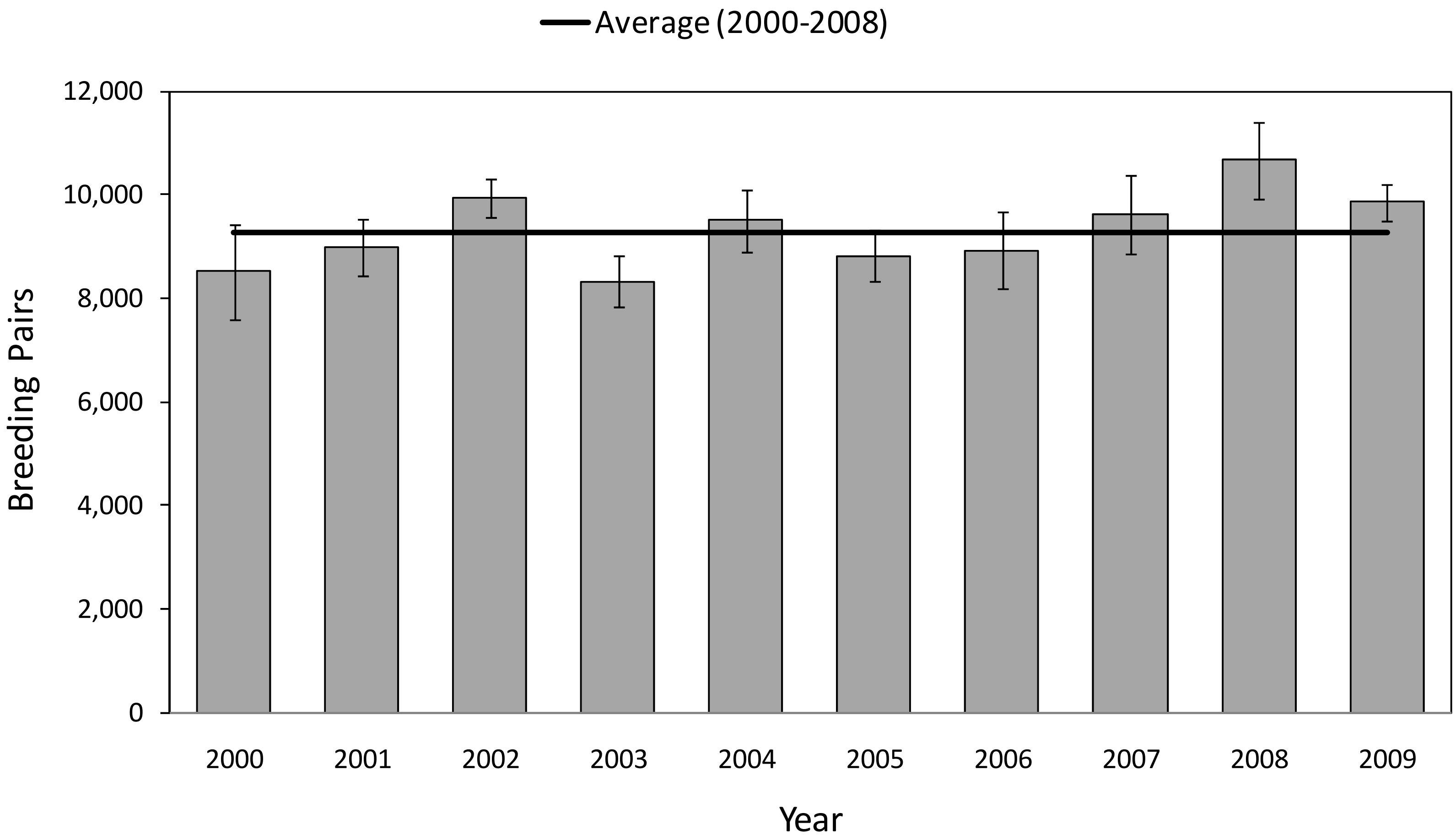


Figure 2. Caspian tern colony size on East Sand Island during 2000-2009. The error bars represent 95% confidence intervals for the number of breeding pairs.

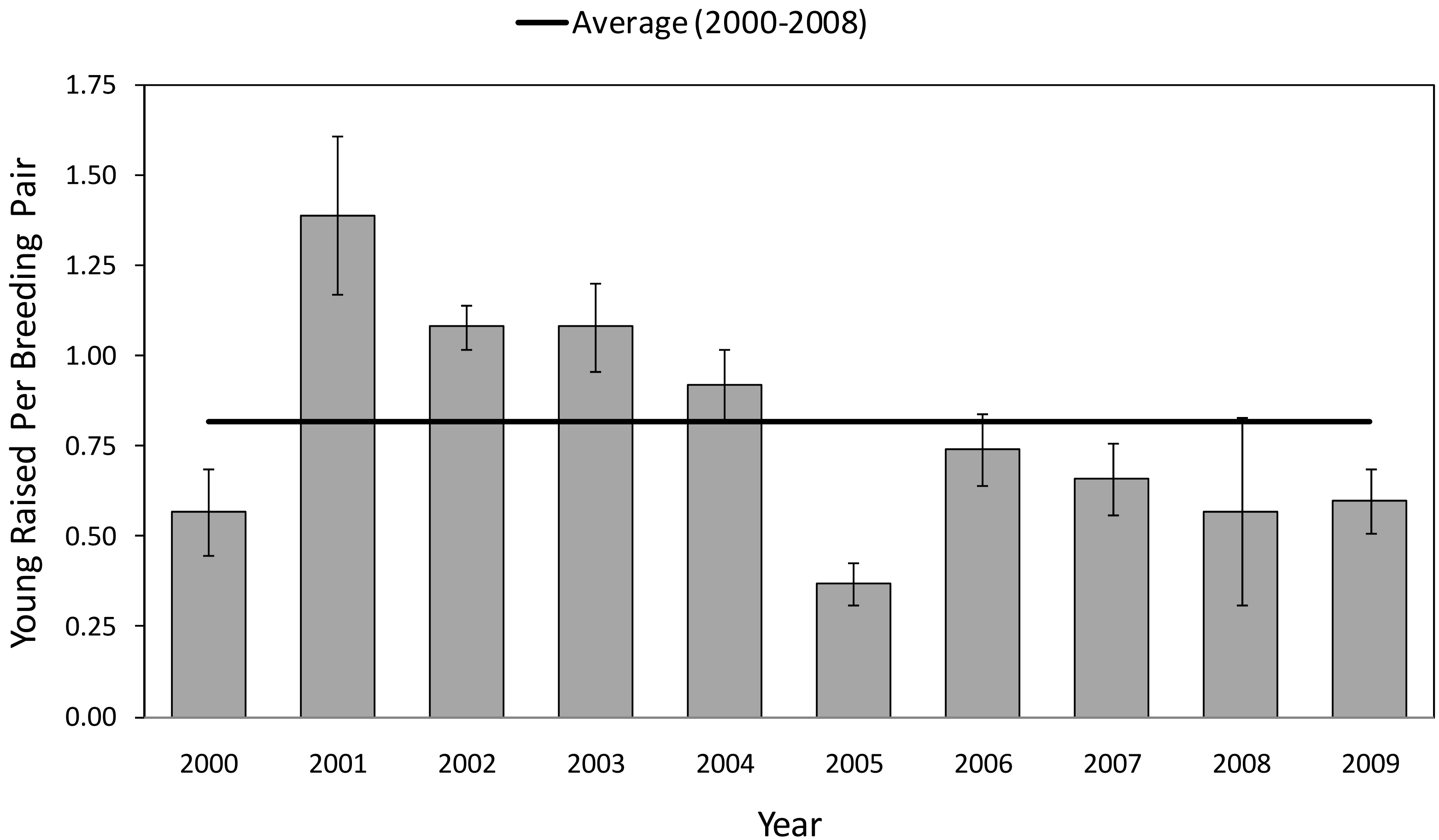


Figure 3. Caspian tern nesting success on East Sand Island during 2000-2009. The error bars represent 95% confidence intervals for the number of young raised per breeding pair.

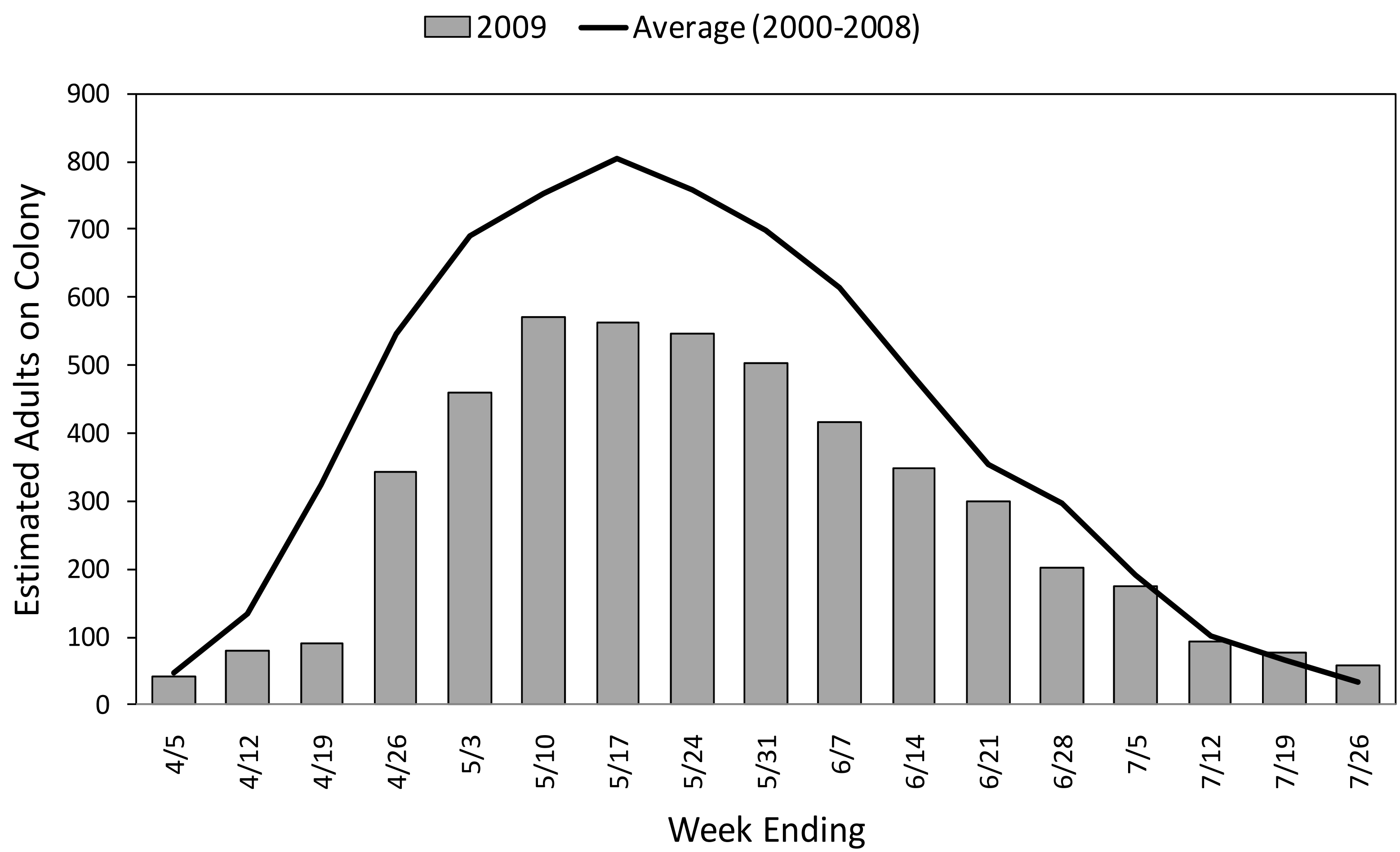


Figure 4. Estimates from the ground of the number of adult Caspian terns on the Crescent Island colony, by week during 2009.

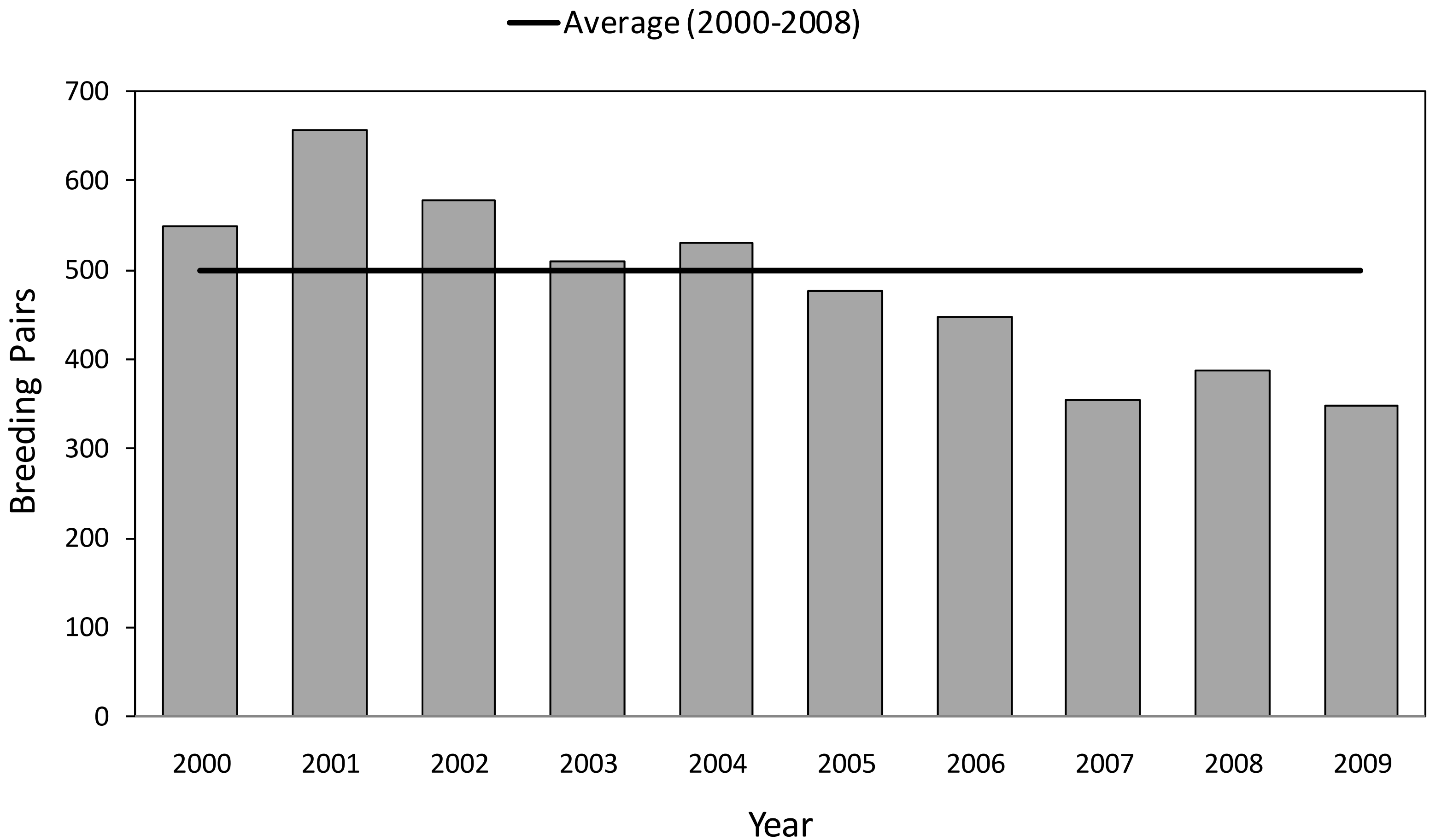


Figure 5. Caspian tern colony size on Crescent Island during 2000-2009.

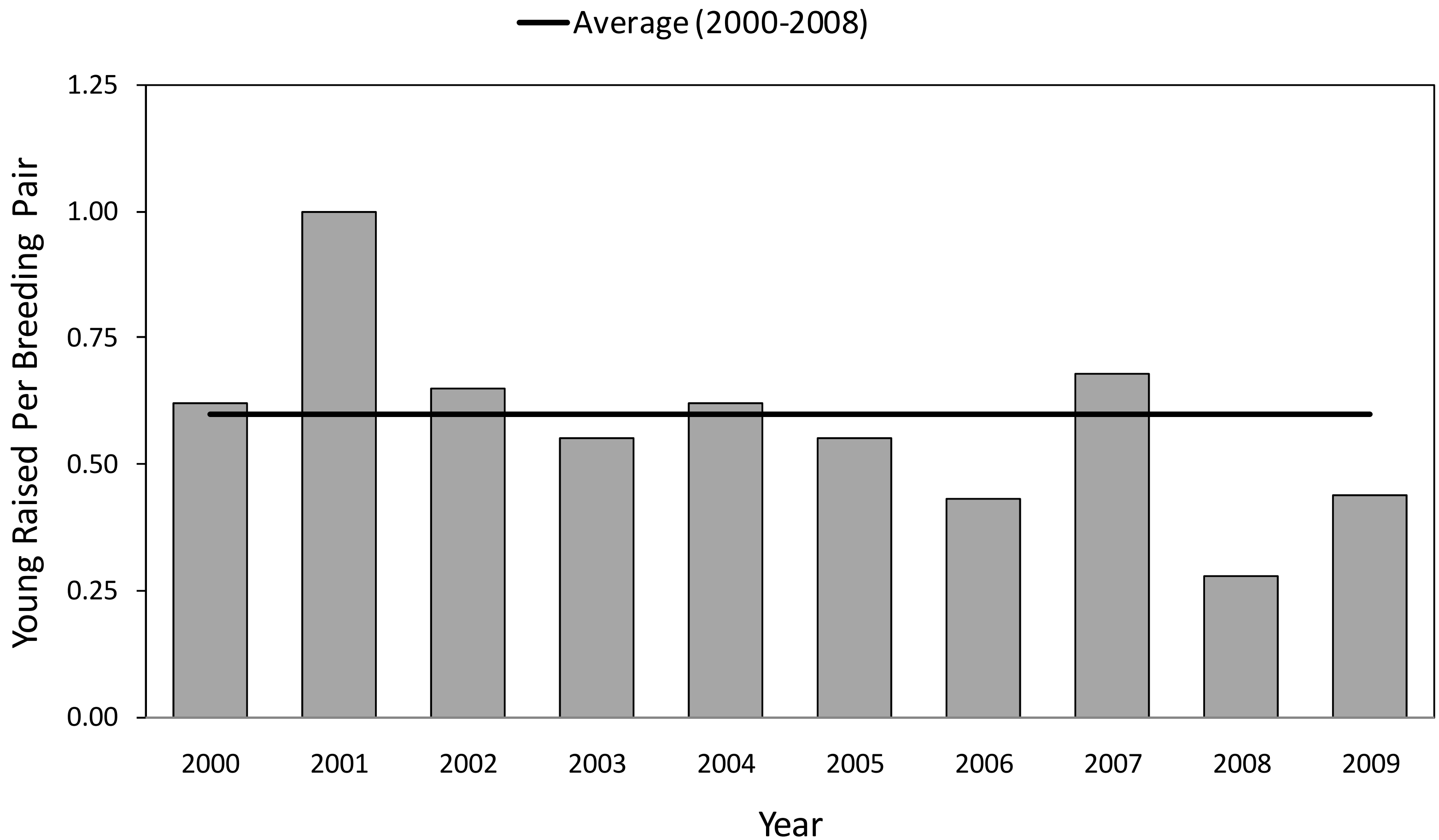


Figure 6. Caspian tern nesting success at the Crescent Island colony during 2000-2009.

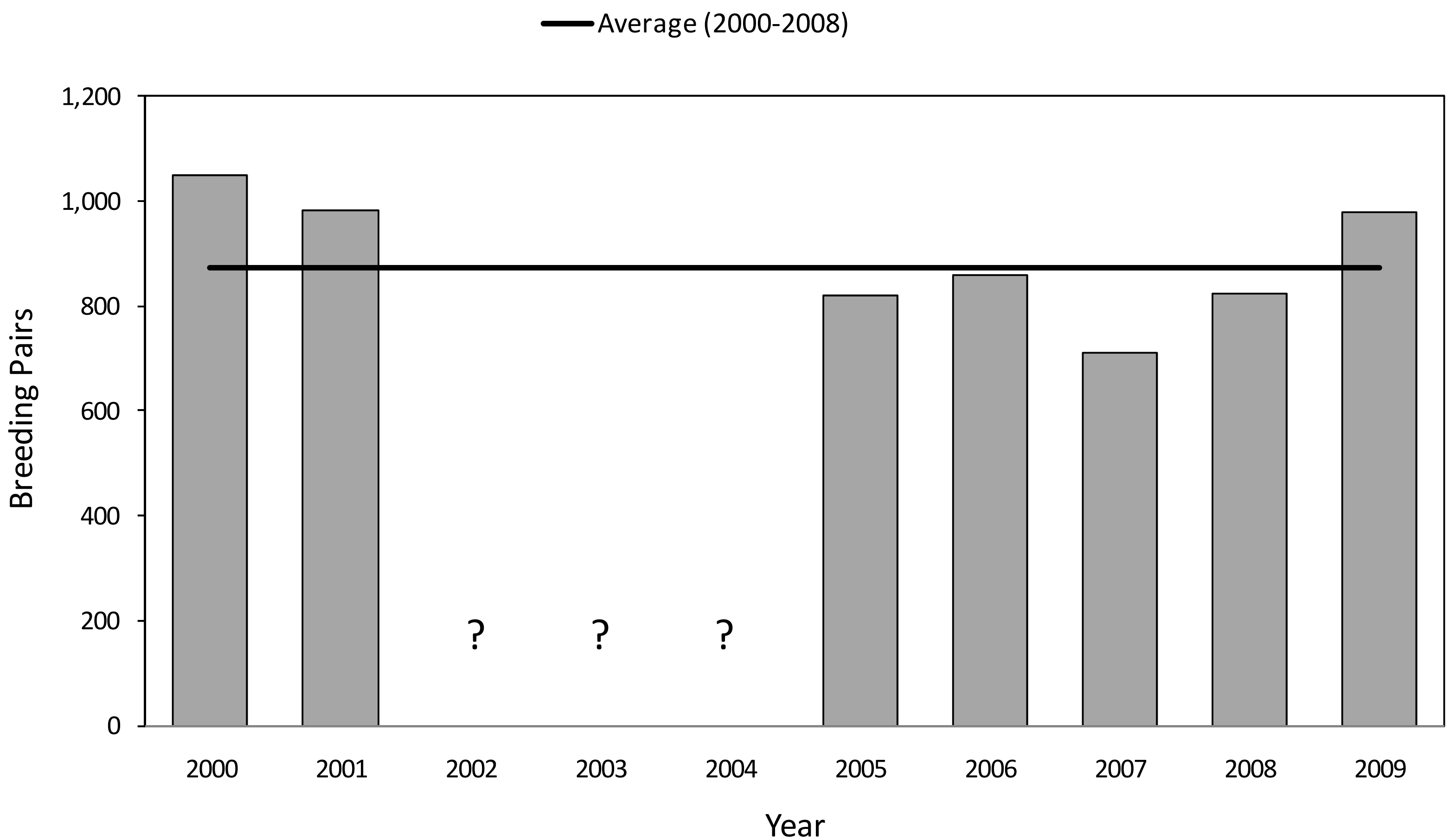


Figure 7. Population counts of Caspian terns nesting at colonies on the Columbia Plateau during 2000-2009. Estimates of the number of breeding pairs were not available for all Caspian tern colonies on the Columbia Plateau during 2002-2004.

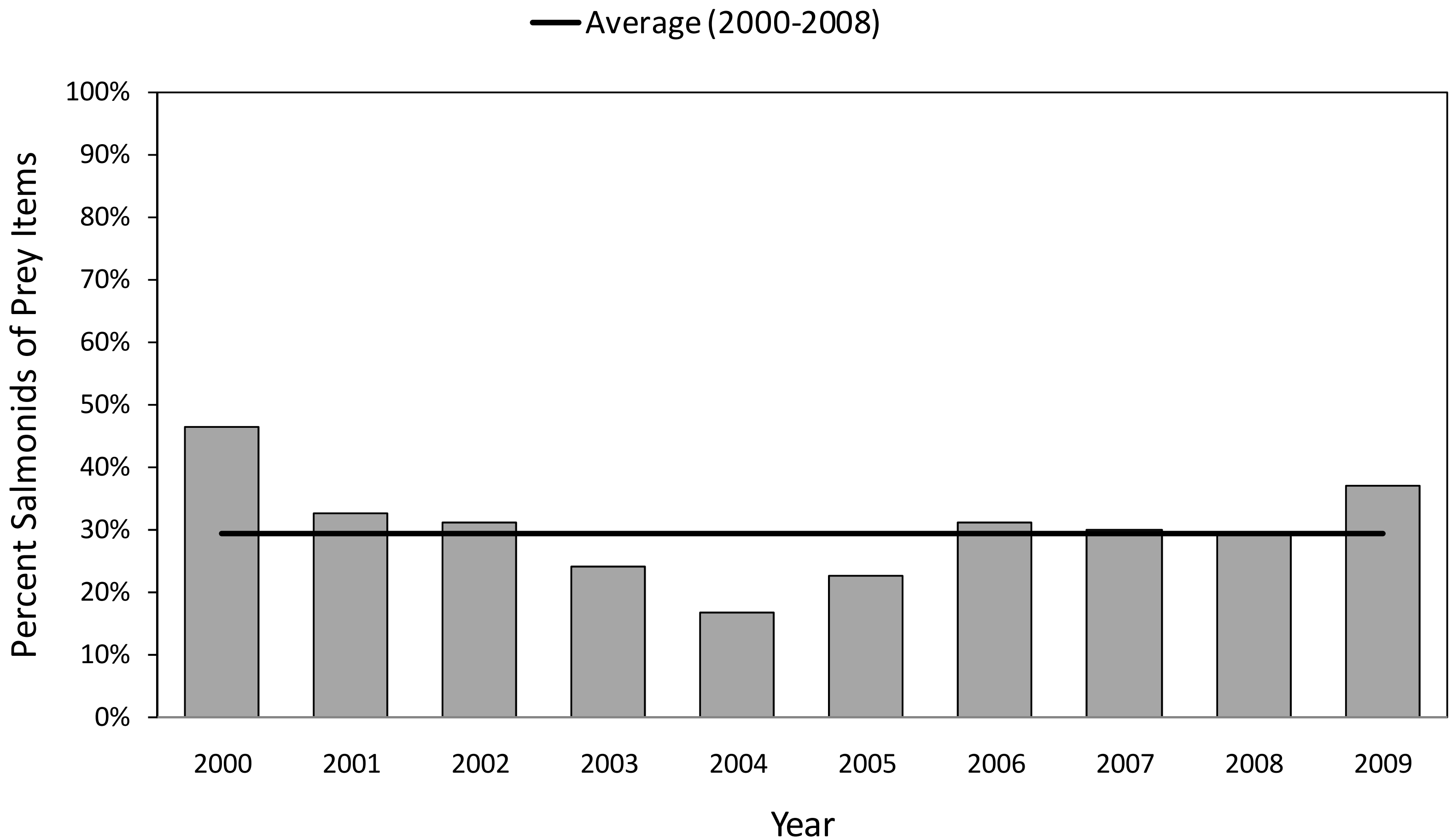


Figure 8. Average annual proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in the Columbia River estuary during 2000-2009.

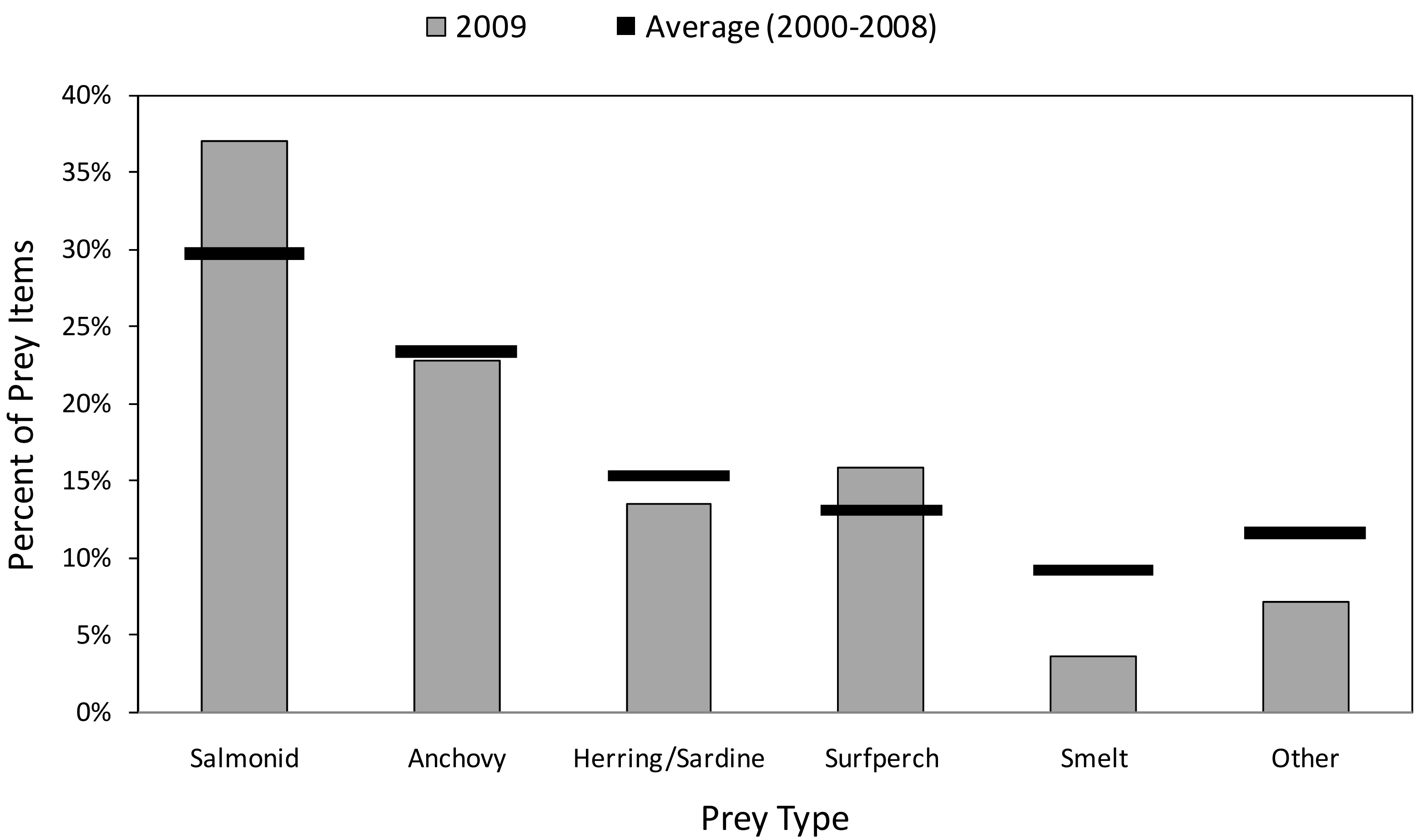


Figure 9. Diet composition of Caspian terns nesting on East Sand Island in the Columbia River estuary during 2009.

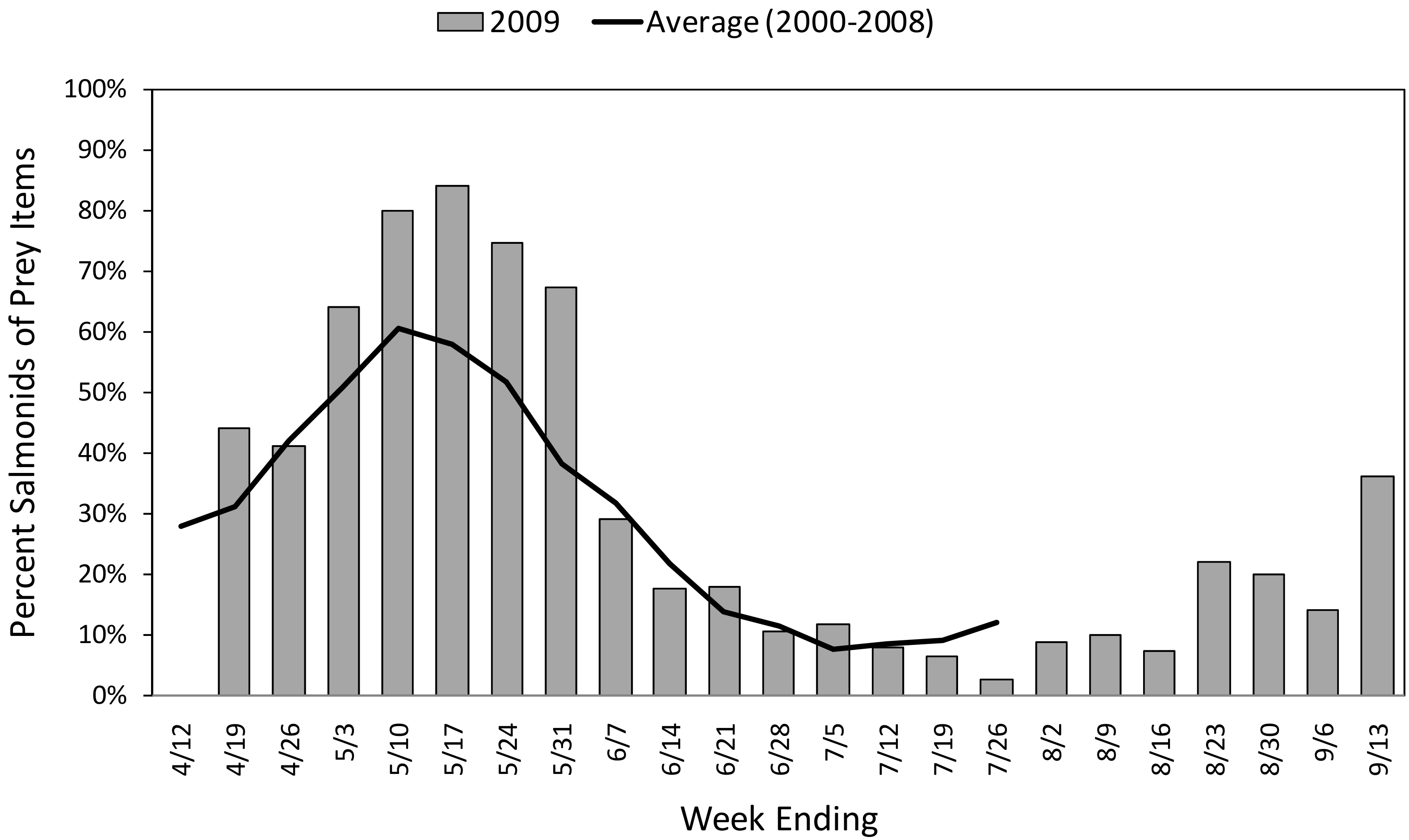


Figure 10. Proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island, by week during 2009.

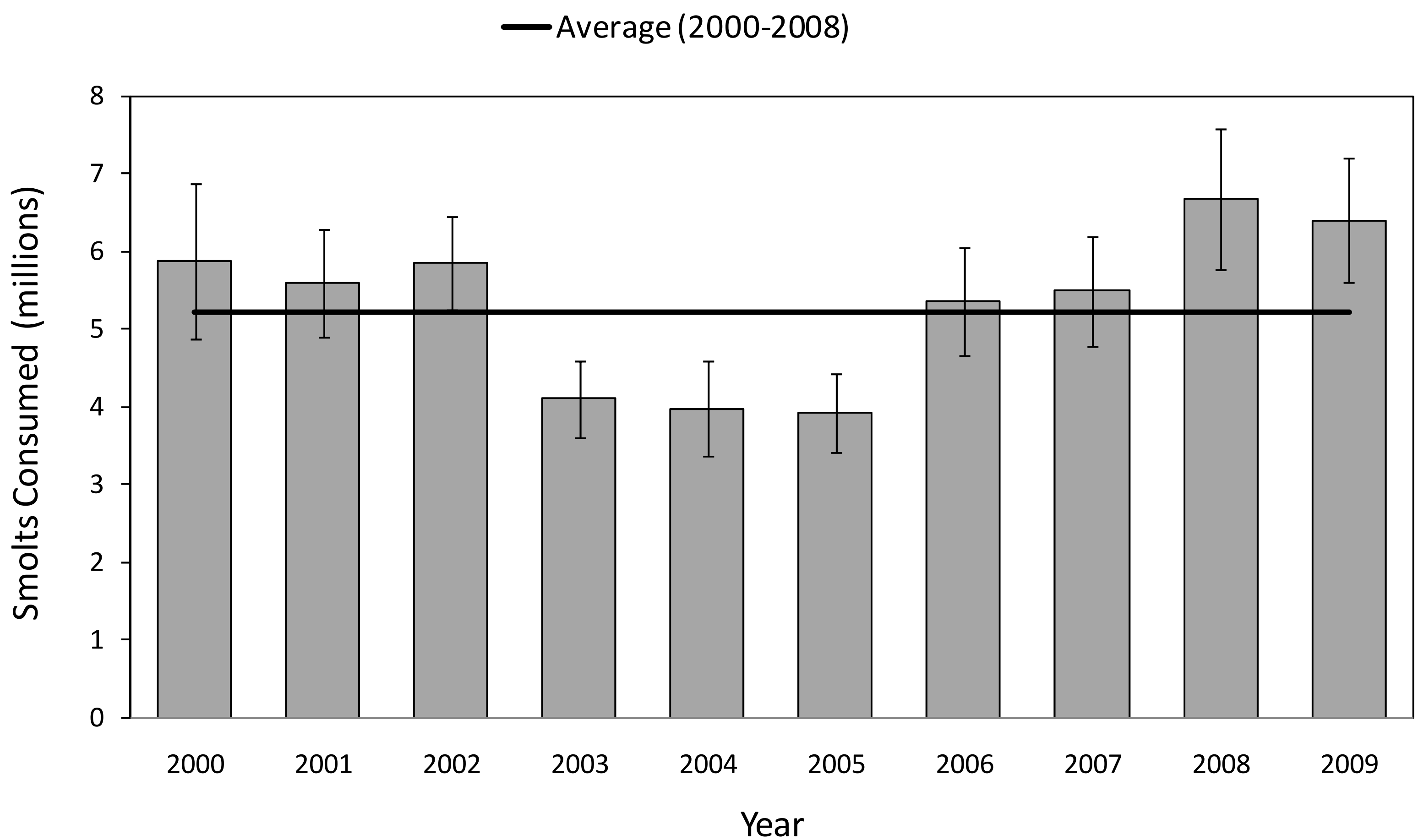


Figure 11. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on East Sand Island during 2000-2009. Error bars represent 95% confidence intervals for the number of smolts consumed.

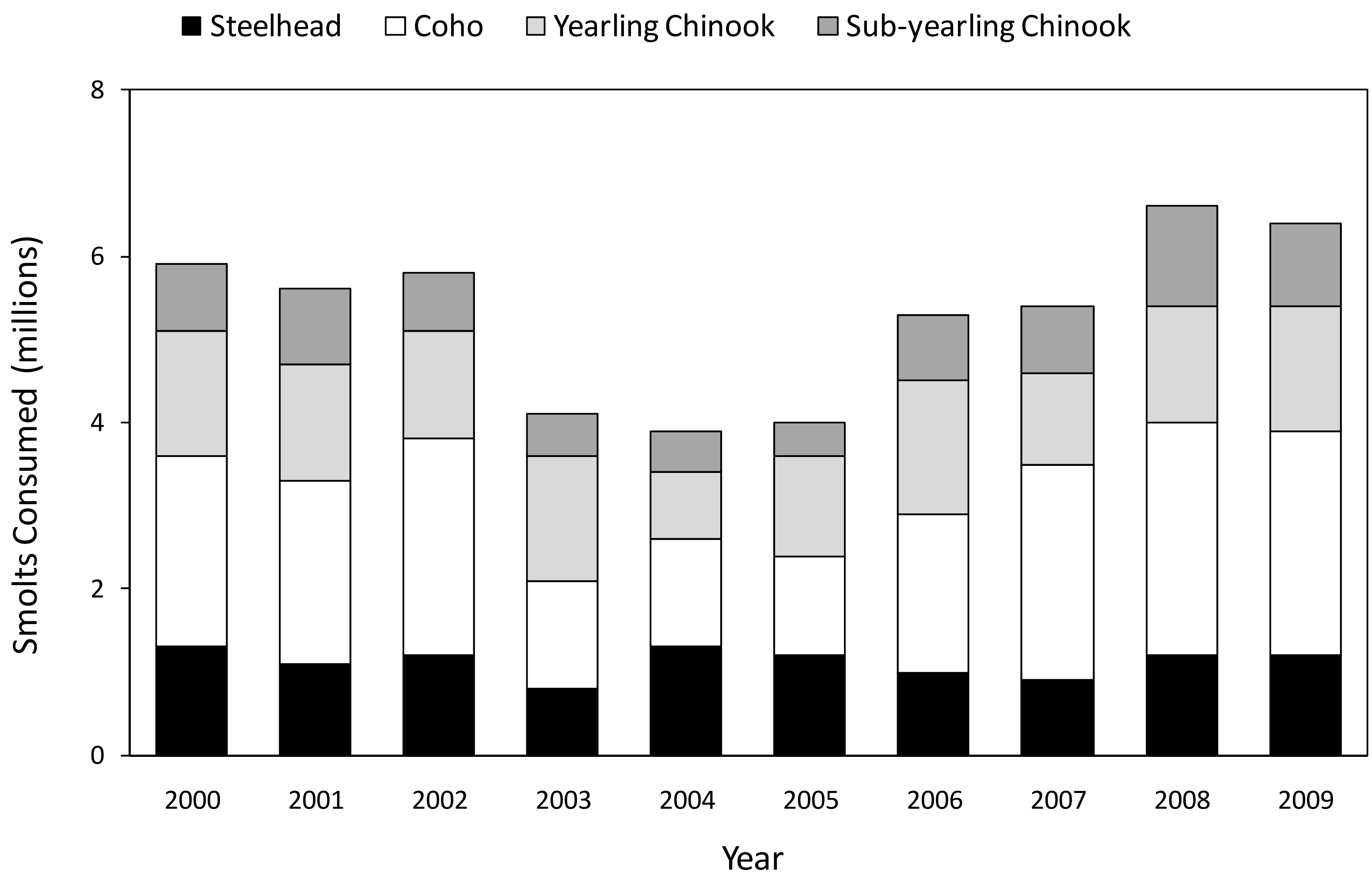


Figure 12. Estimated total annual consumption of juvenile salmonids from four species/run types by Caspian terns nesting on East Sand Island during 2000-2009.

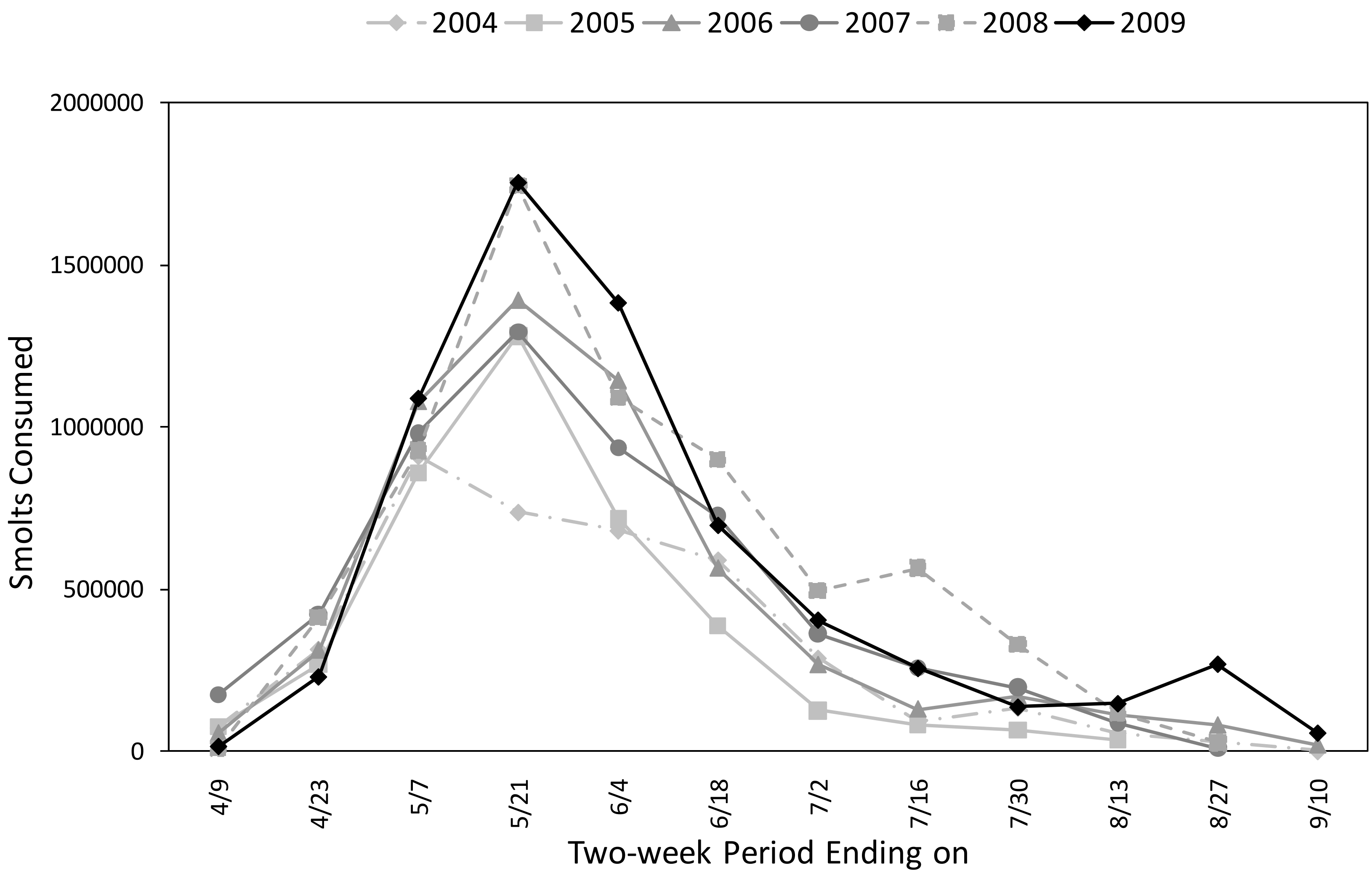


Figure 13. Seasonal trend in consumption of juvenile salmonids by Caspian terns nesting on East Sand Island during the 2004-2009 breeding seasons. Each data point includes steelhead, coho salmon, sockeye salmon, yearling Chinook salmon, and sub-yearling Chinook salmon.

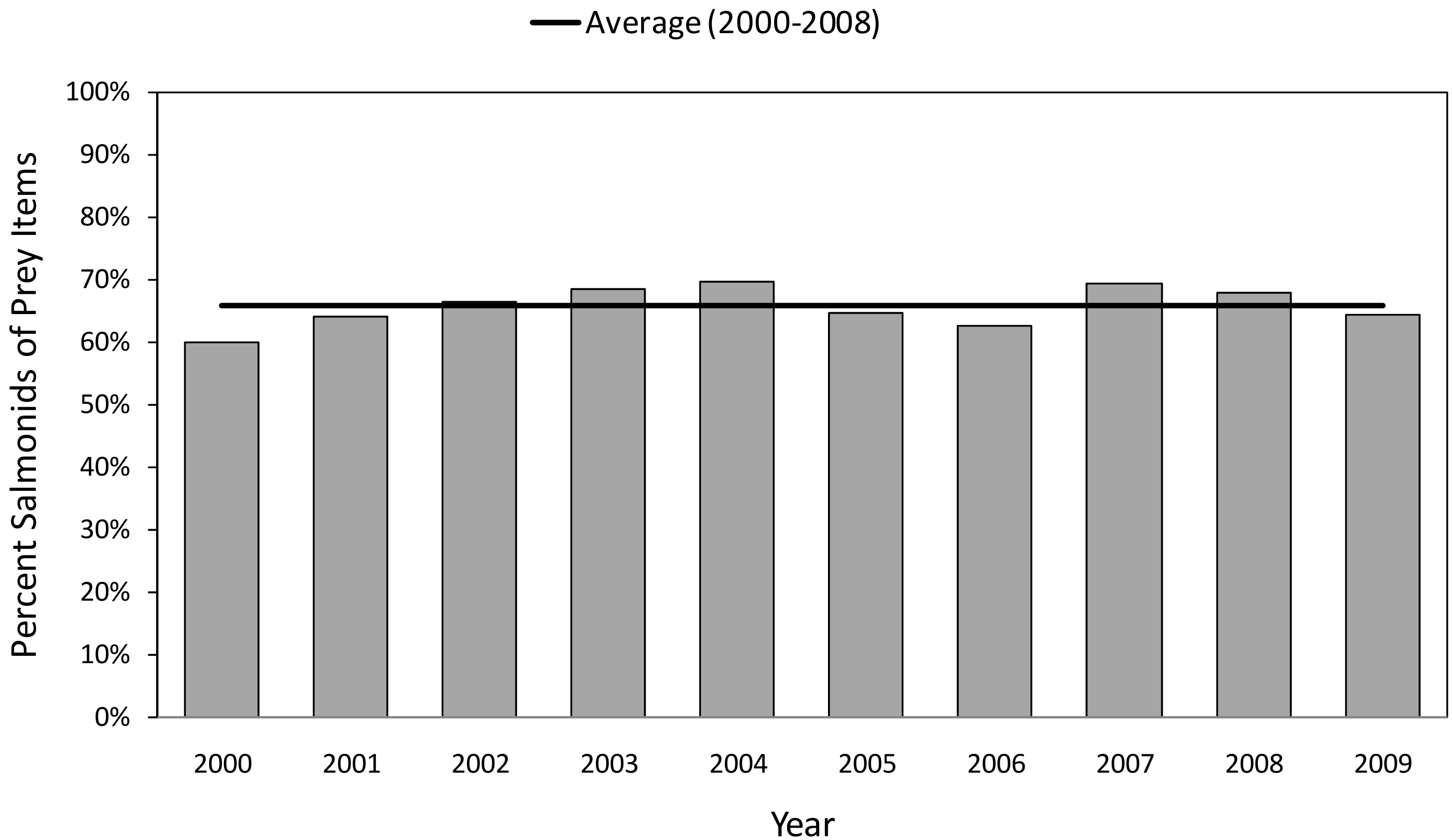


Figure 14. Average annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island, mid-Columbia River, during 2000-2009.

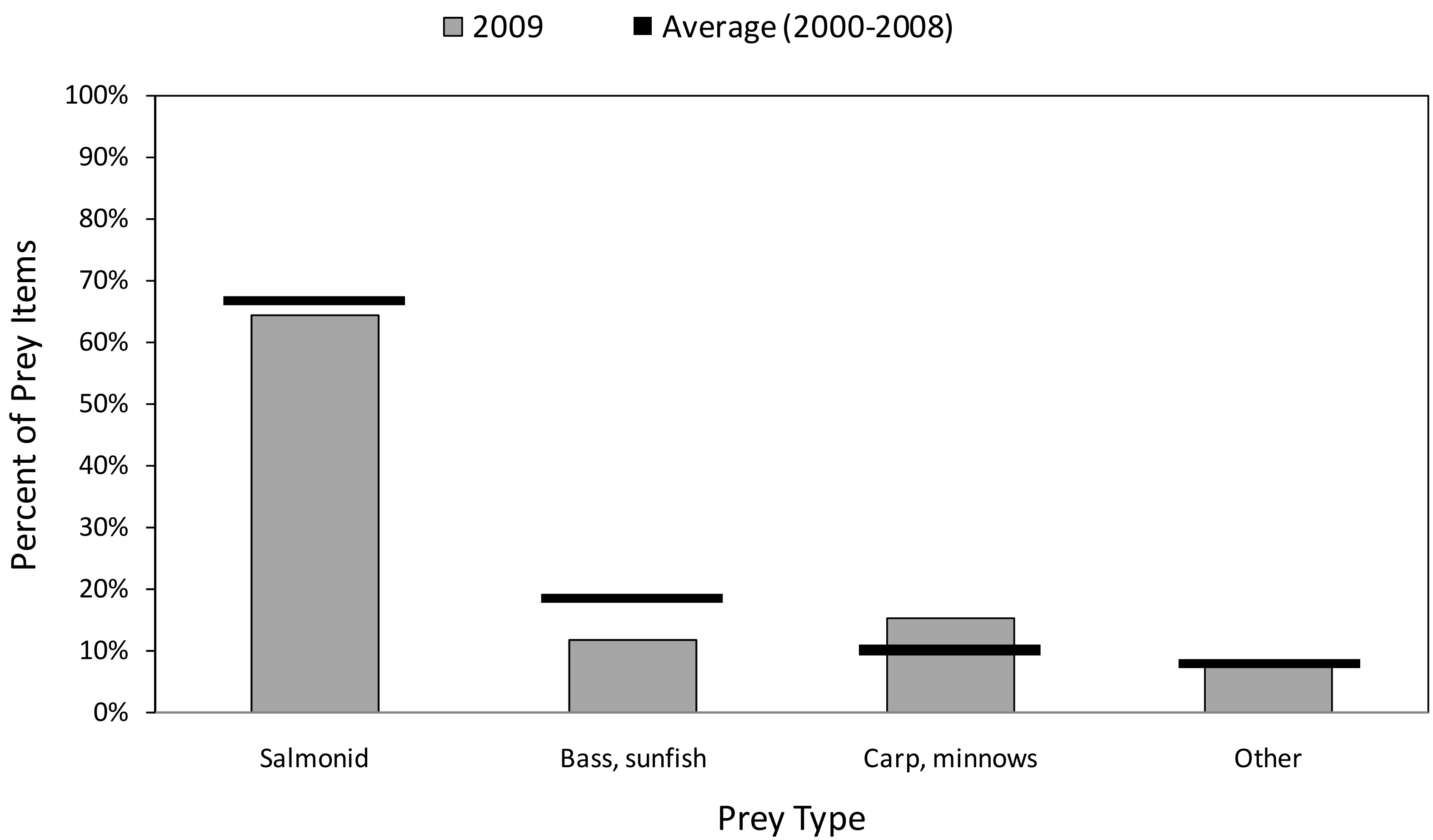


Figure 15. Diet composition of Caspian terns nesting on Crescent Island in 2009.

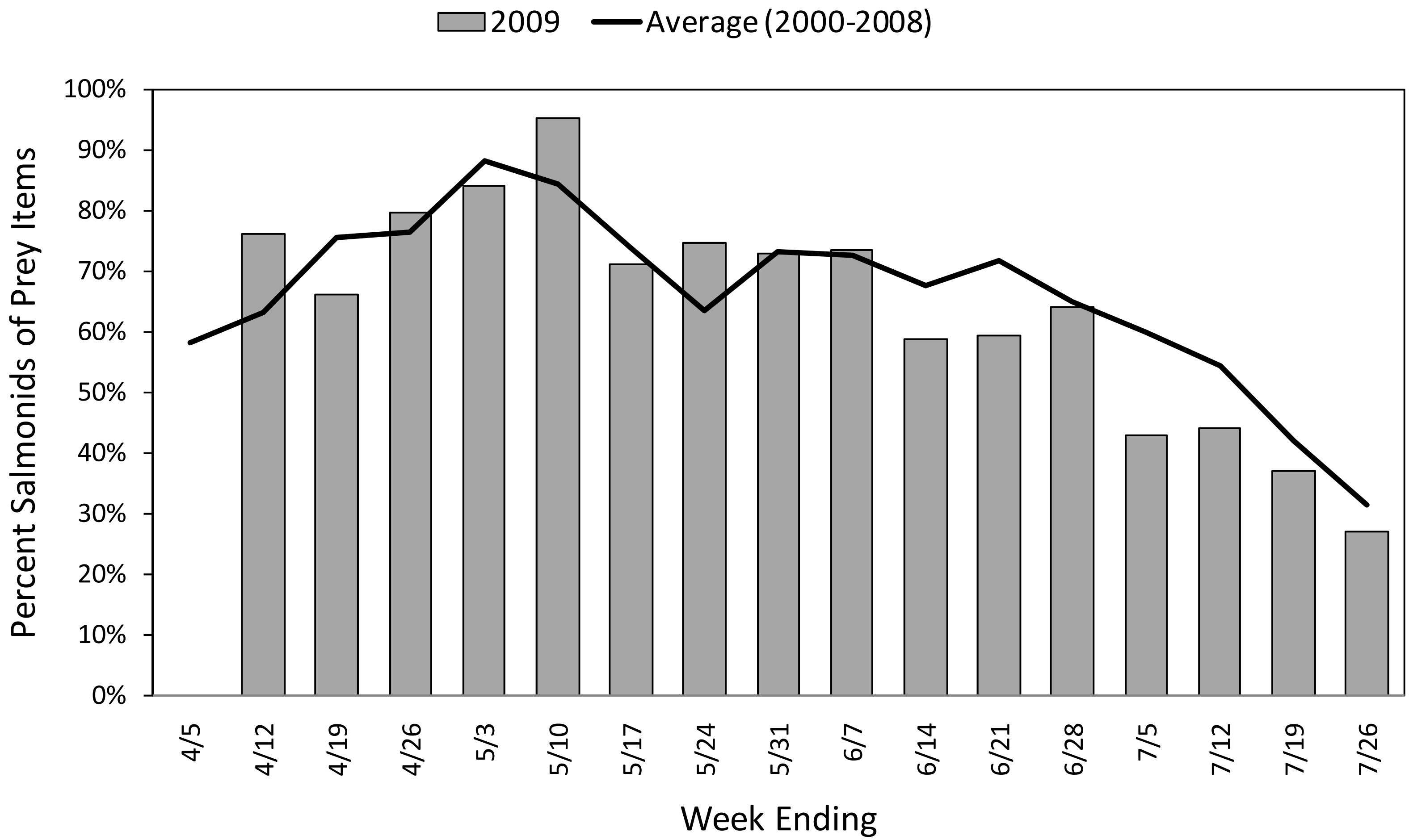


Figure 16. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in 2009, by week.

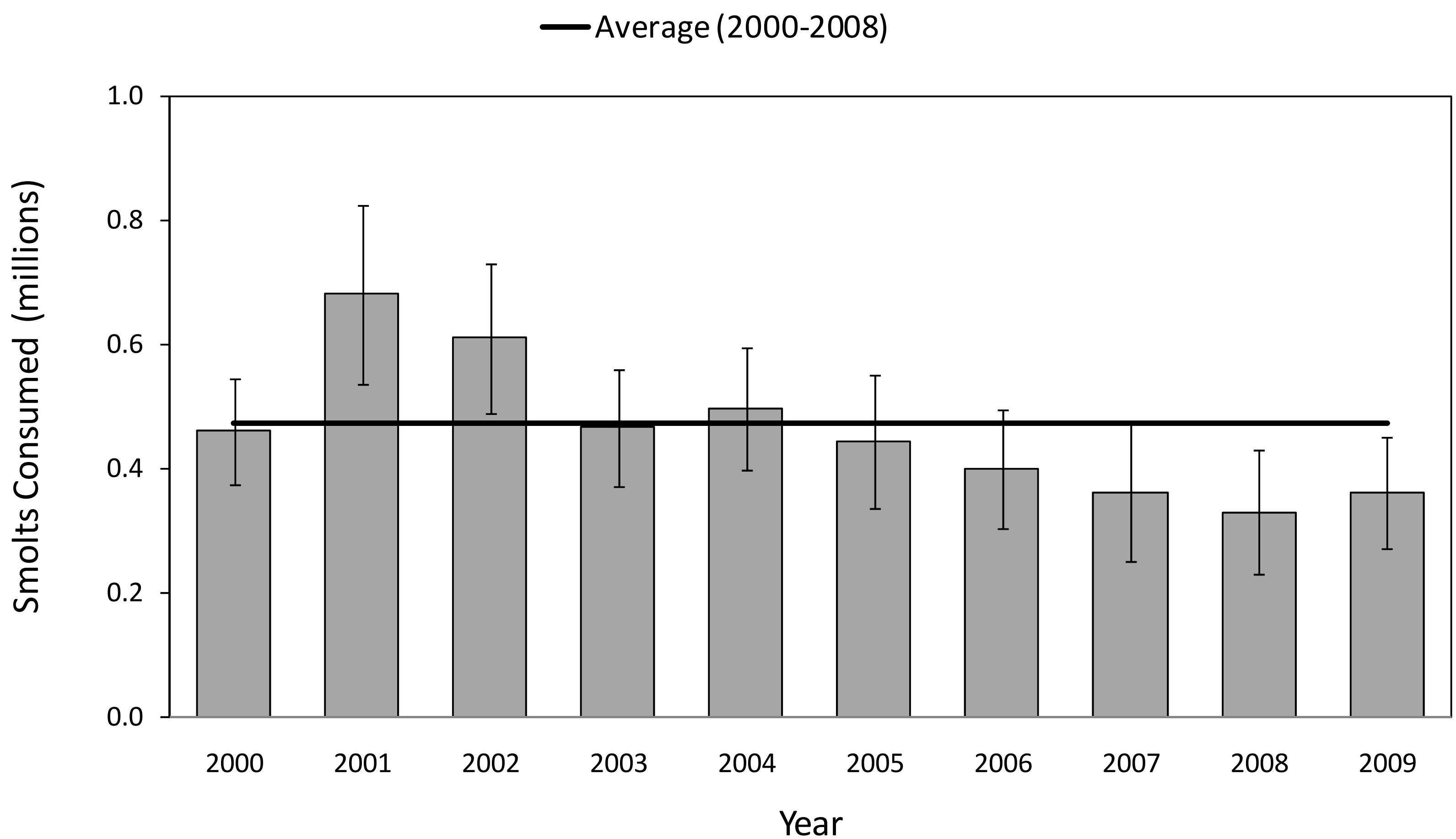


Figure 17. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island during 2000-2009. Error bars represent 95% confidence intervals for the number of smolts consumed.

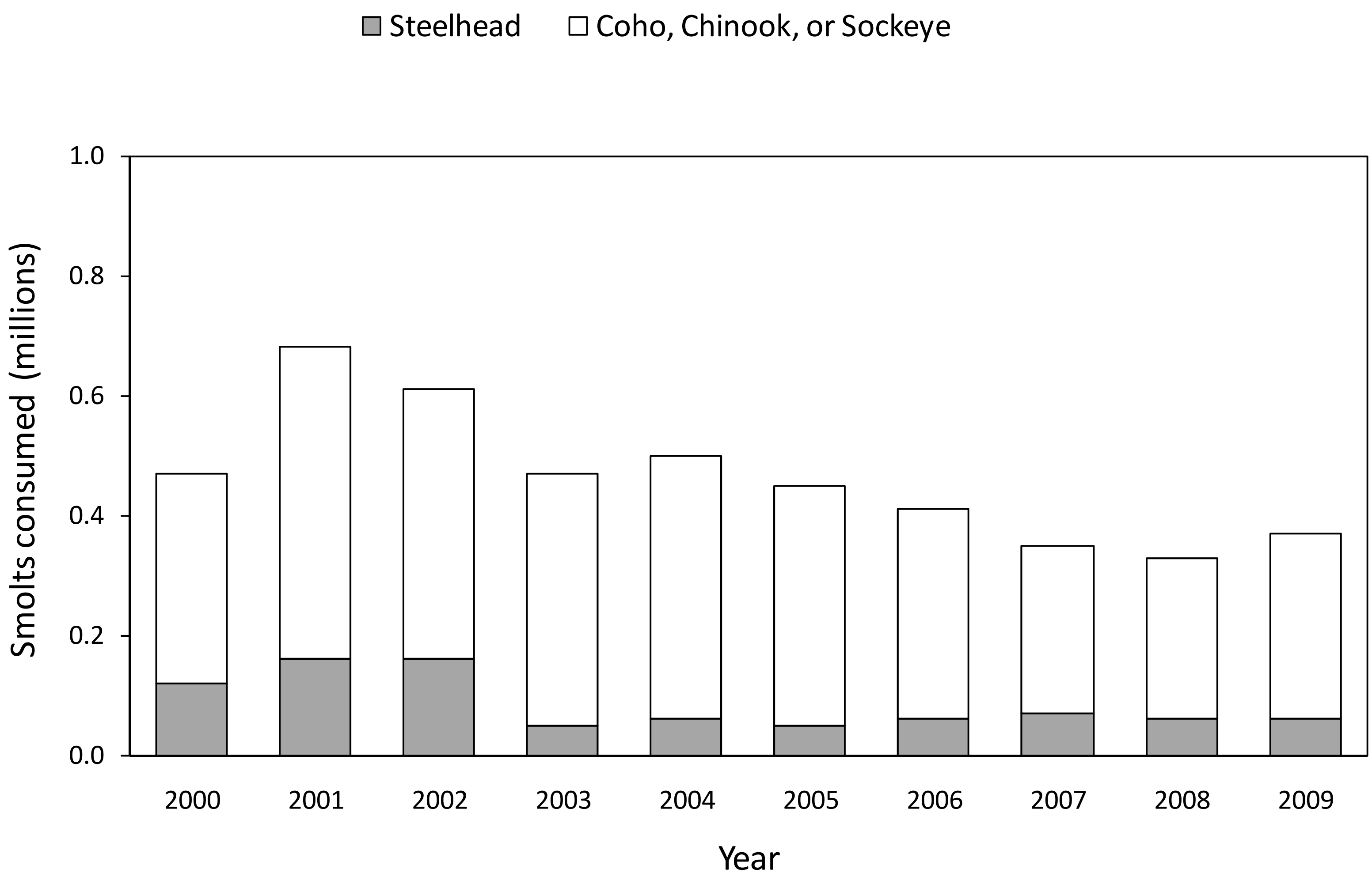


Figure 18. Estimated total annual consumption of steelhead and other salmonids by Caspian terns nesting on Crescent Island during 2000-2009.

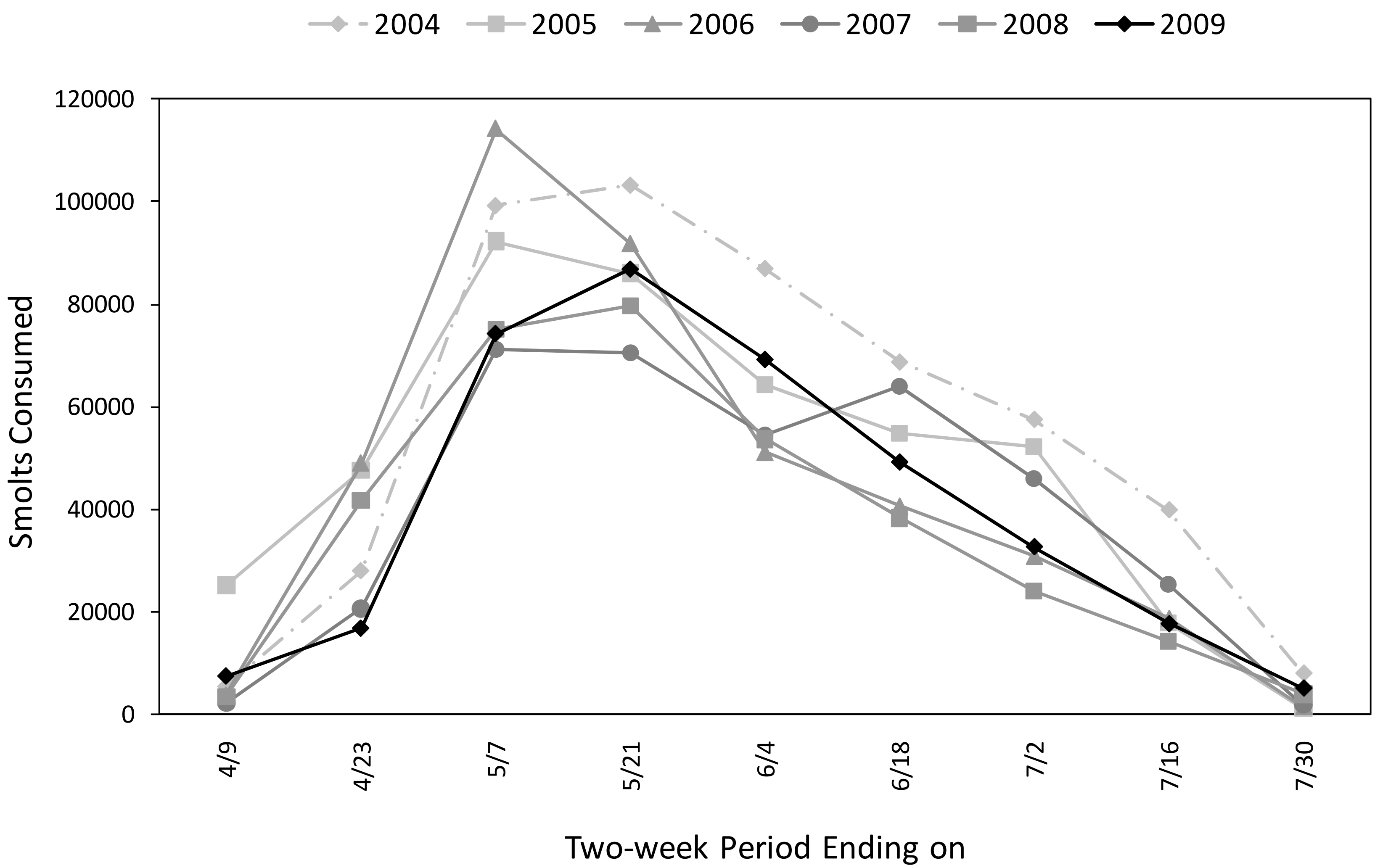
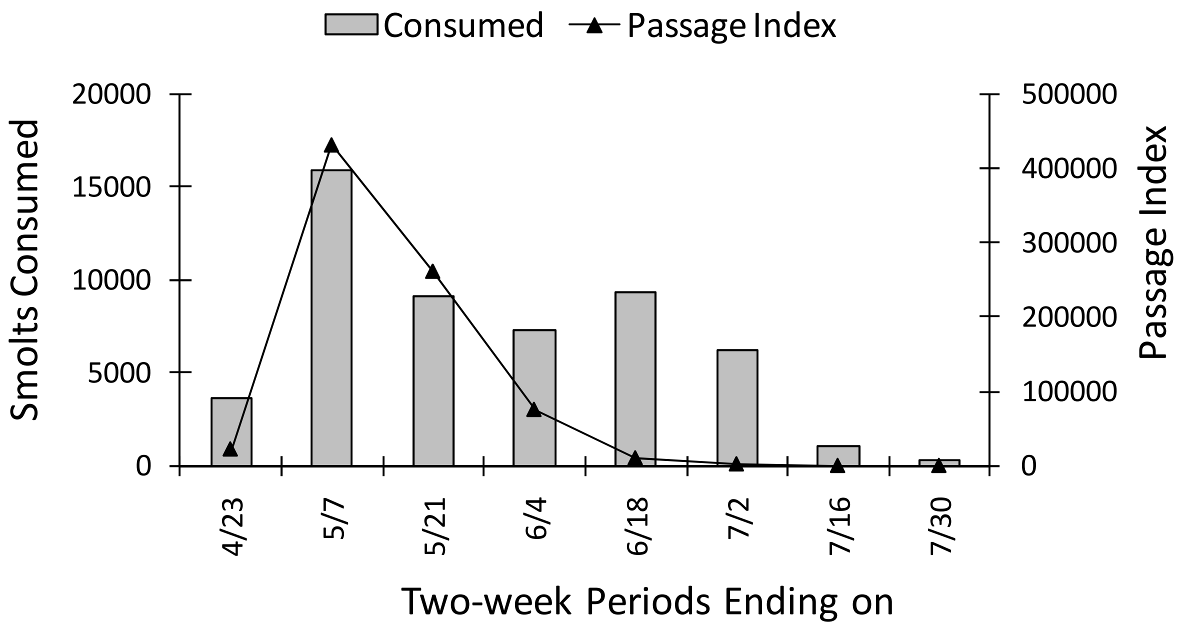


Figure 19. Seasonal trend in consumption of juvenile salmonids by Caspian terns nesting on Crescent Island during the 2004-2009 breeding seasons. Each data point includes steelhead, coho salmon, sockeye salmon, yearling Chinook salmon, and sub-yearling Chinook salmon.

a) Steelhead



b) Coho, Chinook, and Sockeye

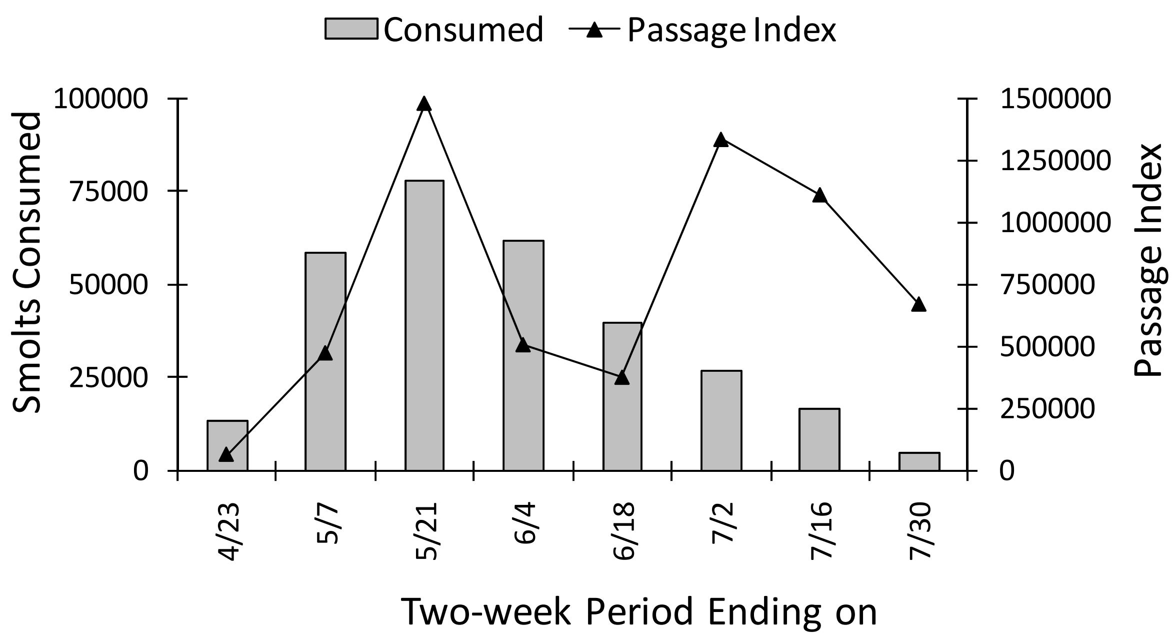


Figure 20. Consumption of steelhead and other salmonids smolts by Caspian terns nesting on Crescent Island in 2009, by two-week period. Smolt passage index is for steelhead and other salmonids passing McNary Dam on the mid-Columbia River (FPC 2010).

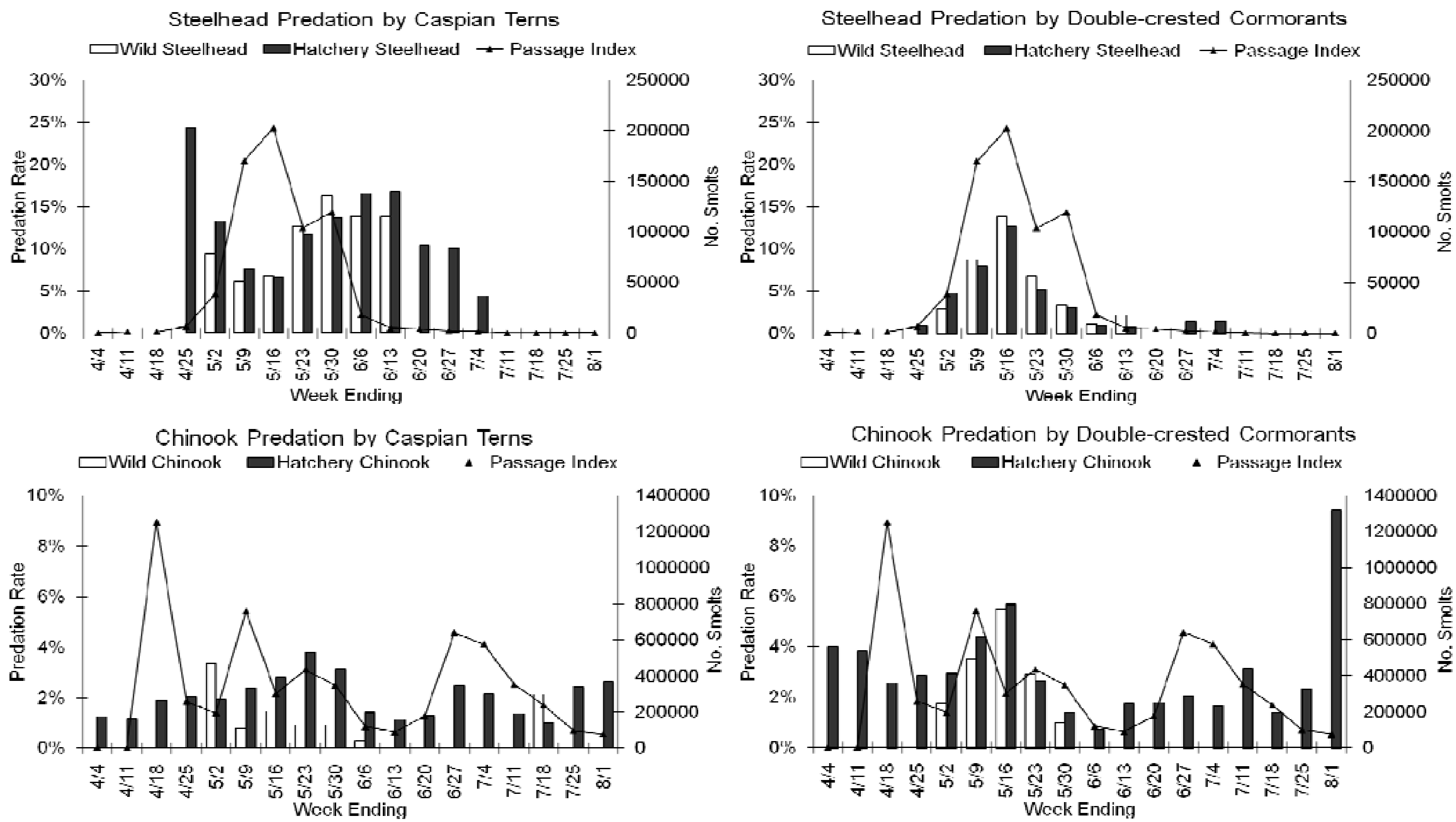


Figure 21. Estimated weekly predation rates on hatchery-reared and wild steelhead and Chinook salmon smolts by Caspian terns and double-crested cormorants nesting on East Sand Island in 2009. Predation rates are based on the proportion of PIT-tagged fish interrogated passing Bonneville Dam that were subsequently recovered on the tern or cormorant colony. Sample sizes of < 100 smolts interrogated at Bonneville Dam per week were not included in the analysis. Smolt passage indices are for steelhead or Chinook salmon passing Bonneville Dam. Predation rates are corrected for on-colony PIT tag detection efficiency, but not for deposition rates, and are therefore minimum estimates.

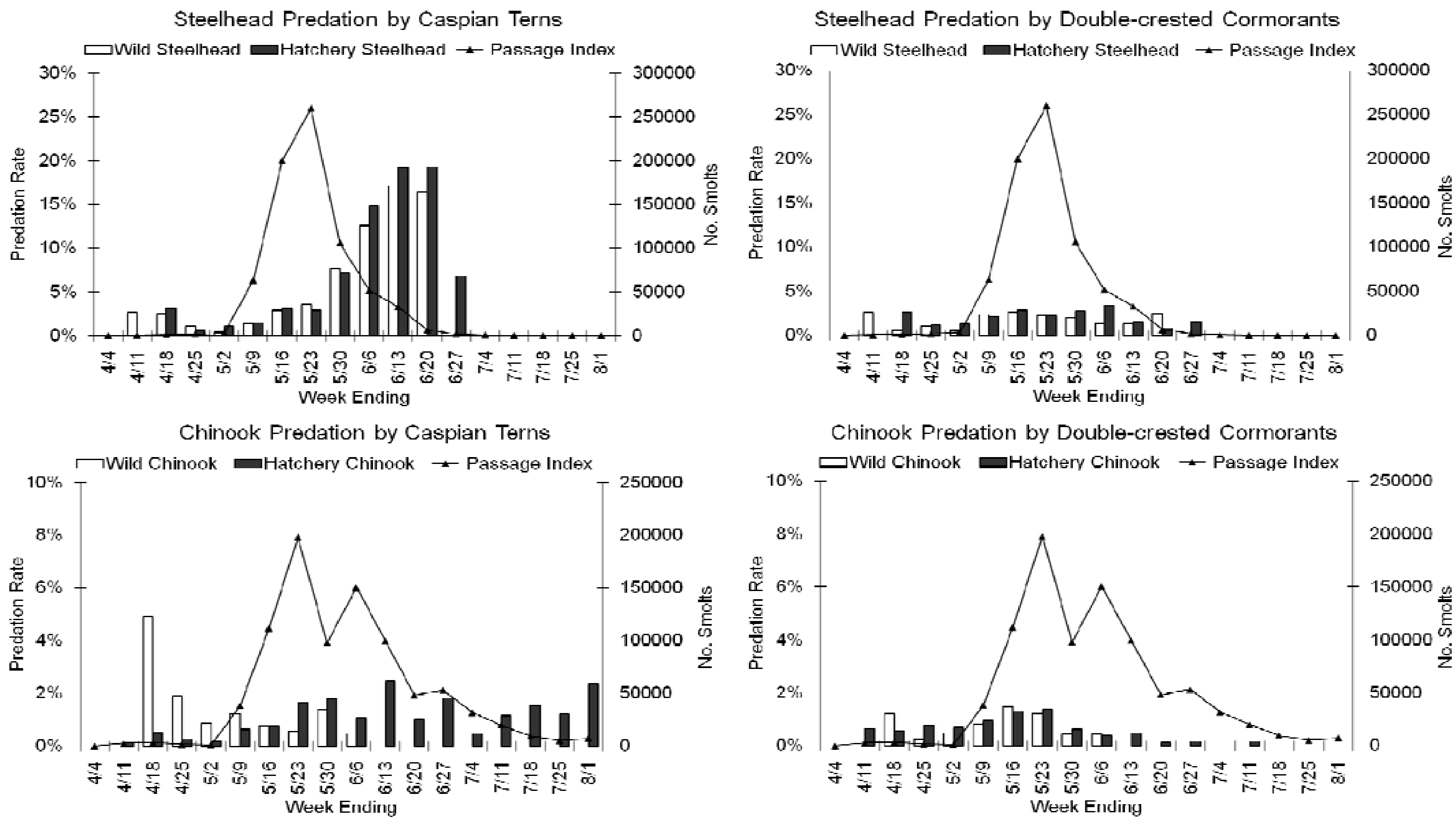


Figure 22. Estimated weekly predation rates on hatchery-reared and wild steelhead and Chinook salmon smolts by Caspian terns and double-crested cormorants nesting on Crescent Island and Foundation Island, respectively, in 2009. Predation rates are based on the proportion of PIT-tagged fish interrogated passing Lower Monumental Dam that was subsequently recovered on the tern or cormorant colony. Sample sizes of < 100 smolts interrogated at Lower Monumental Dam per week were not included in the analysis. Smolt passage indices are for steelhead or Chinook salmon passing Lower Monumental Dam. Predation rates are corrected for on-colony PIT tag detection efficiency, but not for deposition rates, and are therefore minimum estimates.

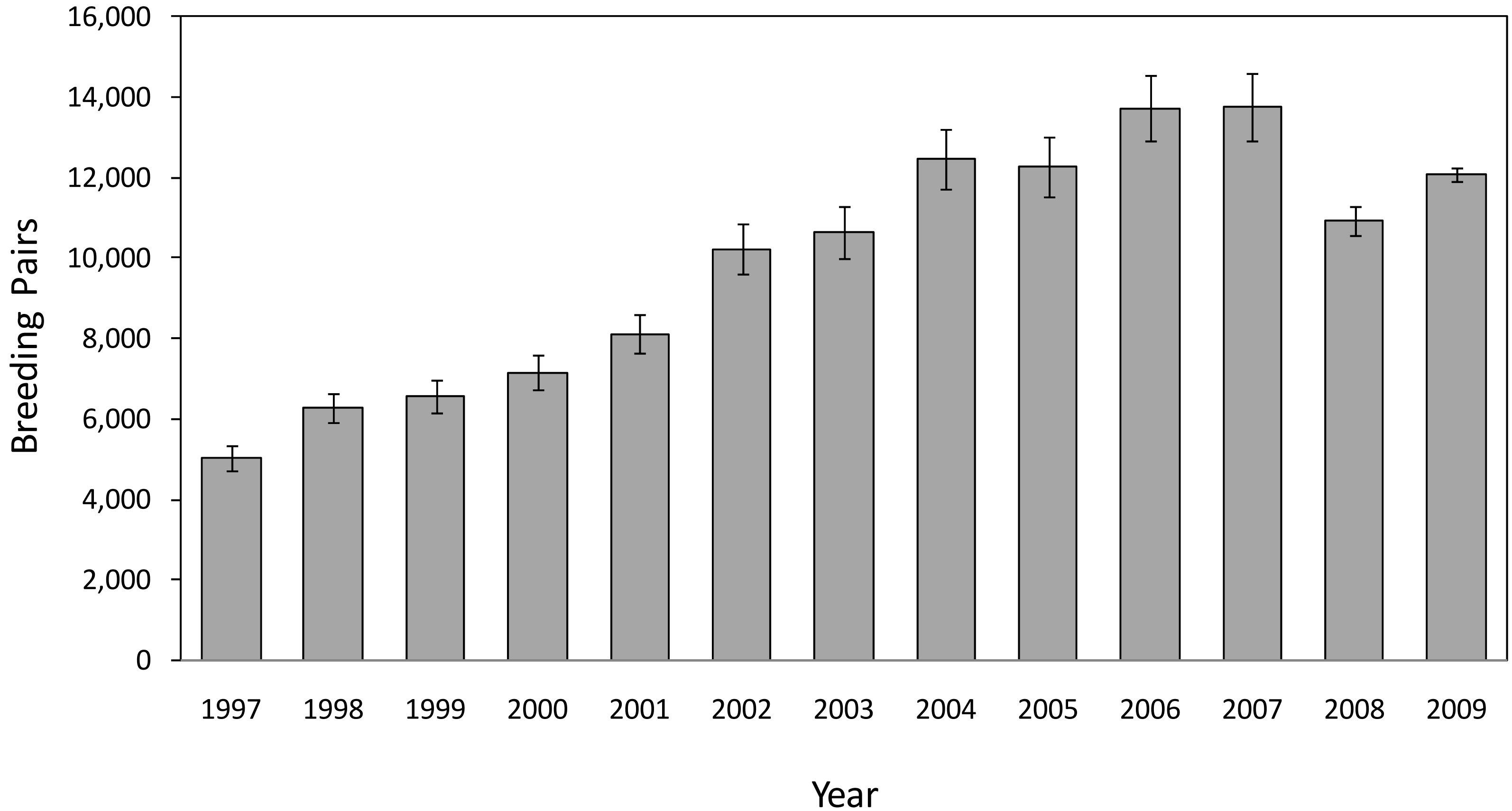


Figure 23. Size of the double-crested cormorant nesting colony on East Sand Island, Columbia River estuary during 1997-2009. Error bars represent 95% confidence intervals for the number of breeding pairs.

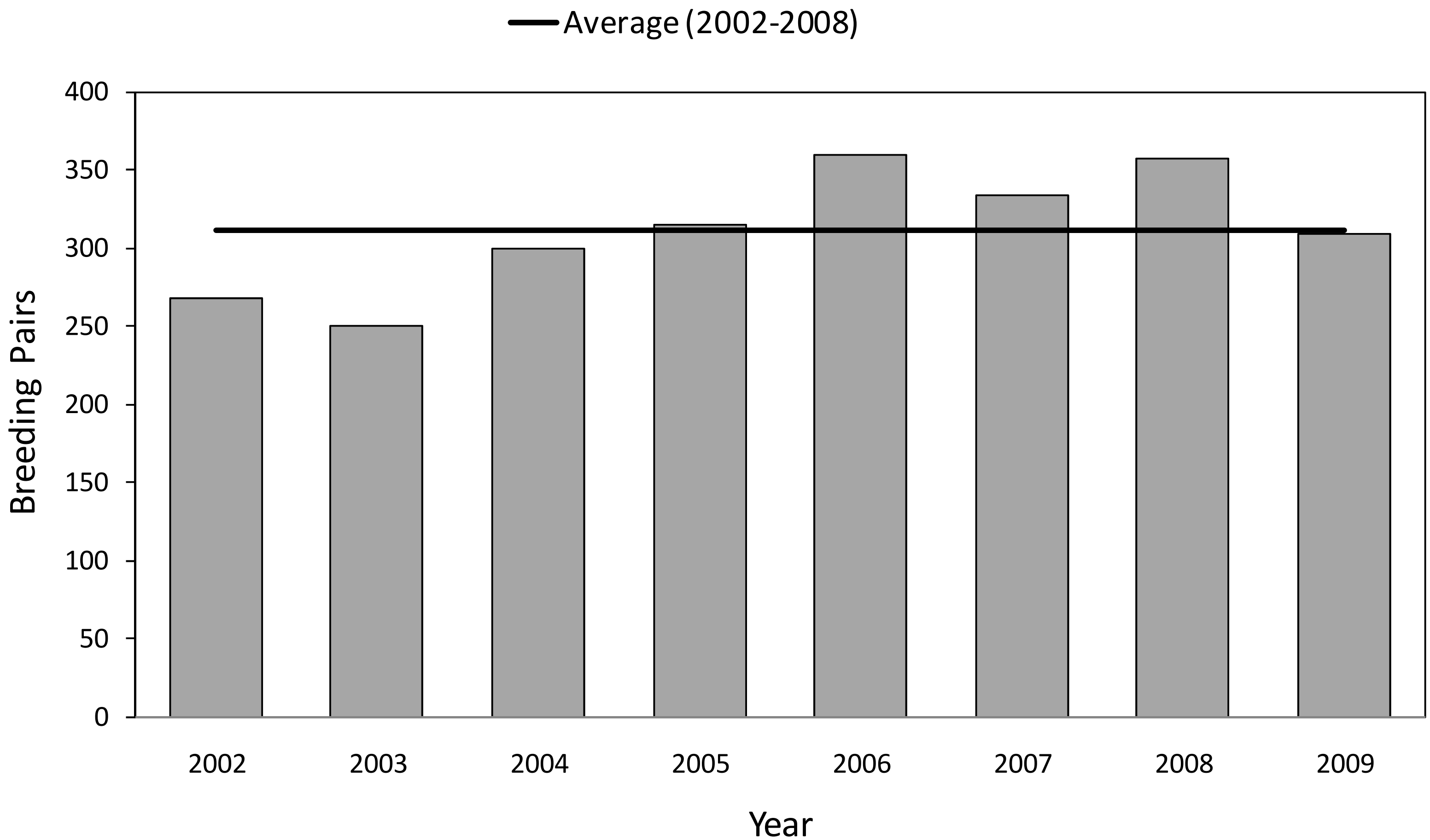


Figure 24. Size of the double-crested cormorant nesting colony on Foundation Island, mid-Columbia River during 2002-2009.

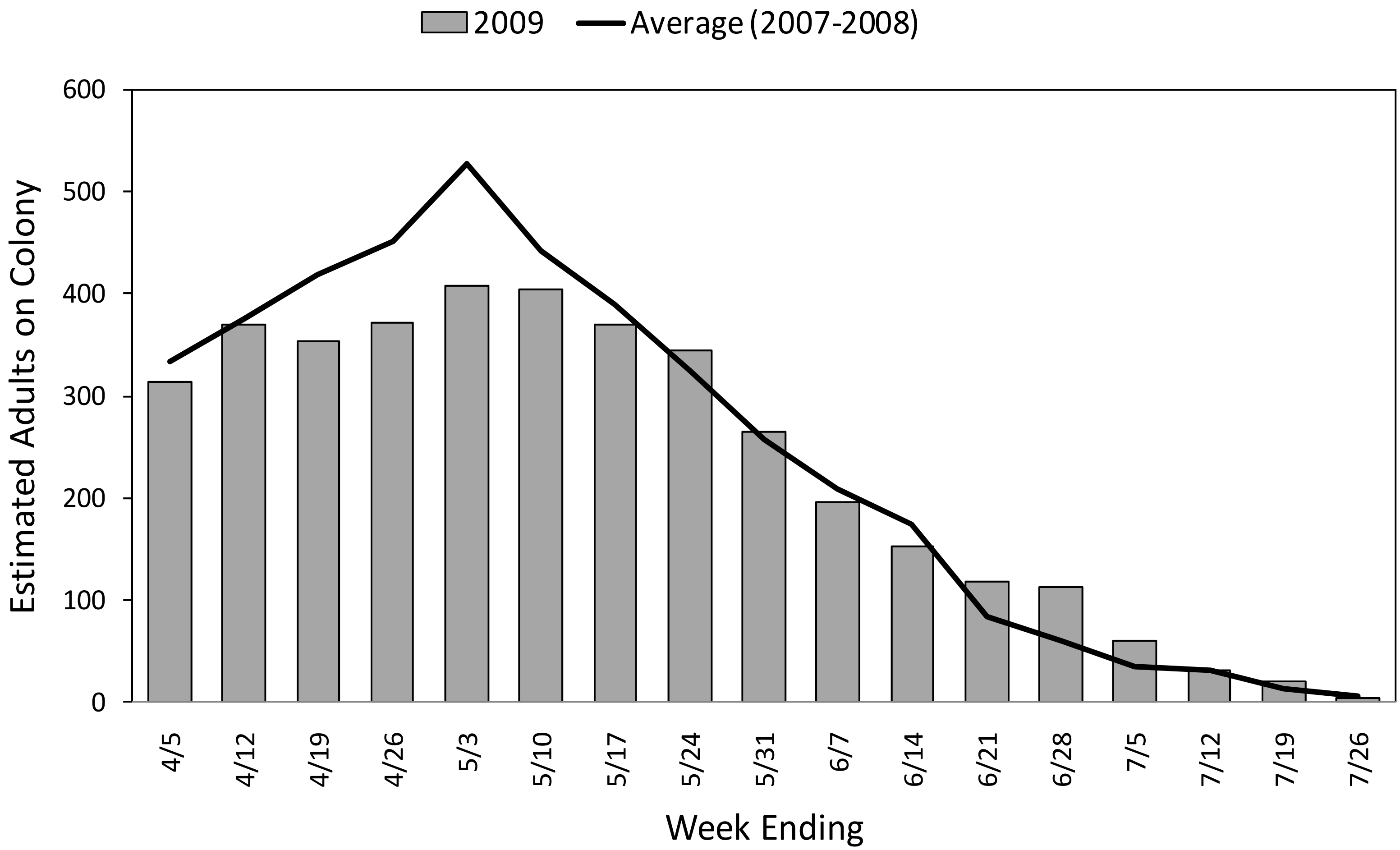


Figure 25. Weekly estimates from the ground of the number of adult double-crested cormorants on the Foundation Island colony on the mid-Columbia River in 2009.

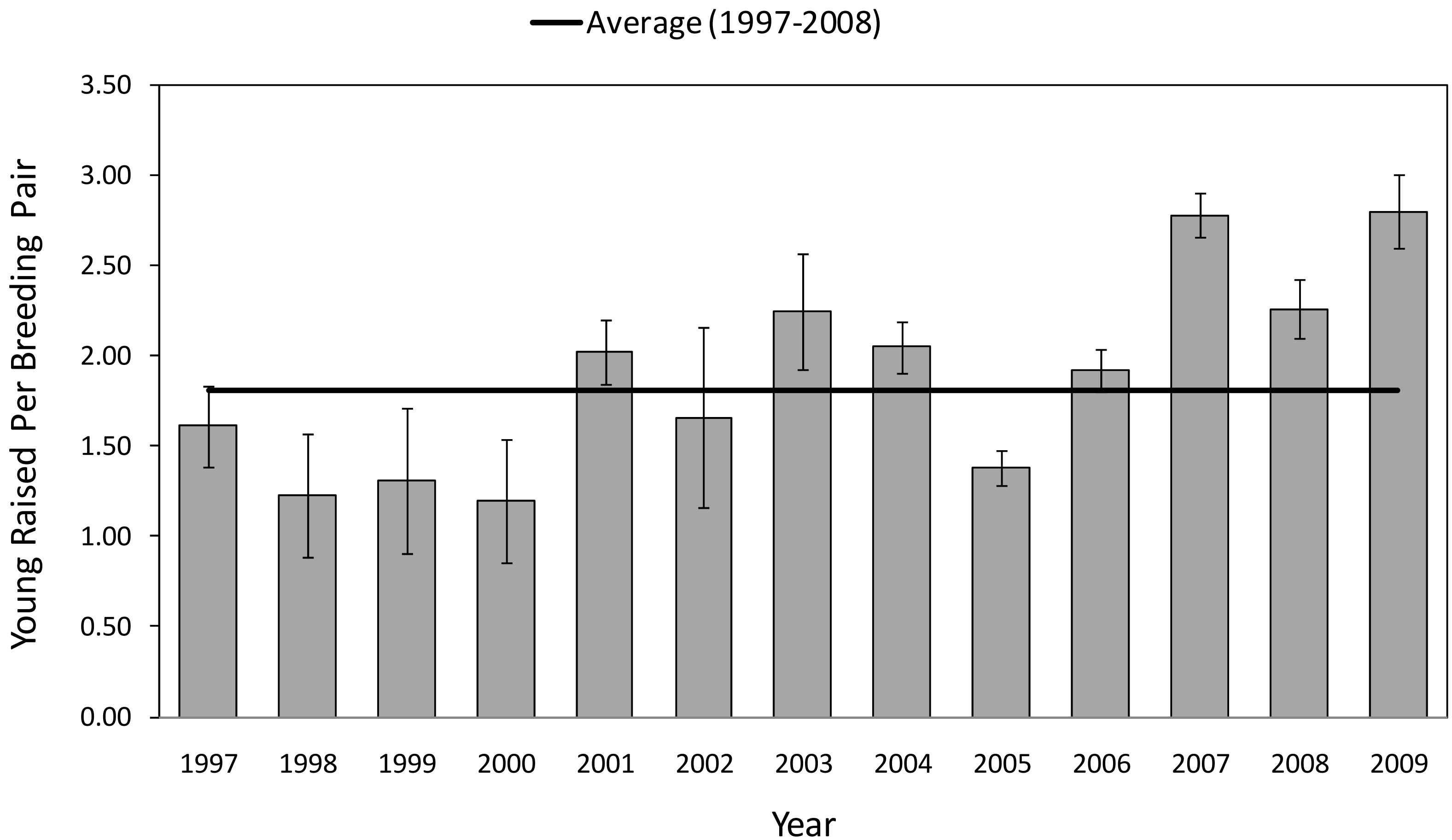


Figure 26. Double-crested cormorant nesting success at the East Sand Island colony during 1997-2009. Error bars represent 95% confidence intervals for the average number young raised per breeding pair.

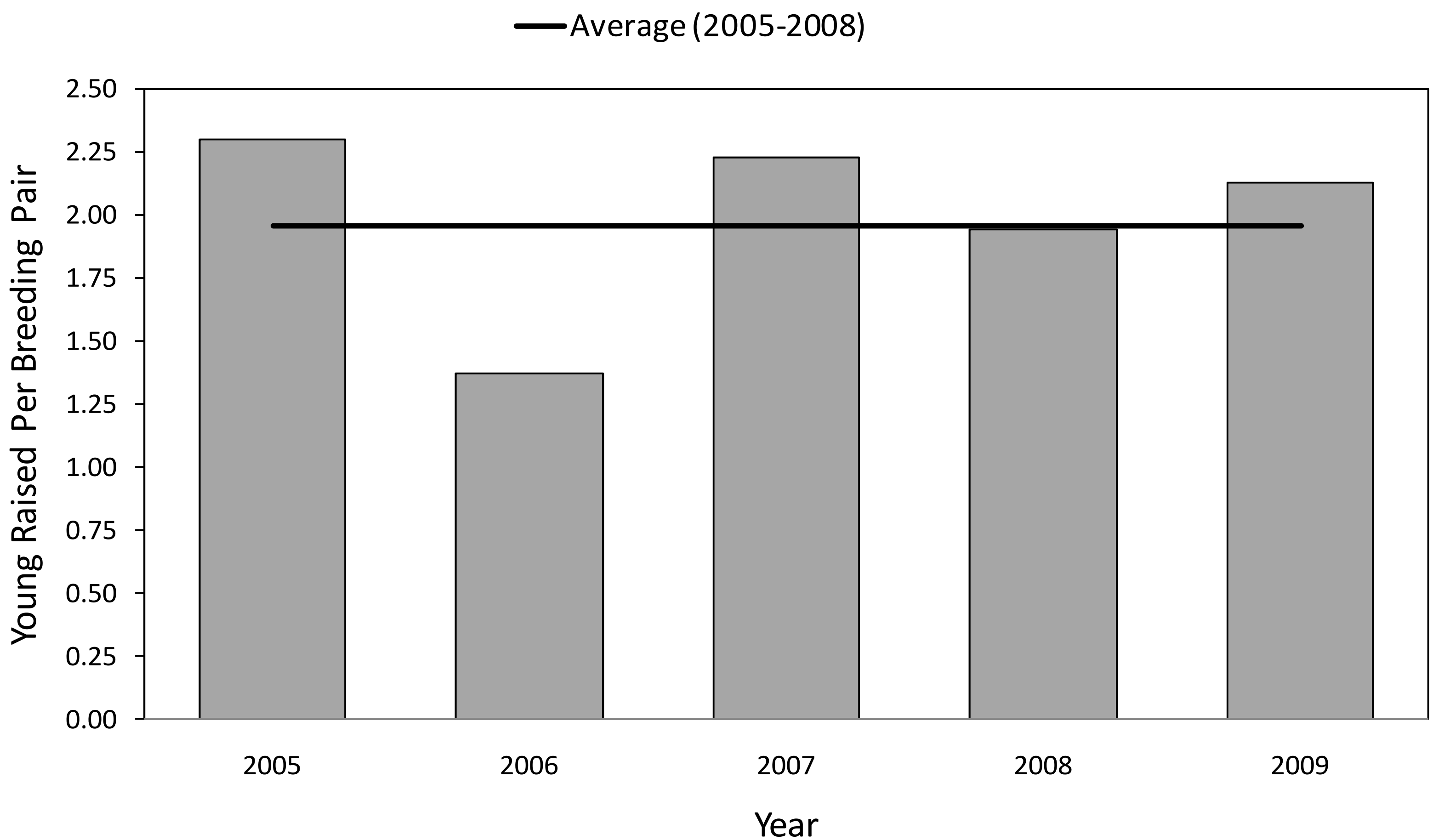


Figure 27. Double-crested cormorant nesting success at the Foundation Island colony during 2005-2009.

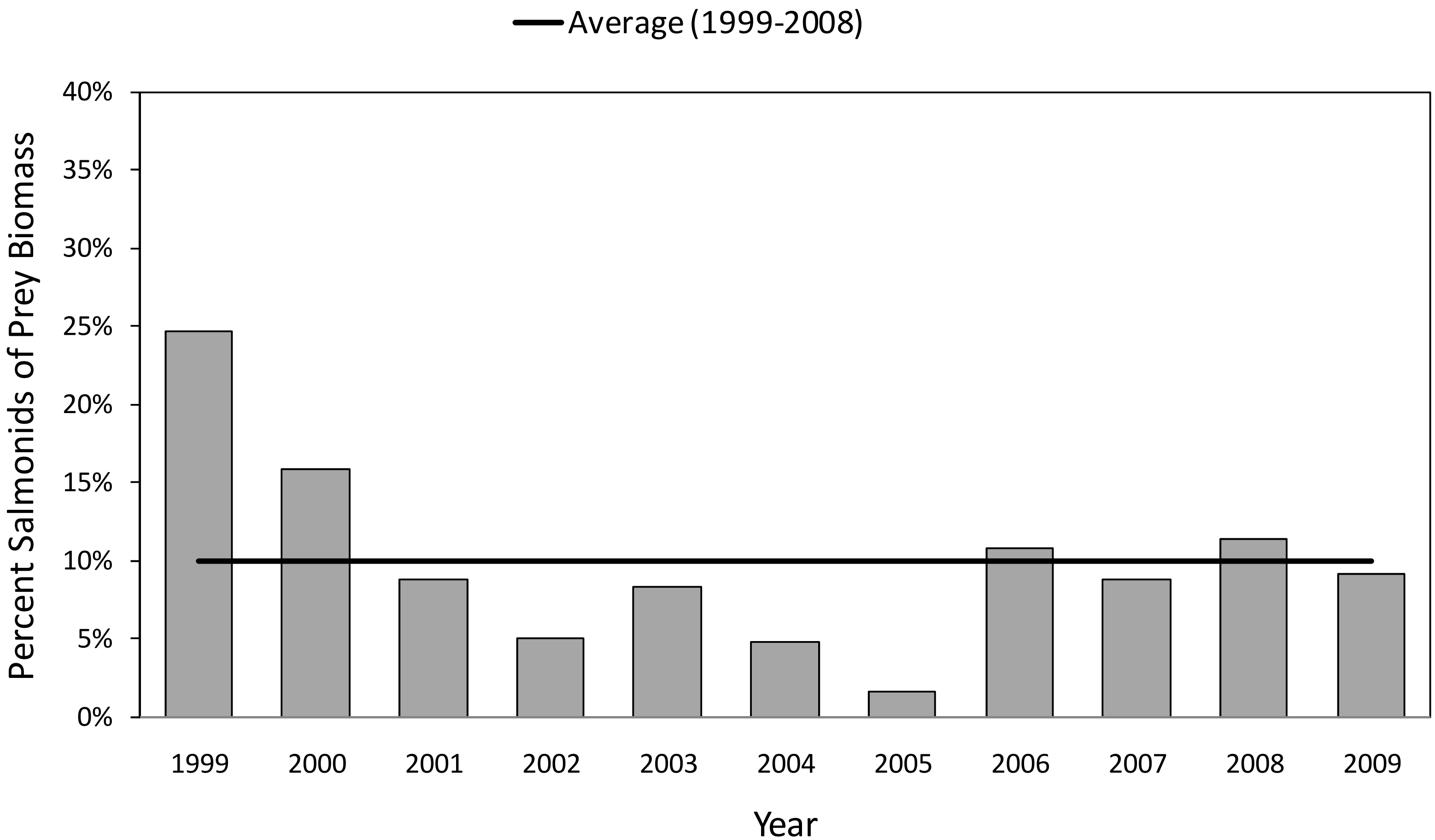


Figure 28. Average annual proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island during 1999-2009.

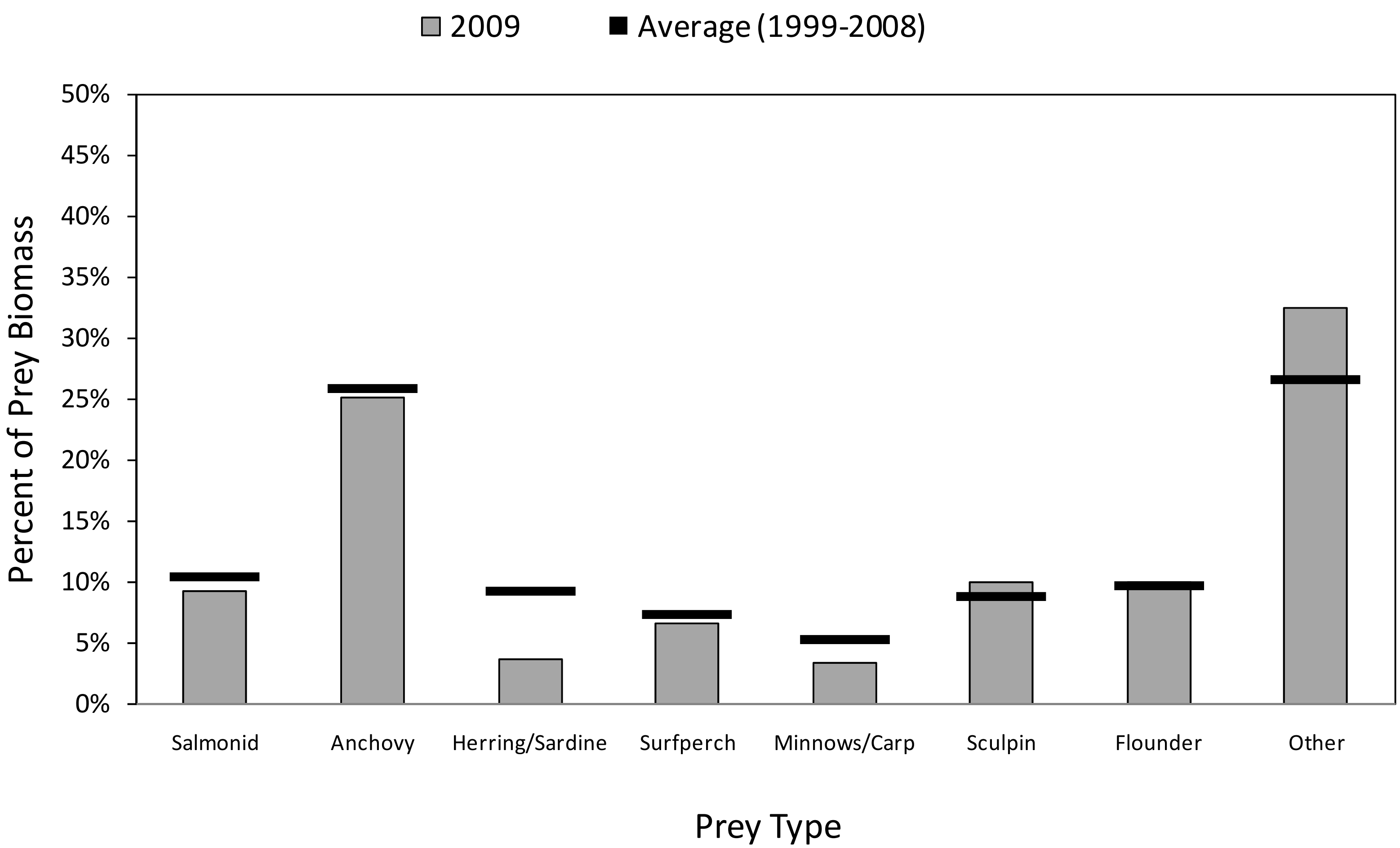


Figure 29. Diet composition of double-crested cormorants nesting on East Sand Island in 2009.

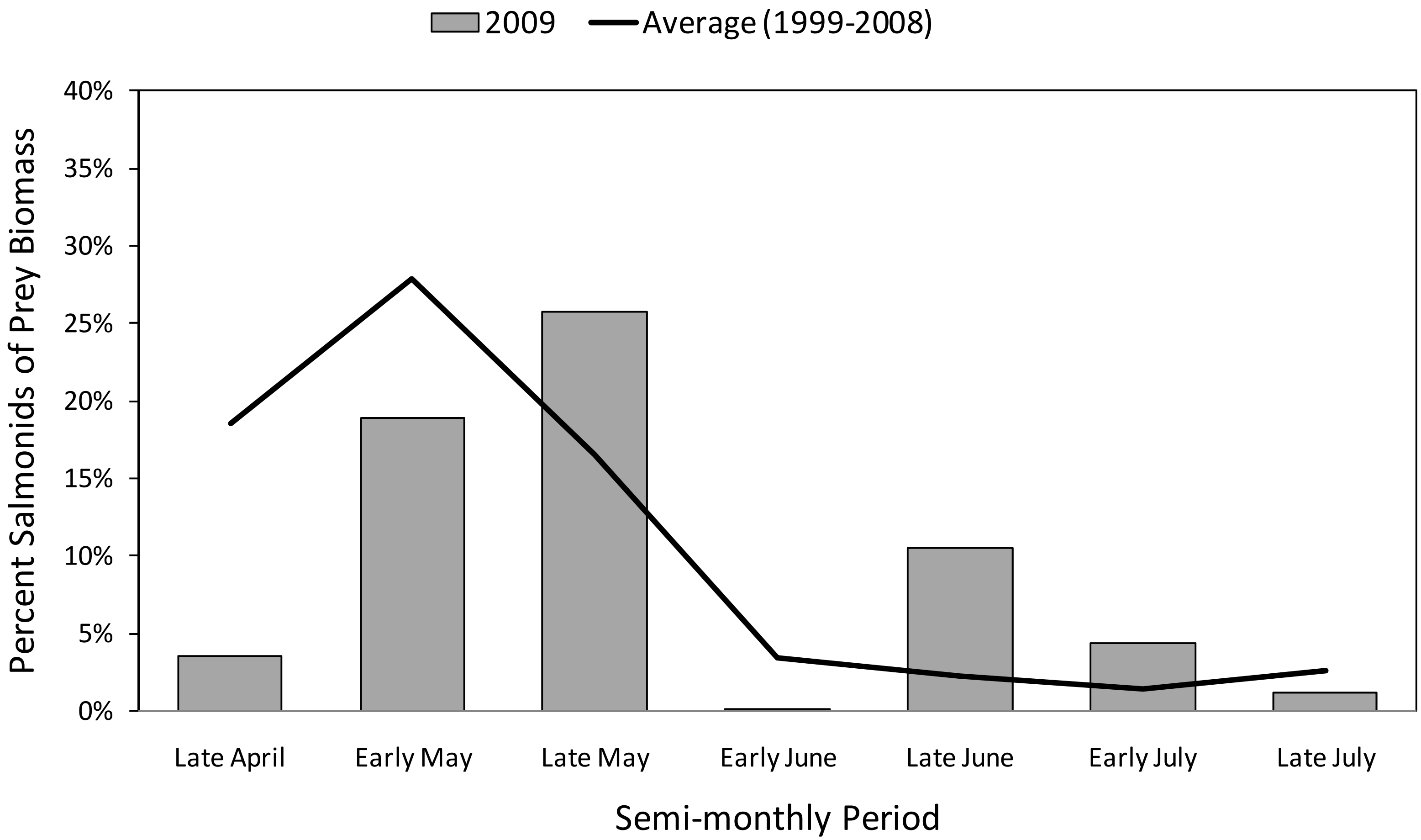


Figure 30. Seasonal trend in the proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in 2009, by half-month period.

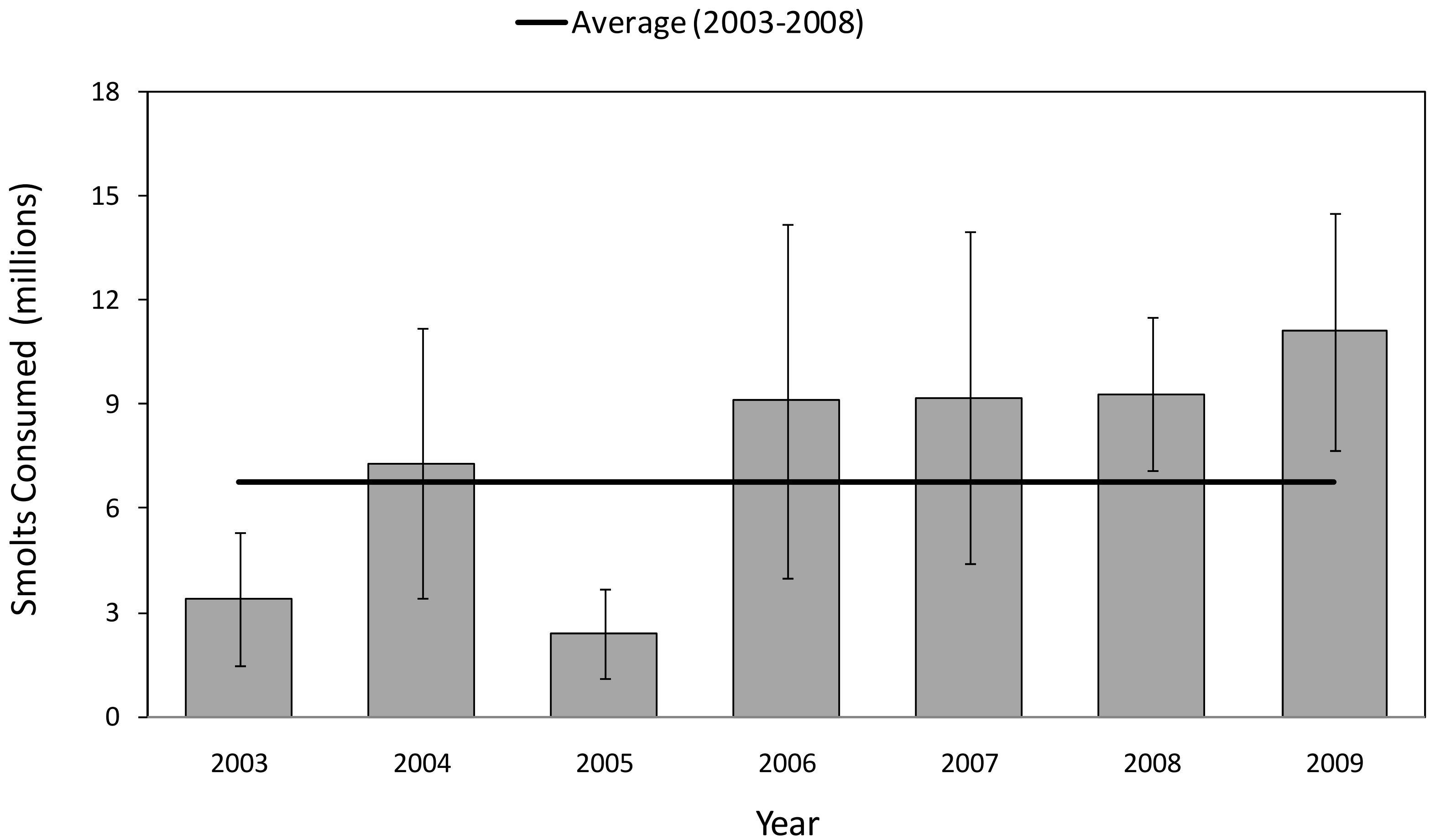


Figure 31. Estimated total annual consumption of juvenile salmonids by double-crested cormorants nesting on East Sand Island during 2003-2009. Error bars represent 95% confidence intervals for the number of smolts consumed.

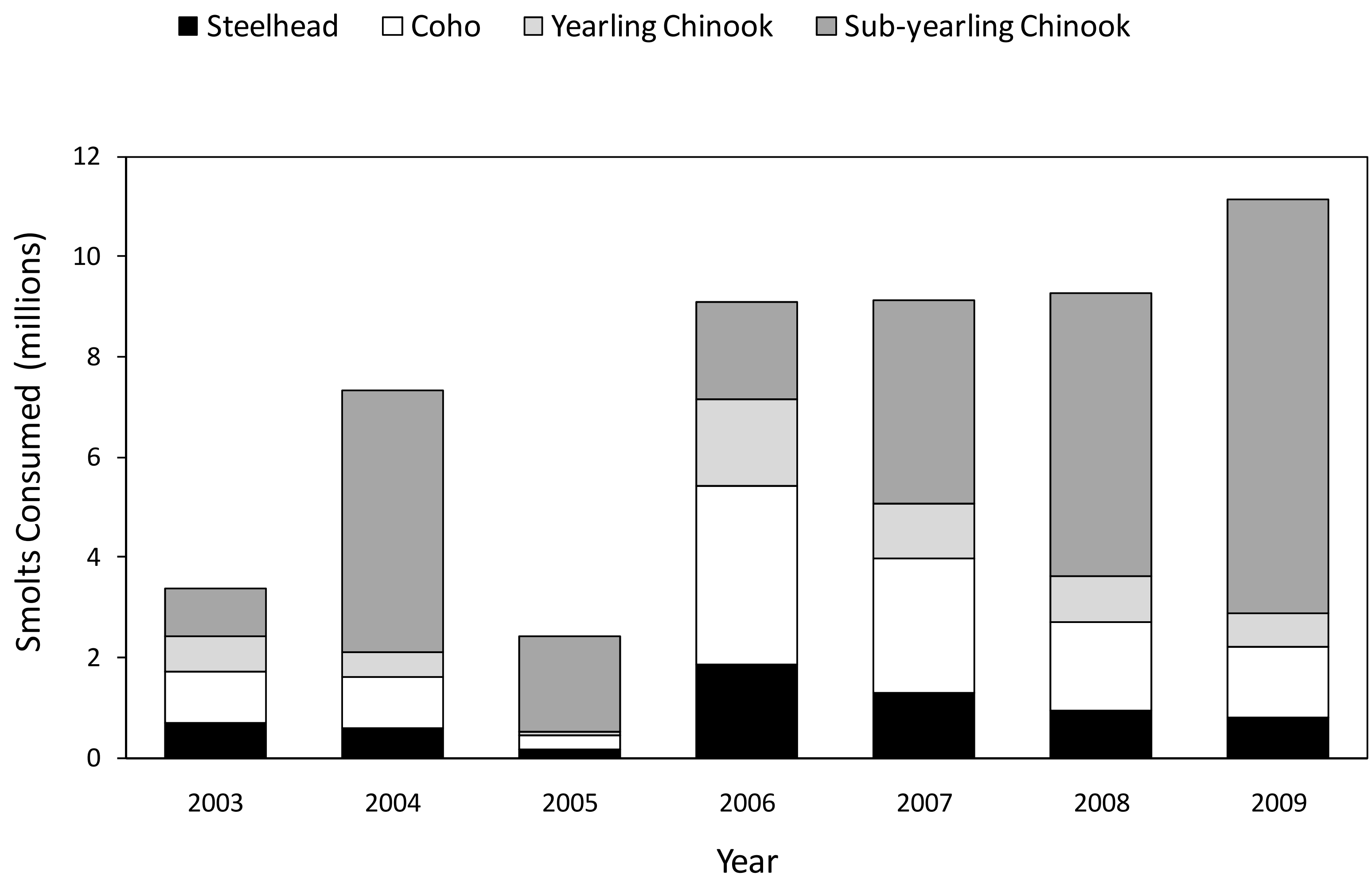


Figure 32. Estimated total annual consumption of juvenile salmonids from four species/run types by double-crested cormorants nesting on East Sand Island in the Columbia River estuary during 2003-2009.

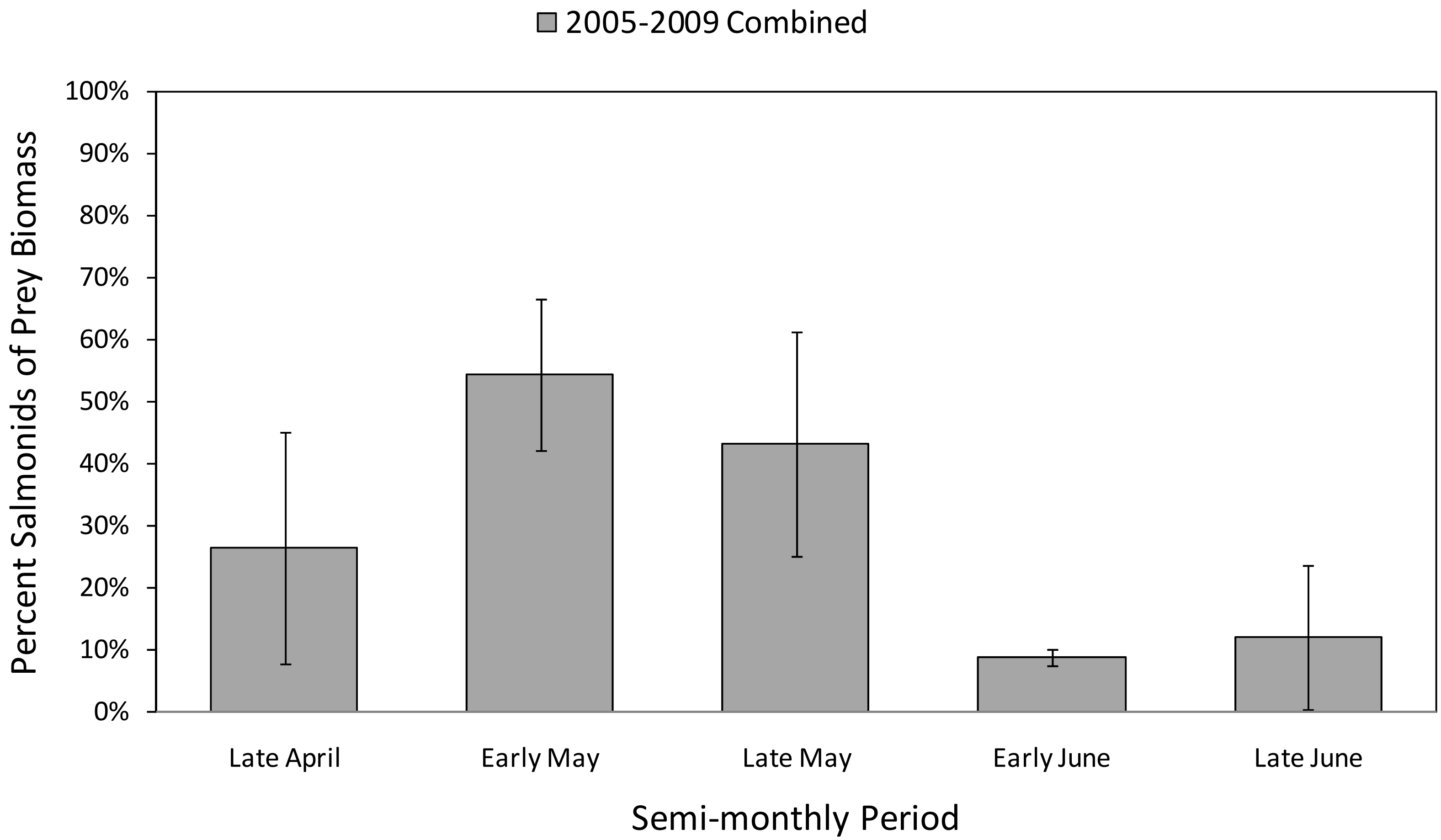


Figure 33. Average proportion of juvenile salmonids in the diet of double-crested cormorants nesting on Foundation Island during 2005-2009, by half-month period.

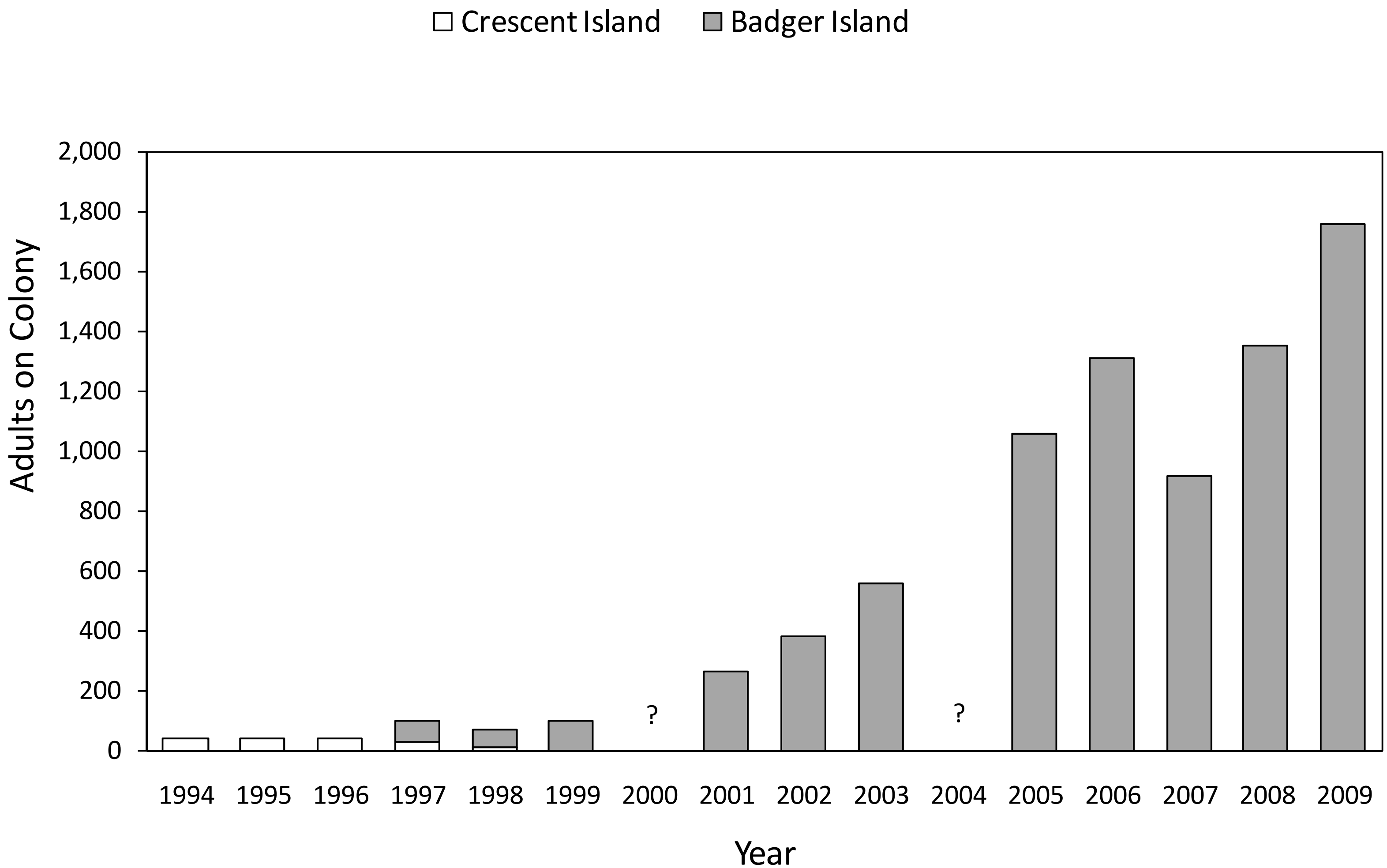
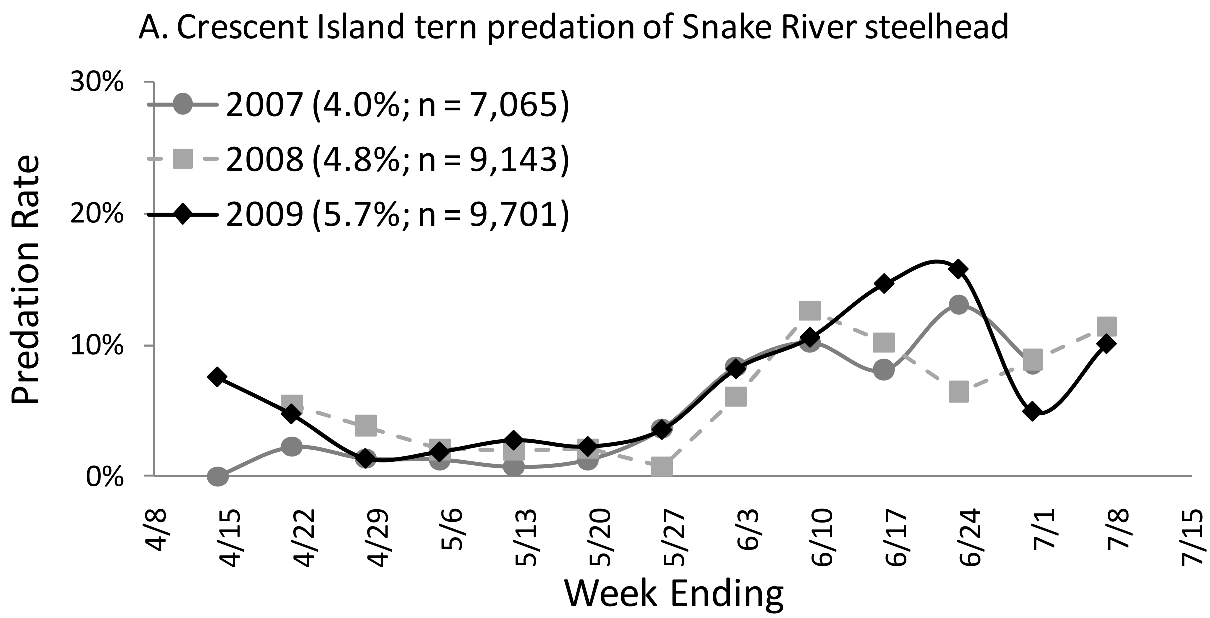


Figure 34. Population trends for American white pelicans nesting on two islands on the mid-Columbia River during 1994-2009. Missing bars indicate that no colony counts were conducted during that year.



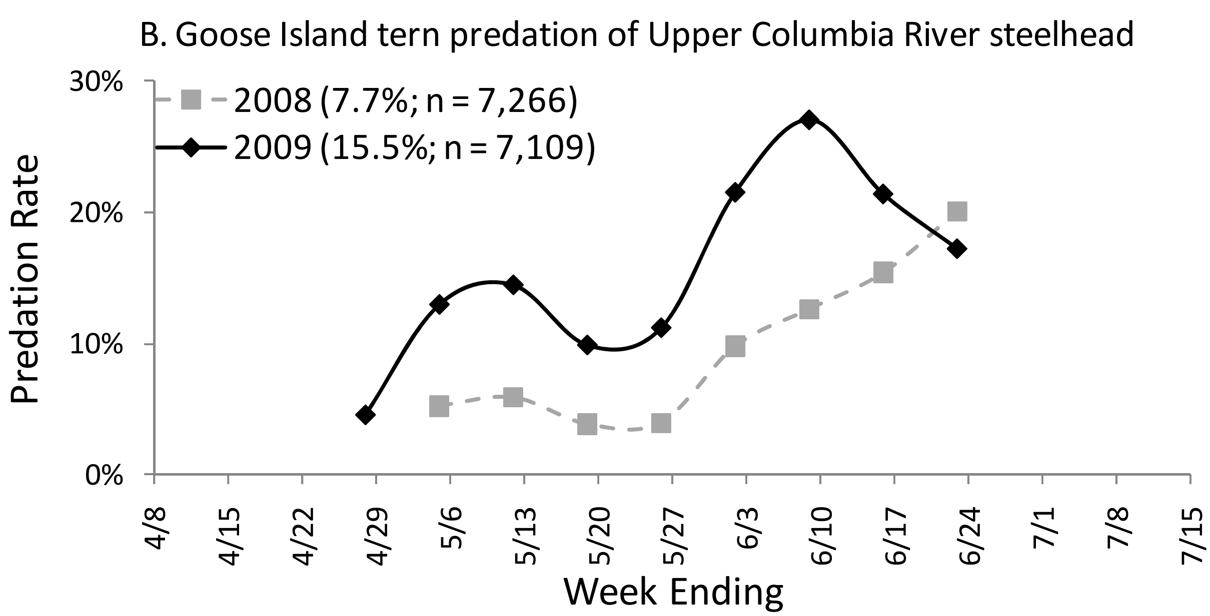


Figure 35. Estimated predation rates by week of (A) PIT-tagged Snake River steelhead (released at Lower Monumental and Ice Harbor dams) by Crescent Island Caspian terns and (B) PIT-tagged Upper Columbia River steelhead (released at Rock Island Dam) by Goose Island (Potholes) Caspian terns. Estimates are separated by migration year, with annual predation rates and number of released steelhead in parentheses. Percentages were corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for deposition rates, and therefore are minimum estimates.

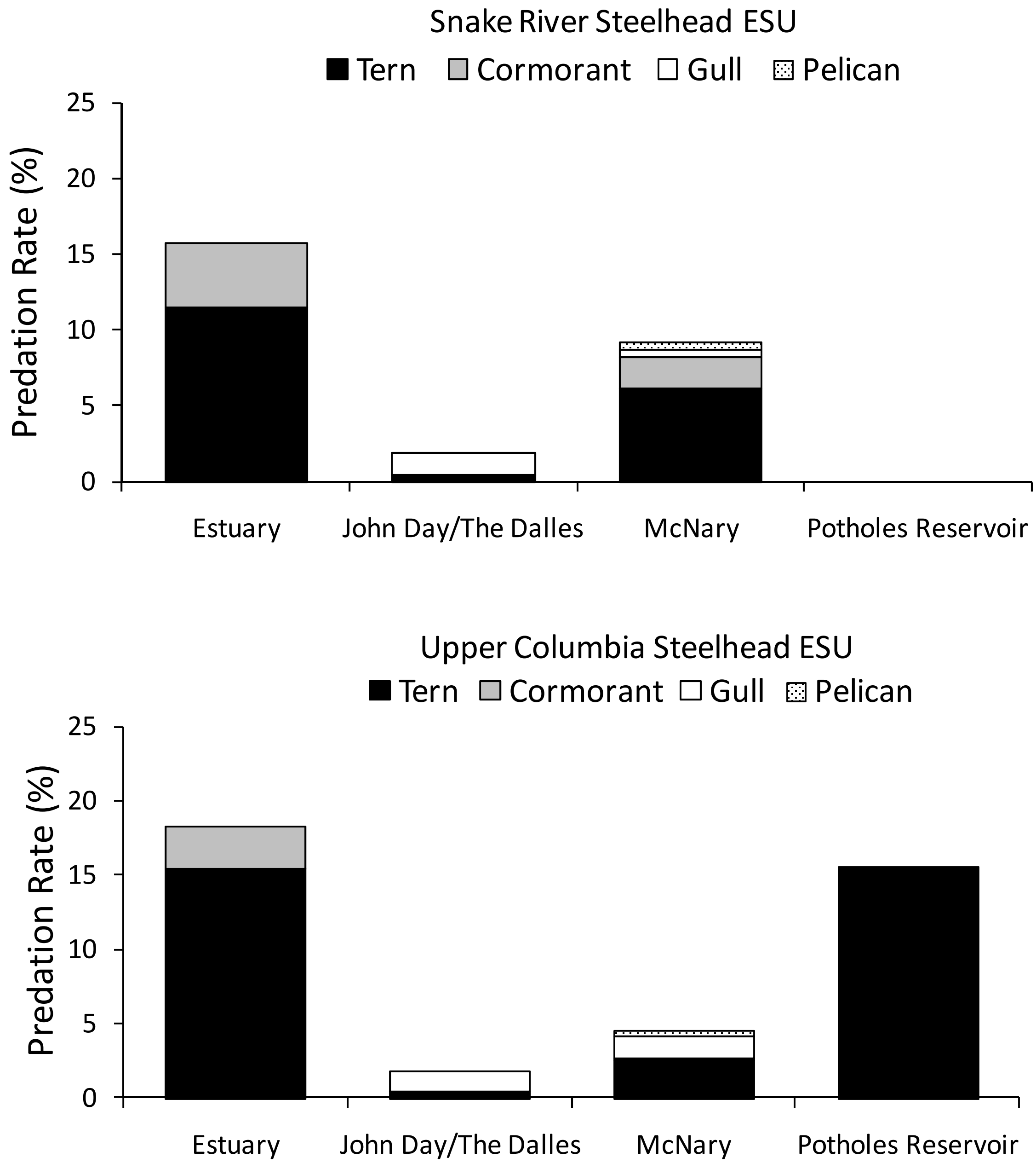


Figure 36. Estimated reach-specific predation rates on steelhead smolts tagged and released at Lower Monumental and Ice Harbor dams (n = 8,285; Snake River ESU) and Rock Island Dam (n = 7,109; Upper Columbia River ESU) by avian predators nesting on islands in the Columbia River basin in 2009. Estimates represent the number of released smolts surviving to each river reach that were subsequently consumed by avian predators nesting in that reach. Predation rates were corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for deposition rates, and therefore are minimum estimates.

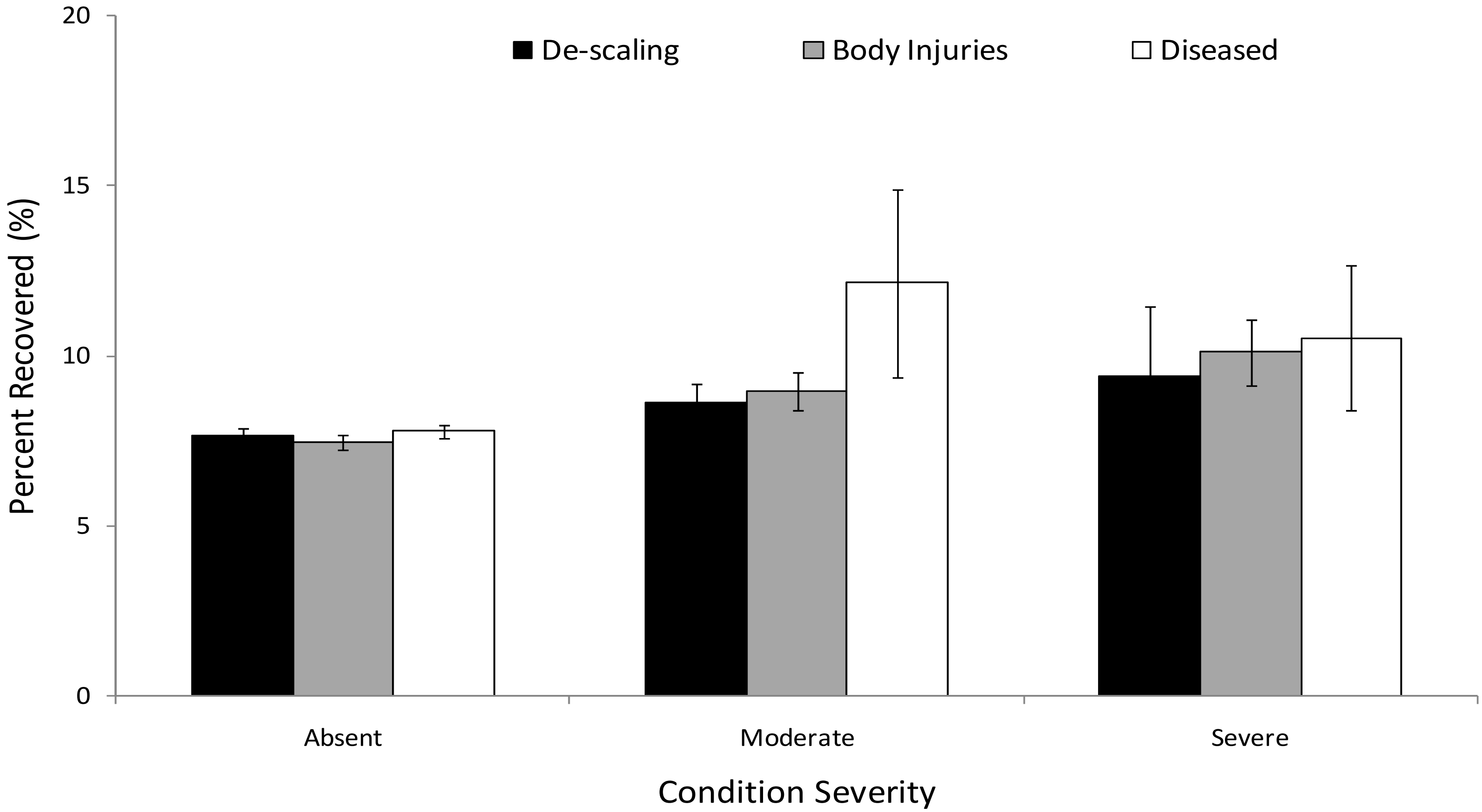


Figure 37. The percentage of steelhead smolts PIT-tagged and released at Lower Monumental, Ice Harbor, and Rock Island dams in 2009 (n = 16,810) that were subsequently recovered on a bird colony in McNary Pool or Potholes Reservoir as a function of the externally-detectable damage to a fish at the time of release. Error bars represent one standard error.

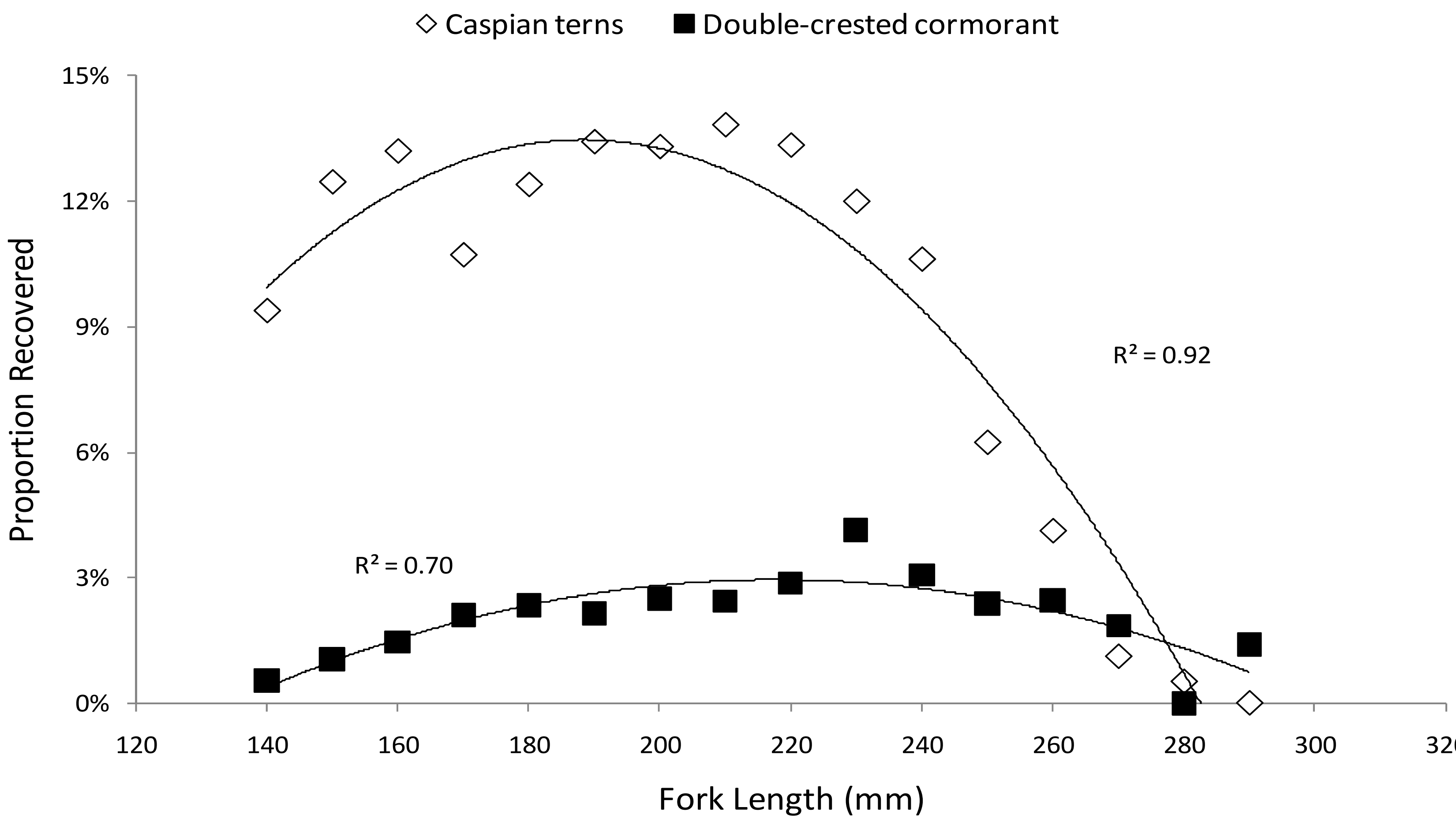


Figure 38. Predation rates on PIT-tagged steelhead smolts by Caspian terns and double-crested cormorants nesting in the Columbia River basin as a function of fish length. Each data point represents the proportion of released PIT-tagged steelhead from Snake River and Upper Columbia River ESUs (n = 16,810) in that size range that was subsequently recovered on a tern or cormorant colony in the Columbia River basin during 2009.

Table 1. Estimates of numbers of piscivorous waterbirds at breeding colonies in the Columbia River basin and along the southwest Washington coast in 2009. Species include American white pelican (AWPE), brown pelican (BRPE), Caspian tern (CATE), double-crested cormorant (DCCO), Brandt's cormorant (BRAC), California gull (CAGU), ring-billed gull (RBGU), and glaucous-winged/western gull (GWGU/WEGU). Counts of terns and cormorants are the number of breeding pairs, counts of gull spp. and American white pelicans are of the number of adults on colony, and the count of brown pelicans is the peak number of roosting individuals; all other counts are of numbers of adults on colony.

		Colony Size	Nesting success (fledglings/breeding pair)	Salmonids in diet (percent of prey items)	Smolt PIT tags recovered on colony in 2009[1]	Smolts consumed (millions)	
Location/Colony	Species	2009 Data					Notes
Columbia River Basin							
East Sand Is.	CATE	9,854	0.60	37.0	41,897	6.40	
	DCCO	12,087	2.80	9.2	35,895	11.10	
	BRAC	684			176		
	RBGU	2,237					
	GWGU/WEGU	6,172					
	BRPE	16,850					
Rice Is.	GWGU/WEGU	1,741					
	RBGU	307					
Miller Sands Spit	GWGU/WEGU	160					
Miller Rocks	CAGU	5,272			5,301		3,954 breeding pairs[2]
	RBGU	744			108		558 breeding pairs[2]
Three Mile Canyon Is.	CAGU	5,868					
	RBGU	293					
Blalock Is.	RBGU	691					
Rock Is.	CATE	79	0.00		1,510		Complete nest failure in 2009; cause unknown
	RBGU	940					
Crescent Is.	CATE	349	0.44	64.4	11,483	0.36	
	CAGU	8,575			2,531		
Badger Is.	AWPE	1,754			2,061		Minimum counts due to obscured view
Foundation Is.	DCCO	309	2.13		10,011		Minimum counts due to obscured view
Island 20	CAGU	9,946					
	RBGU	9,395					
Okanogan	DCCO	36					
Potholes Reservoir	CATE	487			6,340		
	DCCO	809					Minimum counts due to obscured view
	CAGU	2,481					
	RBGU	10,541					
Sprague Lake	CATE	4					
	DCCO	42					
	CAGU	1,798					
	RBGU	4,504					
Banks Lake (Twining Is.)	CATE	61	0.33		57		
	CAGU	3,027					
	RBGU	244					
Banks Lake (Goose Is.)	CAGU	710					
	RBGU	2,621					
Coastal Washington							
Dungeness Spit	CATE	~1,500	0.00				Coyotes caused complete nest failure in 2009
	GWGU/WEGU						Colony present, size unknown

[1] The number of smolt PIT tags recovered on colony is adjusted for detection efficiency at each colony

[2] Counts of all adult gulls in aerial photographs at the Miller Rocks colony were corrected using ground counts of the ratio of incubating gulls on plots within the colony area (.75).

Table 2. Numbers of 2009 migration year salmonid PIT tags recovered on bird colonies in the Columbia River basin. PIT tags were recovered from the entire colony or from a sub-sample of the colony area (denoted by an asterisk). Colonies included American white pelicans (AWPE), Caspian terns (CATE), double-crested cormorants (DCCO), Brandt's cormorants (BRAC), and California, ring-billed, and glaucous-winged/western gulls (GULLS). The total number of tags deposited on-colony was estimated based on a correction for average PIT tag detection efficiency (see Table 3).

River Segment	Location	Colony	Recovered	Deposited
Off-river	Banks Lake	CATE	38	57
	Potholes Reservoir	CATE	2,948	6,340
McNary Pool	Foundation Island	DCCO	7,288	10,011
	Badger Island	AWPE	1,752	2,061
	Crescent	CATE	8,153	11,483
		Gulls	1,835	2,531
John Day Pool	Rock Island	CATE	1,268	1,510
	Three Mile Canyon	Gulls*	188	-
The Dalles Pool	Miller Rock Island	Gulls	4,297	5,509
Estuary	Rice Island	Gulls*	13	40
	East Sand Island	CATE	38,336	41,897
		DCCO	25,270	35,895
		BRCO	146	176
		Gulls*	4	20

Table 3. Average detection efficiency (DE) of test PIT tags sown on bird colonies in the Columbia River basin during 2009. PIT tags were distributed haphazardly throughout the entire colony or within experimental plots (denoted by an asterisk). Colonies included American white pelicans (AWPE), Caspian terns (CATE), double-crested cormorants (DCCO), Brandt's cormorants (BRAC) and California, ring-billed, and glaucous-winged/western gulls (GULLS). NR is the number of discrete release events when tags were sown on-colony and SD is the standard deviation among releases.

Location	Colony	Sample	NR	DE (SD)
Banks Lake	CATE	100	2	67.0 (46.7)
Potholes Reservoir	CATE	400	4	46.5 (22.3)
Foundation Island	DCCO	400	4	72.8 (9.8)
Badger Island	AWPE	200	2	85.0 (12.7)
Crescent Island	CATE	400	4	71.0 (36.6)
	Gull	200	2	72.5 (17.7)
Rock Island	CATE	100	2	84.0 (22.6)
Three Mile Canyon	Gull	-	-	-
Miller Rock Island	Gull	200	2	78.0 (12.7)
Rice Island	Gull*	200	2	32.5 (14.8)
East Sand Island	CATE	600	4	91.5 (7.0)
	DCCO	600	2	70.4 (12.7)
	BRCO	100	2	83.0 (15.6)
	Gull*	200	2	20.0 (11.3)

Table 4. Estimated predation rates on PIT-tagged salmonid smolts by Caspian terns (CATE) and double-crested cormorants (DCCO) nesting on East Sand Island in 2009. Predation rates are based on the number of PIT-tagged fish interrogated (I) passing Bonneville Dam (In-river) or released (Rel) from transportation barges directly below Bonneville Dam (Transport). Rearing-types are for hatchery (H), wild (W), and unknown (U) smolts, and run-types are for summer (Sum), spring/summer (Spr/Sum), fall, and unknown. Sample sizes of interrogated/released fish < 100 were not included in the analysis. Predation rates were corrected for bias due to on-colony PIT tag detection efficiency (Table 3), but not deposition rates, and therefore are minimum estimates.

		In-river			**Transport**		
Species/Run-Type	Rear-type	No. I	CATE	DCCO	No. Rel	CATE	DCCO
Sum Steelhead	Wild	3,725	11.6%	6.3%	7,232	9.5%	3.8%
	Hatchery	25,540	10.3%	7.0%	23,472	11.1%	5.7%
Spr/Sum Chinook	Wild	2,779	1.2%	2.7%	2,985	0.8%	2.1%
	Hatchery	28,502	3.1%	2.5%	27,279	3.2%	3.2%
	Unknown	731	2.2%	2.3%	---	---	---
Fall Chinook	Wild	215	2.0%	0.7%	---	---	---
	Hatchery	31,001	1.4%	3.4%	19,288	1.2%	2.8%
	Unknown	473	4.2%	2.1%	---	---	---
Unknown Chinook	Wild	1,861	0.9%	3.1%	7,490	1.0%	2.4%
	Hatchery	24,117	3.4%	3.0%	531	4.1%	3.5%
	Unknown	5,725	2.1%	2.4%	---	---	---
Coho	Hatchery	4,132	4.7%	1.1%	---	---	---
Sockeye	Hatchery	1,842	0.8%	2.5%	4,478	0.8%	3.6%
	Unknown	209	< 0.1%	2.0%	---	---	---
	Wild	272	0.8%	3.7%	---	---	---

Table 5. Estimated per-capita consumption of 2009 migration year PIT-tagged salmonid smolts by Caspian terns (CATE), double-crested cormorants (DCCO), American white pelicans (AWPE), and California, ring-billed, and glaucous-winged/western gulls (GULLS) nesting at various locations in the Columbia River basin. Tagged juvenile salmonids included steelhead, Chinook salmon, coho salmon, and sockeye salmon. Values for per capita consumption were corrected for PIT tag detection efficiency, but not deposition, and therefore are minimums. PIT tags were recovered from nesting locations using two different approaches: recoveries from the entire colony (C) or from plots within the colony (P). Estimates of per capita PIT tag consumption were derived by dividing the total number of tags recovered (R; corrected for detection efficiency) by the estimated number of breeding adults on the colony or in the plots.

River Segment / Avian Colony (breeding individuals)	Approach	R	Steelhead	Chinook	Coho	Sockeye	Total
Inland Reservoirs and Lakes							
Potholes Reservoir CATE (972)	C	6,340	4.6	1.4	0.5	<0.1	6.5
Potholes Reservoir DCCO (236)	P	20[1]	<0.1	<0.1	<0.1	<0.1	0.1
Banks Lake CATE (122)	C	84	0.3	0.1	<0.1	0.0	0.5
McNary Pool							
Badger Island AWPE (2,632)[2]	C	2,041	0.2	0.5	<0.1	0.0	0.7
Foundation Island DCCO (618)	C	10,018	6.6	8.8	0.2	0.6	16.2
Crescent Island CATE (698)	C	11,485	7.7	8.1	0.6	0.2	16.5
Crescent Island Gull (12,862)[2]	C	2,524	0.1	<0.1	<0.1	<0.1	0.2
John Day Pool							
Rock Island CATE (158)	C	1,510	5.1	4.1	0.2	0.1	9.6
Three Mile Canyon Gull (5,268)[2]	P	330[1]	<0.1	<0.1	<0.1	<0.1	<0.1
The Dallas Pool							
Miller Rocks Gulls (9,028)[2]	C	5,409	0.3	0.3	<0.1	<0.1	0.6
Columbia River Estuary							
Rice Island Gull (148)[2]	P	34	0.2	0.0	0.0	0.0	0.2
East Sand Island Gull (236)[2]	P	20	<0.1	<0.1	0.0	0.0	0.1
East Sand Island CATE (19,708)	C	41,905	1.2	0.8	<0.1	<0.1	2.1
East Sand Island DCCO (24,174)	C	35,895	0.5	0.9	<0.1	<0.1	1.5
East Sand Island BRCO (1,368)	C	176	<0.1	0.1	<0.1	<0.1	0.1

[1] Raw number of PIT tags recovered, no measure of detection efficiency available
[2] Number of breeding individuals calculated by multiplying the total number of adults on-colony by 0.75 (estimated proportion of adults on colony that were attending nests) and then multiplying that number by two (estimated number of breeding individuals)

Table 6. Estimated predation rates on PIT-tagged salmonid smolts last detected in the vicinity of McNary Pool by avian predators nesting at colonies in McNary Pool during 2009. Colonies include American white pelicans (AWPE) on Badger Island, Caspian terns (CATE) on Crescent Island, double-crested cormorants (DCCO) on Foundation Island, and California and ring-billed gulls (GULLS) on Crescent Island. Predation rates are based on the proportions of fish interrogated/tagged at Lower Monumental Dam (LMO), Rock Island Dam (RIS), or in the McNary Pool (McP; fish tagged and released below Priest Rapids and Ice Harbor dams but upstream of McNary Dam) that were subsequently detected on-colony. Predation rates on hatchery-reared (H), wild (W), and unknown (U) rearing-type smolts are listed separately. Chinook salmon are designated by run-type as spring/summer (Spr/Sum), Fall, or Unknown. Sample sizes (N) of interrogated/tagged fish < 100 were excluded. Predation rates were corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not deposition, and therefore are minimum estimates.

				Predation Rate				
Location	Species/Run-type	Rear-type	N	CATE	DCCO	Gulls	AWPE	All
LMO	Steelhead	Hatchery	43,954	2.9%	1.8%	0.7%	0.4%	5.7%
		Wild	8,091	4.8%	1.7%	0.6%	0.2%	7.3%
	Spr/Sum Chinook	Hatchery	16,214	0.9%	1.0%	0.1%	0.2%	2.2%
		Wild	4,554	1.4%	0.6%	0.1%	0.1%	2.2%
	Fall Chinook	Hatchery	26,057	0.6%	0.5%	0.1%	0.1%	1.3%
		Unknown	1,141	2.9%	0.9%	0.1%	0.6%	4.5%
	Unknown Chinook	Hatchery	12,486	1.3%	1.0%	0.2%	0.1%	2.6%
		Wild	4,396	1.4%	0.8%	0.1%	0.1%	2.2%
	Sockeye	Hatchery	2,596	0.6%	2.1%	0.4%	0.0%	3.0%
RIS	Steelhead	Hatchery	5,281	1.6%	0.2%	1.2%	0.3%	3.3%
		Wild	1,945	1.6%	0.0%	0.4%	0.1%	2.1%
	Spr/Sum Chinook	Unknown	2,085	0.0%	0.0%	0.0%	0.0%	0.0%
	Sockeye	Unknown	2,059	0.1%	0.0%	0.1%	0.0%	0.2%
	Coho	Hatchery	550	0.8%	0.0%	0.2%	0.0%	1.0%
McP	Steelhead	Hatchery	14,999	0.9%	4.0%	0.2%	0.2%	5.3%
		Wild	5,455	1.0%	1.7%	0.1%	0.1%	2.8%
	Spr/Sum Chinook	Hatchery	79,842	0.2%	0.8%	0.0%	0.6%	1.6%
		Wild	5,746	0.1%	0.1%	0.0%	0.1%	0.3%
		Unknown	5,963	0.4%	2.3%	0.0%	0.2%	3.0%
	Fall Chinook	Hatchery	19,141	0.8%	1.2%	0.0%	0.3%	2.3%
		Wild	728	0.4%	0.0%	0.0%	1.1%	1.5%
	Coho	Hatchery	63,135	0.3%	0.1%	0.1%	0.1%	0.6%
		Wild	3,618	0.3%	0.0%	0.0%	0.2%	0.4%

Table 7. Caspian tern nesting island construction as part of the federal agencies' Caspian Tern Management Plan (USFWS 2005, 2006) that has been completed to date.

Location	Site	Construction date	Island Type	Island Size (acre)	Acreage available in 2010	Notes:
Fern Ridge Lake	Fern Ridge	Feb 2008	Rock core	1.0	1.0	
Crump Lake	Crump Lake	Mar 2008	Rock core	1.0	1.0	
Summer Lake Wildlife Area	East Link Pond	Jan 2009	Rock core	0.5	0.5	
	Dutchy Lake	Mar 2009	Floating island	0.5	0.5	
	Gold Dike	Sep 2009	Rock core	0.5		No water
Tule Lake NWR	Sump 1B	Aug 2009	Rock core	2.0		No water in May
Lower Klamath NWR	Orems Unit	Sep 2009	Mud core	1.0		No water
	Sheepy Lake	Mar 2010	Floating island	0.8	0.8	
			TOTAL	**7.3**	**3.8**	

Table 8. Average number of double-crested cormorants observed over-wintering on the lower Snake River during four monthly surveys conducted from November 2009 to February 2010. River reaches were from the mouth of the Snake River (SR) to Ice Harbor Dam (IHR), from Ice Harbor Dam to Lower Monumental Dam (LMN), from Lower Monumental Dam to Little Goose Dam (LGS), from Little Goose Dam to Lower Granite Dam (LWG), and from Lower Granite Dam to Swallows Park, 4 Rkm above the mouth of the Clearwater River (SWP).

	Survey Month			
River Reach (Rkm Distance)	November	December	January	February
SR to IHR (16)	79	111	43	47
IHR to LMN (51)	38	27	18	30
LMN to LGS (46)	52	32	23	14
LGS to LWG (60)	46	43	36	42
LWR to SWP (56)	57	44	40	67
TOTAL (229)	**272**	**257**	**159**	**200**

Table 9. Percentages of double-crested cormorants observed over-wintering along the lower Snake River that were recorded at the dams (i.e., Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, or Lower Granite Dam). Data are based on counts of cormorants conducted during four monthly river surveys from November 2009 to February 2010.

	Distribution of Double-crested Cormorants	
Survey Month (total count)	At Dams	Away from Dams
November (395)	19%	81%
December (320)	35%	65%
January (180)	19%	81%
February (161)	8%	92%
AVERAGE	**20%**	**80%**

Table 10. The average number of piscivorous waterbirds observed over-winter on the lower Snake River during each of four monthly surveys conducted from November 2009 to February 2010. Piscivorous waterbirds were categorized as California and ring-billed gulls (Gulls), double-crested cormorants (Cormorants), Western and Clark's grebes (Grebes), common mergansers (Mergansers), and American white pelicans (Pelicans).

	Bird Species				
Survey Month	Gulls	Grebes	Cormorants	Pelicans	Mergansers
November	654	474	272	20	5
December	389	244	257	80	53
January	487	123	159	115	39
February	179	87	200	4	5
AVERAGE	**427**	**232**	**222**	**55**	**26**

Table 11. Diet composition (% identifiable prey biomass in stomach contents) of double-crested cormorants over-wintering on the lower Snake River. Cormorants were collected between Lower Monumental and Lower Granite dams during four 2-day collection periods from November 2009 to February 2010.

Date [a]	N	Salmonid	Shad	Minnows and Carp	Sunfish and Bass	Suckers	Perch	Catfish	Unid. Non-salmonid
11/16/09	9	23.5	26.0	22.2	12.4	11.1	0.0	0.0	4.7
12/8/09	10	24.7	25.3	10.0	10.0	10.0	2.5	10.0	7.5
1/13/10	7	1.5	0.0	0.0	66.6	0.0	2.7	8.9	20.4
2/12/10	9	0.0	0.0	0.0	30.3	30.7	8.6	9.4	20.3
AVERAGE	**35**	**12.4**	**12.8**	**8.1**	**29.8**	**5.9**	**3.4**	**7.1**	**13.2**

[a] Date listed is the first day of each of four monthly two-day collection periods.

Table 12. Percentages of steelhead PIT-tagged and released at Rock Island Dam (n = 7,109; Columbia River) and Lower Monumental and Ice Harbor dams (n = 9,701; Snake River) recovered on bird colonies in the Columbia River basin during 2009. Percentages are listed separately for wild and hatchery-reared steelhead. Recovery percentages were corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for steelhead survival to the vicinity of the bird colony or for off-colony deposition rates, and therefore are minimum estimates.

			Columbia River		**Snake River**	
Location	Island	Avian Colony	Hatchery	Wild	Hatchery	Wild
Banks Lake	Dry Falls Dam	Caspian tern	0.1%	0.0%	0.0%	0.0%
Potholes Reservoir	Goose Is.	Caspian tern	15.9%	14.6%	0.0%	0.0%
McNary Pool	Crescent Is.	Caspian terns	1.7%	1.8%	5.8%	5.2%
		California/ring-billed gulls	1.2%	0.4%	0.7%	0.3%
	Foundation Is.	Double-crested cormorant	0.2%	0.0%	2.7%	1.4%
	Badger Is.	American white pelican	0.3%	0.1%	0.4%	0.1%
John Day Pool	Rock Is.	Caspian tern	0.1%	0.3%	0.3%	0.3%
	Three Mile Canyon Is.[a]	California/ring-billed gulls	0.1%	0.2%	0.1%	0.1%
The Dalles Pool	Miller Rocks	California/ring-billed gulls	0.9%	0.5%	1.1%	1.1%
Estuary	East Sand Is.	Caspian tern	6.3%	4.6%	6.4%	7.4%
		Double-crested cormorant	1.1%	1.3%	2.3%	3.6%
		Brandt's cormorant	0.0%	0.0%	0.0%	0.0%
TOTAL			**27.9%**	**23.8%**	**19.8%**	**19.5%**

[a] Corrected for scanning effort that covered 57% of nesting area