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

2005 Final Season Summary

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This 2005 Final Season Summary has been prepared for the Bonneville Power Administration and the U.S. Army Corps of Engineers for the purpose of assessing project accomplishments. This report is not for citation without permission of the authors.

Ken Collis, Co-Principal Investigator
Real Time Research, Inc.
52 S.W. Roosevelt Ave.
Bend, Oregon 97702
Internet: kcollis@realtimeresearch.org
Telephone: 541-382-3836

Daniel D. Roby, Principal Investigator
USGS - Oregon Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 97331-3803
Internet: daniel.roby@orst.edu
Telephone: 541-737-1955

Jessica Y. Adkins, Chris Couch, Brendan Courtot, Rachel Lord,
Donald E. Lyons, and Yasuko Suzuki
USGS - Oregon Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 97331-3803

Allen Evans and Mike Hawbecker
Real Time Research, Inc.
52 S.W. Roosevelt Ave.
Bend, Oregon 97702

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EXECUTIVE SUMMARY

We initiated a study in 1997 to investigate the impacts of piscivorous colonial waterbirds on the survival of juvenile salmonids (*Oncorhynchus* spp.) in the lower Columbia River (Roby et al. 1998; Collis et al. 2002). The study area included the Columbia River from the mouth (river km 0) to the head of the impoundment created by McNary Dam (river km 553). The species of piscivorous waterbirds investigated were California gulls (*Larus californicus*), ring-billed gulls (*L. delawarensis*), glaucous-winged/western gulls (*L. glaucescens* X *L. occidentalis*), Caspian terns (*Sterna caspia*), double-crested cormorants (*Phalacrocorax auritus*), and, more recently, American white pelicans (*Pelecanus erythrorhynchos*) and California brown pelicans (*Pelecanus occidentalis californicus*). This study revealed differences in diet composition among the various bird species and colony locations (Collis et al. 2002). Terns, cormorants, and pelicans were strictly piscivorous, whereas the three gull species consumed a diverse array of food types. Gulls nesting at up-river colonies consumed primarily anthropogenic food items (e.g., cherries, potatoes, human refuse).

In general, piscivorous waterbirds nesting in the Columbia River estuary consumed more juvenile salmonids than those nesting up-river. On Rice Island (river km 34), salmonids accounted for 74% of the diet in Caspian terns, 46% in double-crested cormorants, and 11% in glaucous-winged/western gulls (Collis et al. 2002). Juvenile salmonids were especially prevalent in the diets of colonial waterbirds on Rice Island during April and May. By comparison, juvenile salmonids were significantly less prevalent in the diets of cormorants and gulls nesting above The Dalles Dam, although Caspian terns nesting in the John Day and McNary pools also consumed a high proportion of juvenile salmonids. These up-river Caspian tern colonies combined, however, were only about 1/10th the size of the Rice Island tern colony. These results indicated that avian predation on juvenile salmonids is more prevalent in the Columbia River estuary than in the Lower and Middle Columbia River. Furthermore, the high incidence of salmonids in the diets of Caspian terns, cormorants, and gulls nesting on Rice Island suggested that the impact of avian predation on survival of smolts would be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites closer to marine foraging areas.

In 1997 and 1998, Caspian terns nesting on Rice Island consumed the highest percentage of juvenile salmonids of those species of piscivorous colonial waterbirds nesting in the Columbia River estuary (Collis et al. 2002). Rice Island, a dredged material disposal site, supported an expanding colony of about 8,500 breeding pairs of terns in 1998 (Collis et al. 2002). This colony was the largest known Caspian tern breeding colony in the world. Using bioenergetics modeling, we estimated that in 1998 this tern colony consumed approximately 13% (95% c.i. = 9.1%–16.9%; Roby et al. 2003) of the estimated 96.6 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.5% of all PIT-tagged steelhead smolts (*O. mykiss*) that reached the estuary were consumed by terns in 1998 (Collis et al. 2001).

The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999 (Roby et al. 2002). A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 26 km closer to the ocean on East Sand Island (river km 8), where it was hoped terns would consume fewer salmonids. Efforts to attract terns to nest on East Sand Island included creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island. This approach was successful, and in three years all nesting terns shifted from Rice Island to East Sand Island. Juvenile salmonids decreased and marine forage fishes (e.g., Pacific herring [*Clupea pallasi*], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae]) increased in the diet of Caspian terns nesting on East Sand Island compared with terns nesting on Rice Island.

Our monitoring of tern management in the Columbia River estuary has continued through the 2005 nesting season. In 2005, the size of the Caspian tern colony on East Sand Island was approximately 8,800 nesting pairs, nearly the same size as the Rice Island tern colony in 1998. Consumption of juvenile salmonids by the East Sand Island tern colony in 2005 was approximately 3.6 million smolts (95% c.i. = 2.0–4.2 million), ca. 9 million fewer smolts consumed compared to 1998, when all terns nested on Rice Island. Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply, even in 2005 when availability of marine forage fishes declined due to poor ocean conditions.

Although numbers of Caspian terns nesting in the Columbia River estuary have remained stable over the last 8 years, the numbers of double-crested cormorants nesting on East Sand Island have nearly tripled during the same period to ca. 12,500 breeding pairs. This colony is now the largest known breeding colony for the species in North America. Although juvenile salmonids represented only ca. 5% of the diet of cormorants nesting on East Sand Island in 2004, estimated smolt consumption by the cormorant colony (6.4 million smolts; 95% c.i. = 2.5–10.3 million) was comparable to or greater than that of the East Sand Island tern colony (CBR 2005). This is due mostly to the larger size of the cormorant colony on East Sand Island and the greater food requirements of cormorants relative to terns. The nesting success of the double-crested cormorant colony on East Sand Island in 2005 (1.38 young/breeding pair) was more than three times the nesting success of the East Sand Island Caspian tern colony. The double-crested cormorant colony is expected to continue to expand for the foreseeable future, perhaps posing an increasing risk to survival of juvenile salmonids in the estuary.

The Caspian tern colony on Crescent Island in the mid-Columbia River is the largest of its kind on the Columbia Plateau (Antolos et al. 2004). But the Crescent Island tern colony, which consisted of ca. 476 nesting pairs in 2005, is roughly 1/20th the size of the East Sand Island tern colony in the Columbia River estuary. At Crescent Island, salmonid smolts represented about 65% of tern prey items in 2005. Consumption of juvenile salmonids by the Crescent Island tern colony was approximately 440,000 smolts (95% c.i. = 340,000–550,000 smolts) in 2005, compared to about 3.6 million smolts consumed by East Sand Island terns during the same year.

Despite the much smaller numbers of salmonid smolts consumed annually by the Crescent Island tern colony, predation rates on certain salmonid stocks have been unexpectedly high, particularly on some steelhead stocks during years of low river flow. For example, PIT tag recoveries on the tern colony in 2004 and 2005 (low flow years) indicate that the predation rate by Crescent Island terns on in-river Snake River steelhead smolts was 34% and 17%, respectively (based on the proportion of PIT-tagged smolts interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony). In-river steelhead smolts from the Snake River were more vulnerable to tern predation than in-river steelhead smolts from the Upper and Middle Columbia River (predation rates between ca. 6% and 4%, based on the proportion of PIT-tagged smolts interrogated at Rock Island Dam that were subsequently recovered on the Crescent Island tern colony in 2004 and 2005). The higher predation rate on in-river migrants from the Snake River, however, was offset by the transportation of > 95% of Snake River steelhead smolts past Crescent Island. Conversely, no juvenile salmonids that originated from the Upper Columbia River were transported past Crescent Island, resulting in the entire run being susceptible to predation by Crescent Island terns. Predation rates on salmonids by Crescent Island terns are unlikely to increase appreciably considering habitat constraints on tern colony expansion, limited capacity for increased per capita smolt consumption by terns, and current high transportation rates past Crescent Island for Snake River smolts.

The colony of double-crested cormorants on Foundation Island, near the confluence of the Snake and Columbia rivers and less than 8 Rkm from Crescent Island, is the largest cormorant colony on the mid-Columbia River. This colony consisted of over 315 breeding pairs in 2005, only about 1/40th the size of the cormorant colony on East Sand Island in the Columbia River estuary. The proportion of juvenile salmonids in the diet of Foundation Island cormorants was much less than that of Crescent Island terns, but the incidence of salmonids in the diet of Foundation Island cormorants was much higher early in the nesting season than during the chick-rearing period. A comparison of PIT tag recovery rates between the Crescent Island tern colony and Foundation Island cormorant colony suggests that the cormorants consumed ca. 1/4th as many smolts as the terns in 2005. The Foundation Island cormorant colony is growing slowly, however, and the consumption of salmonids, especially early in the season, appears to be increasing. The American white pelican colony on nearby Badger Island is also growing (> 500 pairs in 2005), but based on smolt PIT tag detections on the pelican colony by NOAA Fisheries, this colony is not a source of significant smolt mortality. For example, only 611 smolt PIT tags were recovered on the Badger Island pelican colony in 2005, compared to 16,003 smolt PIT tags and 4,101 smolt PIT tags recovered from the upriver tern and cormorant colonies, respectively.

A system-wide assessment of avian predation using the available data indicates that the most significant impact on survival of juvenile salmonids occurs in the estuary. Caspian terns and double-crested cormorants nesting on East Sand Island together consumed ca. 10 million smolts in 2004 (CBR 2005). Additionally, when compared to the impact of avian predation further up-river, avian predation that occurs in the estuary affects juvenile salmonids that have survived freshwater migration to the estuary and presumably have a higher probability of survival compared to those fish that have not yet completed their 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 terns and cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonids across the Columbia Basin, compared to management of other bird populations. One possible exception is the Caspian tern colony on Crescent Island, where tern management may benefit certain ESA-listed ESUs of steelhead.

Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is imminent; the Caspian Tern Management Plan for the Columbia River Estuary lists as the management goal the redistribution of approximately two-thirds of the East Sand Island colony to alternative colony sites in Washington, Oregon, and California (USFWS 2005). Management to reduce or limit smolt losses to the expanding double-crested cormorant colony in the estuary and the Caspian tern colony on Crescent Island in the mid-Columbia River are under consideration. Options for management initiatives to reduce the impact of these avian predators on survival of ESA-listed salmonid smolts include partial or complete relocation of these colonies to alternative sites where Columbia Basin salmonids would not constitute a significant proportion of the diet. Colony relocation would likely involve a combination of attraction to the new site using habitat enhancement, social attraction, and nest predator deterrence, coupled with reductions in the availability of suitable nesting habitat at the old colony site. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) for relocating nesting cormorants have shown some promise; cormorants were induced to nest at two sites on East Sand Island where they had not previously nested, and one site on Miller Sands Spit where they had not attempted to nest in several years. Restoration, enhancement, or establishment of tern and cormorant colony sites outside the Columbia River estuary would likely benefit Columbia Basin salmonids without negatively affecting protected populations of fish-eating birds. If resource management agencies decide that further management of avian predators (e.g., the East Sand Island cormorant colony, the Crescent Island tern colony) is warranted to increase survival of ESA-listed salmonids, additional research in support of a Draft EIS will be required.

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(proportion of ingested tags deposited off-colony). Consequently, all predation rates presented here are minimums.

SECTION 1: CASPIAN TERNS

1.1. Preparation and Modification of Nesting Habitat

1.1.1. Columbia River Estuary

On 2 April 2002, Federal District Judge Barbara Rothstein signed a settlement agreement between the plaintiffs (National Audubon Society, Defenders of Wildlife, Seattle Audubon Society, and American Bird Conservancy) and defendants (U.S. Army Corps of Engineers [USACE] and U.S. Fish and Wildlife Service [USFWS]). The signed agreement allowed habitat work to resume on East Sand Island (to encourage Caspian tern [*Sterna caspia*] nesting) and Rice Island (to discourage tern nesting), and allowed limited hazing of terns (i.e., prior to egg laying) attempting to nest in the upper estuary in 2002–2005 (see Map 1). In 2005, habitat improvement on the Caspian tern colony site on East Sand Island was accomplished by the U.S. Army Corps of Engineers during 24-25 March. Similar to the last three years, approximately 6.5 acres of suitable bare sand nesting habitat was prepared at the eastern end of East Sand Island by mechanical removal of encroaching European beach grass and other invasive plants. Tern decoys (30) and an audio playback system were deployed on the colony site. On March 31, a camp was set up on East Sand Island and was continuously occupied by two colony monitors throughout the tern breeding season. Limited gull (*Larus* spp.) control activities that were performed during the 1999 and 2000 nesting seasons to enhance prospects for tern colony restoration at East Sand Island were not conducted in 2005.

In previous years, work crews from NOAA Fisheries, Oregon Department of Fish and Wildlife, and USACE carried out various habitat modifications on the former 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 2005 because the former colony site on Rice Island (ca. 7 acres) has become completely vegetated and was consequently unsuitable for tern nesting. No hazing of terns to discourage nesting was conducted on Rice Island in 2005.

1.2. Colony Size and Productivity

1.2.1. Columbia River Estuary

Methods: The number of Caspian terns breeding on East Sand Island in the Columbia River estuary in 2005 (see Map 1) was estimated using aerial photographs of the colony taken near the end of the incubation period. The average of 2 direct counts of adult terns in aerial photos was corrected to estimate the number of breeding pairs on the colony using ground counts of incubating and non-incubating terns on 12 different plots within the colony area. Nesting success (number of young raised per breeding pair) at the East Sand Island tern colony was estimated using aerial photos taken of the colony just prior to the fledging period. The average of 2 direct counts of all terns (adults and juveniles) in aerial photos was corrected to estimate the number of fledglings on the colony using ground counts of adults and fledglings on 12 different plots within the colony area. The confidence intervals for number of breeding pairs and nesting success were calculated using a Monte Carlo routine to incorporate the variance of the multiple counts from the aerial photos and the plot counts used to generate these estimates.

In 2005, periodic boat-based surveys were conducted of the dredged material disposal islands in the upper estuary (i.e., Rice Island, Miller Sands Spit, Pillar Rock Sands; see Map 1) to look for early signs of nesting by Caspian terns.

Results and Discussion: As was the case during 2001–2004, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2005. Figure 1 presents weekly average counts from the ground of adult Caspian terns on the East Sand Island colony during the 2005 breeding season. Based on aerial photo census results, we estimate that 8,822 breeding pairs (95% c.i. = 8,324–9,319 breeding pairs) attempted to nest at East Sand Island in 2005. This estimate is 7% less than our estimate of colony size at East Sand Island in 2004 (9,502 breeding pairs, 95% c.i. = 8,905–10,099 breeding pairs). Nevertheless, the East Sand Island colony still represents the largest known breeding colony of Caspian terns in the world. The decrease in colony size at East Sand Island in 2005, as compared to the previous year, was likely due at least in part to the unusually late onset of coastal upwelling in 2005, and the associated poor ocean conditions along the coast of the Pacific Northwest. Unusually high numbers of beached, starved piscivorous seabirds and widespread nesting failures indicated that the availability of marine forage fishes to coastal seabirds was exceptionally low.

We estimate that 3,285 fledglings (95% c.i. = 2,755–3,814 fledglings) were produced at the East Sand Island colony in 2005. This corresponds to nesting success of 0.37 young raised per breeding pair (95% c.i. = 0.31–0.44 fledglings/breeding pair), which was considerably lower than the estimate of nesting success for the East Sand Island tern colony in 2004 (0.92 fledglings/breeding pair, 95% c.i. = 0.82–1.02 fledglings/breeding pair). This is the lowest productivity we have measured at the East Sand Island tern colony since terns first started nesting there in 1999, and is comparable to the low productivity observed at Rice Island in 1998 and 1999. Low productivity also agrees with reports from throughout the coastal Pacific Northwest of poor ocean conditions and widespread seabird nesting failure in 2005.

On 13 April, 36 Caspian terns were observed loafing on the upland area of Pillar Rock Sands (a dredged material disposal island in the upper estuary; see Map 1). On 17 April, as many as 396 terns were seen on the upland area of Pillar Rock Sands during low tide. This was significant because if the terns were just loafing near a foraging area, they would likely roost on the beach at low tide. Other indications of their intention to nest on Pillar Rock Sands were courtship displays, exchange of courtship meals, copulations, and digging of nest scrapes. Resource managers were informed of the situation and on 21-22 April a USACE contractor (Ken Larson) deployed stakes fixed with brightly colored flagging and eagle silhouettes to dissuade the terns from nesting on the upland area of Pillar Rock Sands. No terns were observed on the upland area of Pillar Rock Sands following the deployment of these passive measures to dissuade terns from nesting there.

No other aggregations of Caspian terns were observed at other dredged material disposal areas in the upper estuary (i.e., Rice Island, Miller Sands Spit, Puget Island) in 2005.

1.2.2. Columbia Plateau

Methods: : The number of Caspian tern breeding pairs nesting at Crescent Island (see Map 2) was estimated by averaging 2 independent colony counts that were corrected using ground counts of incubating and non-incubating terns on 7 different plots within the colony area. Nesting success was estimated from ground counts of all fledglings on the colony just prior to fledging.

Periodic boat or aerial surveys of former Caspian tern breeding colony sites (i.e., Three Mile Canyon Island, Miller Rocks, Cabin Island, Sprague Lake, Banks Lake) were conducted during the 2005 nesting season to determine whether these colony sites had been re-occupied (Map 2). We also flew aerial surveys of the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, and the Potholes Reservoir searching for new or incipient Caspian tern colonies.

In 2005, Caspian tern colonies in Potholes Reservoir (see Map 2) were monitored by NOAA Fisheries (POC: Tom Good); the results from this separately funded study are provided in an appendix to this report.

Results and Discussion: Figure 2 presents weekly average counts of all adult Caspian terns on the Crescent Island colony during the 2005 breeding season. About 476 breeding pairs of Caspian terns attempted to nest at the Crescent Island colony in 2005, about 10% fewer pairs than in 2004. We estimated that 261 young were fledged from the Crescent Island tern colony in 2005, or 0.55 young raised per breeding pair, lower nesting success than in 2004.

A small Caspian tern breeding colony was discovered this season on Rock Island in the Blalock Islands, John Day pool (between the towns of Boardman and Irrigon, Oregon). On 5 July, there were 3 adults and one black-capped fledgling observed on the island. This one fledgling appears to be the only young tern raised at this colony in 2005; as many as six breeding pairs were observed during earlier visits to the island. Nesting Caspian terns shared the island with nesting California gulls and Forster’s terns (ca. 60 pairs), but no Forster’s terns apparently raised young on the island.

Caspian terns nested on Harper Island in Sprague Lake (ca. 80 km east of Moses Lake) again in 2005, but apparently no young were successfully raised. In early July, 19 adult Caspian terns were counted on Dry Falls Island and 7 adult terns were counted on Goose Island, both located in Banks Lake (just above Dry Falls Dam near Coulee City). Caspian tern chicks were observed on both of these islands, indicating that terns nesting on Banks Lake were successful in hatching young.

We found no evidence of Caspian terns attempting to nest on Three Mile Canyon Island, Miller Rocks, or Cabin Island in 2005 (see Map 2). An American mink (*Mustela vison*) disrupted tern nesting at Three Mile Canyon Island in 2000 and 2001, causing the colony to fail in both years. Caspian terns were found nesting on Miller Rocks in the mid-Columbia River just upstream of the mouth of the Deschutes River for the first time in 2001; up to 20 breeding pairs attempted to nest on the edge of a large gull colony. We suspect that terns nesting on Miller Rocks in 2001 were failed breeders from the Three Mile Canyon Island colony. Cabin Island above Priest Rapids Dam, 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.

Total numbers of Caspian terns nesting throughout the Columbia Plateau Region (including colonies in Potholes Reservoir) in 2005 was less than 850 pairs (Table 10). This suggests that the numbers of Caspian terns nesting throughout the Columbia Plateau have been declining slowly since 2000, when the number of breeding Caspian terns was estimated at 1,000 pairs (Antolos et al. 2004).

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 (see Map 1), were conducted on a periodic basis throughout the breeding season in order to detect any new Caspian tern colonies outside the Columbia River estuary.

Results and Discussion: Although Caspian terns were commonly observed foraging and roosting in Willapa Bay and Grays Harbor throughout the 2005 breeding season, no nesting attempts by terns were detected in either area in 2005. This suggests that suitable tern nesting sites (i.e., upland island or mainland sites that are unvegetated, unoccupied by other colonial nesting birds, and free of mammalian predators) are not currently available in either Willapa Bay or Grays Harbor.

1.3. Diet Composition and Salmonid Consumption

1.3.1. Columbia River Estuary

Methods: Because terns transport whole fish in their bills to their mates (courtship meals) and young (chick meals), 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 and low tide, to control for potential tidal and time of day effects on diet. 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. J. Kettratad at the Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University provided verifications of salmonids collected as bill loads that were difficult to identify.

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, on average 23% were juvenile salmonids (n = 5,536 bill loads). As in previous years, marine forage fishes (i.e., Pacific herring [*Clupea pallasi*], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae] were prevalent (average of 70% of identified bill loads) in the diets of terns nesting on East Sand Island (Figure 3; Table 1). The proportion of the diet that was salmonids peaked at ca. 55% during the second week of May (Figure 4), approximately the same time as in the previous two years. We estimate that Caspian terns nesting on East Sand Island consumed a total of 3.6 million juvenile salmonids in 2005 (95% c.i. = 3.0–4.2 million), nearly the same smolt consumption as in the previous year (2004 best estimate = 3.5 million smolts, 95% c.i. = 2.9–4.0 million). Of the juvenile salmonids consumed in 2005, we estimate that 42% were coho salmon (best estimate = 1.5 million, 95% c.i. = 1.2–1.7 million), 27% were yearling chinook salmon (best estimate = 1.0 million, 95% c.i. = 0.8–1.1 million), 20% were steelhead (best estimate = 0.7 million, 95% c.i. = 0.6–0.9 million), 10% were sub-yearling chinook salmon (best estimate = 0.4 million, 95% c.i. = 0.3–0.5 million), and 1% were sockeye salmon (best estimate = 19 thousand, 95% c.i. = 15–24 thousand).

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 was 150 bill load identifications per week at Crescent Island (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 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 the identifiable prey items in tern diets was calculated for each two-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 for the Crescent Island Caspian tern 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.

Results and Discussion: Juvenile salmonids were the most prevalent prey type for Caspian terns nesting on Crescent Island (65% of identifiable bill loads), followed by centrarchids (bass and sunfish, 25%) and cyprinids (carp and minnows, 7%; n = 2,975 bill loads; Figure 5). The proportion of salmonids in the diet was higher and more variable over the breeding season compared to that of terns nesting on East Sand Island in 2005. The salmonid portion of the diet peaked in April and early May at 80% or more of identifiable prey items (Figure 6). Seasonal changes in the proportion of salmonids in the diet probably reflected changes in availability of hatchery-reared juvenile salmonids near the colony in April and early May. We estimated that Caspian terns nesting on Crescent Island consumed 440,000 juvenile salmonids in 2005 (95% c.i. = 340,000–550,000), a ca. 12% decline in smolt consumption compared to 2004 (best estimate = 500,000, 95% c.i. = 400,000–600,000; Figure 7). Steelhead comprised an estimated 10.7% of the identifiable salmonid smolts or roughly 50,000 fish. Per capita smolt consumption in 2005 (462 smolts nesting tern^{-1} breeding season^{-1}) was similar to the previous year (472 smolts nesting tern^{-1} breeding season^{-1}), but lower than in 2001 and 2002 (Figure 8).

1.4. Salmonid Predation Rates: PIT Tag Studies

Each spring millions of downstream migrating juvenile salmonids 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 information. Each year, thousands of these PIT-tagged fish are consumed by colonial waterbirds and many of the ingested tags are subsequently deposited on bird nesting colonies throughout the Columbia River basin (e.g., East Sand Island and Crescent Island Caspian tern colonies). The recovery of PIT tags on bird colonies can be used as a direct measure of predation rates on Endangered Species Act (ESA)-listed salmonid populations (Collis et al. 2001, Ryan et al. 2003, Antolos et al. 2005) and these data can be used to assess the relative vulnerability of various salmonid species, stocks, and rearing types to avian predators.

Previous predation rate estimates based on PIT tag recoveries are considered minimums because not all tags consumed by birds are deposited on the nesting colony and not all tags deposited on the colony are detected. In 2004 and 2005, we worked collaboratively with NOAA Fisheries (the agency responsible for on-colony PIT tag recoveries) to generate more accurate and defensible predation rate estimates based on PIT tag recoveries. This was accomplished by (1) physically removing tags from the Crescent Island tern colony, where tag collision is believed to significantly reduce PIT tag detection efficiency; (2) systematically spreading PIT tags with known tag codes on the East Sand Island and Crescent Island tern colonies in order to directly measure PIT tag detection efficiencies; and (3) conduct experiments to measure on-colony deposition rates of ingested PIT tags by terns nesting at the East Sand Island and Crescent Island colonies. These data will be used to generate more accurate predation rate estimates based on PIT tags.

1.4.1. PIT Tag Collision

Methods: Throughout the course of the nesting season, PIT tags are accumulating on the Crescent Island tern colony and causing tag signals to collide, a phenomenon that renders tags unreadable and thereby decreases on-colony tag recovery (see Ryan et al. 2003 for detailed description of NOAA Fisheries PIT tag recovery methods). One method of minimizing collision is to physically remove PIT tags from the tern colony (hereafter referred to as “hand removal”). To accomplish this, a six-person crew manually removed PIT tags from the Crescent Island tern colony on 8-9 August 2005. Tags were removed by breaking up the surface layer of the colony with rakes and then passing rolling sweeper magnets over the colony surface. In addition to magnetic sweepers, we also placed small magnets on the tines of metal rakes to collect tags while raking through the colony substrate. To ensure that tags were removed efficiently, 60 cm wide transects were spread across the colony and each transect was swept and raked at least twice. All PIT tags removed were then scanned using a handheld transceiver to determined tag functionality and all tag codes were noted. Following the hand removal of tags from the colony, NOAA Fisheries used electronic equipment to detect tags in situ that were not removed from the colony.

Results and Discussion: We removed 15,907 PIT tags, 659 radio tags, 70 hydro-acoustic tags, and 5 floy tags – tags that had been implanted in out-migrating juvenile salmonids – from the Crescent Island tern colony in 2005. Of the 15,907 PIT tags collected from the colony, 14,549 (91.4%) were still functional or readable. PIT tag codes from the recovered tags were uploaded to the regional smolt PIT tag database (PTAGIS) and the owners of other fish tracking tags (e.g., radio tags) were notified, when possible.

Using specially designed electronic equipment, NOAA Fisheries detected an additional 8,307 functional PIT tags on the tern colony, tags that had been missed during the hand removal effort. In total, 22,856 functional PIT tags were removed from or detected on the Crescent Island tern colony following the 2005 tern nesting season. Of these, 16,003 (70%) were from smolts released during the 2005 migration year.

1.4.2. Detection Efficiency

Methods: Not all smolt PIT tags that Caspian terns egest on their nesting colony are subsequently detected on-colony after the nesting season. In years past, a correction factor to convert number of detected PIT tags on-colony to number of PIT tags egested on the colony was estimated by distributing a known number of PIT tags on-colony prior to the nesting season, and then assessing detection rates of those tags using electronic equipment after the nesting season (Ryan et al. 2003). Using this single release strategy, NOAA Fisheries estimated a detection rate of only 15.0% and 44.7% at the Crescent Island tern colony in 2002 and 2003, respectively (Ryan et al. 2003). These estimates of detection efficiency were thought to be underestimates, however, because tags placed on the colony early in the nesting season are potentially subject to higher rates of loss and damage compared to PIT tags deposited on the colony later in the nesting season. In 2004, we learned that the systematic sowing of PIT tags on multiple occasions throughout the tern nesting season – as apposed to a single release prior to the nesting season – resulted in a more accurate and defensible estimate of PIT tag detection efficiency (CBR 2005).

In 2005, we repeated this systematic approach by intentionally spreading 967 PIT tags on the Crescent Island tern colony on four discrete plots on four different occasions: (1) prior to the birds arrival on colony (16 March), (2) during incubation (9 May), (3) during fledging (30 June), and (4) following the nesting season once the birds had left the colony (26 July). Each discrete plot measured 4 x 10 m and plots were located within the core colony area. Detection efficiency estimates were then analyzed relative to the release date and the release plot, thereby describing both temporal and spatial variation in detection efficiency. At the East Sand Island tern colony we intentionally spread 1,200 PIT tags on three discrete plots (10 x 10 m) on four different occasions: (1) prior to the birds arrival on colony (31 March), (2) during incubation (18 May), (3) during fledging (13 July), and (4) following the nesting season once the birds had left the colony (22 August).

Results and Discussion: Of the 967 test tags intentionally spread on Crescent Island, 684 or 70.7% were subsequently detected on-colony (Table 2). Detection efficiency ranged from as low as 29.3% for the pre-season tag release group to as high as 95.0% during the post-season tag release group (Table 2). Average detection efficiency was estimated to be 72.1% (linear fit) during the nesting season (i.e., during the period when terns were observed on the colony and were presumably depositing PIT tags). There was a positive association between test tag release date and detection efficiency ($R^2 = 0.8403$, $P < 0.001$), with those tags released later in the nesting season more likely to be detected than tags released earlier in the nesting season. For the second consecutive year, 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 on-colony as compared to PIT tags from later migrating smolts. Therefore, previously reported predation rate estimates (i.e., those reported prior to 2004) may under-estimate impacts of Caspian tern predation on survival of early migrant smolts relative to late migrant smolts.

Of the 1,200 test tags intentionally spread on East Sand Island, 999 or 83.3% were subsequently detected on-colony. Detection efficiency ranged from 75.3% for tags spread during the incubation period to 89.0% for tags spread during the chick-rearing period (Table 3). Unlike results from the Crescent Island tern colony, however, there was no evidence that detection efficiency increased as a function of when the tags were spread on the colony ($R^2 < 0.01$, $P = 0.8806$).

1.4.3. Deposition Rates

Methods: Not all smolt PIT tags consumed by terns are deposited on the nesting colony. Some proportion of the consumed PIT tags is regurgitated by terns while they are not on-colony, for example during flight or at off-colony loafing areas. Therefore, predation rate estimates based on on-colony PIT tag recoveries are still minimums, even after accounting for detection efficiency. In 2004 and 2005 we conducted two experiments to measure on-colony deposition rates of PIT tags ingested by terns nesting on Crescent Island. First, we allowed terns to forage on PIT-tagged fish confined to net pen enclosures and then scanned for those tag codes at the colony following the nesting season. Secondly, we captured nesting terns on colony and force fed them PIT-tagged fish and then scanned for those tag code following the nesting season. Until multiple years of deposition rate data from several different locations are compiled, results from these experiments will not be used to adjust/corrected predation rate estimates (i.e., those presented in Section 1.5.).

Two circular net pens (roughly 6 meters in diameter) were anchored in backwater areas of the Columbia and Snake rivers in 2005; one in Burbank Slough (approximately 11 kilometers northeast of Crescent Island) and the other in the lower Snake River (upstream of Ice Harbor Dam, approximately 23 kilometers northeast of Crescent Island). On 19 April, a total of 697 juvenile rainbow trout (*O. mykiss*) of two different size classes (small: mean = 11.01 cm fork length, SD = 1.39, n = 399; large: mean = 18.80 cm, SD = 1.10, n = 298) were PIT-tagged and placed in the lower Snake River net pen. On 20 April, a total of 902 juvenile rainbow trout (*O. mykiss*) of two different size classes (small: mean = 10.58 cm fork length, SD = 1.04, n = 501; large: mean = 19.41 cm, SD = 1.49, n = 401) were PIT-tagged and placed in the Burbank Slough net pen. All trout were certified disease free, triploids (sterile as adults) and were obtained from the Trout Lodge Hatchery, WA. After stocking, the net pens were monitored daily (8 to 15 hrs/day) to determine tern foraging behavior (i.e., arrival times, number of foraging attempts per bird, and duration of foraging bout) and foraging success (i.e., number of fish captured, size class of fish captured) from 21 April to 1 July 2005. Each net pen was covered with nylon mesh to prevent terns from foraging when observers were not present. The number of fish removed from each net pen was then recorded throughout the 72-day observation period. At the conclusion of the net pen study, all fish remaining in the net pen were rescanned to determine PIT tag retention rates (i.e., proportion of tagged trout that retained tags throughout the study period), a parameter needed to correct for the total number of PIT-tagged fish captured by terns. A deposition rate (DR) for the PIT tags of fish removed by terns from the net pen was then calculated by dividing the number of net pen tags detected on the Crescent Island tern colony by the total number of net pen fish removed by adult terns.

Deposition rates were also estimated at the Crescent Island and East Sand Island tern colonies by force-feeding PIT-tagged trout to adult terns that were nesting at each colony. Breeding adult terns were captured near the peak of incubation (9 May and 18 May at Crescent and East Sand islands, respectively) by placing noose mats around active nests. Following capture, adult terns were force-fed one PIT-tagged juvenile rainbow trout by opening the mandibles, inserting the fish head-first into the esophagus, and gently massaging the fish down the esophagus. Each adult tern used in the experiment was then weighed, measured, color-banded (as described below), marked with bright pink dye on the breast (for easy on-colony identification) and immediately released back onto the colony. Following release, the presence/absence of each marked bird and the birds post-release behavior (e.g., actively attending a nest site) was observed from a blind until nightfall or until all of the force-fed birds were observed on the colony. A deposition rate (DR) of PIT tags from force-fed fish at each colony was then calculated by dividing the number of force-fed tags detected on the colony by the total number of force-fed tags used in experiment.

Results and Discussion: Terns began foraging on fish within the Burbank Slough net pen 1 day after stocking the net pen with PIT-tagged trout. During the 72-day study period, a total of 91 PIT-tagged trout were removed from the Burbank net pen by Caspian terns. Caspian terns made a total of 157 attempts to capture fish (i.e., plunge dives into the net pen). Of the 91 fish captured, 33 were immediately consumed and 58 were observed in the tern's bill as it flew back toward the Crescent Island colony. In total, 52 large and 39 small trout were successfully removed by terns from the Burbank Slough net pen. The frequency of trout captures in the Burbank Slough net pen increased dramatically during the later half of the study period (25 May to 1 July), with 92% of the captured fish being removed during this period. This time period coincided with the later stage of chick-rearing at the Crescent Island tern colony in 2005.

Of the 91 PIT-tagged trout captured by Caspian terns from the Burbank Slough net pen, 43 were detected on the Crescent Island tern colony. The estimated deposition rate for PIT tags from the net pen fish was 65.5%, after accounting for PIT tag retention (96.4%) and on-colony detection efficiency (74.8%; based on a linear fit of detection efficiency estimates during the study period). Based on these results, we estimate that 34.5% of the PIT tags from trout that were removed from the Burbank net pen by Caspian terns were deposited off-colony.

Terns were not observed removing PIT-tagged fish from the Snake River net pen in 2005. Due to a lack of tern foraging activity, continuous monitoring of the Snake River net pen was terminated on 24 May. The net pen, however, was left open and periodically monitoring until 1 July to determine if Crescent Island terns would find and eventually consume PIT-tagged fish from the net pen. In total, two PIT tags from Snake River net pen fish were detected on the Crescent Island tern colony, confirming that terns did eventually capture fish from the Snake River net pen. Because the net pen was not continuously monitored, however, no estimate of deposition rate is possible. Based on the over-all lack of foraging behavior at this net pen, we recommend that deployment of a net pen at this location be discontinued in 2006.

Fifty-nine adult terns from Crescent Island were captured and force-fed PIT-tagged trout in 2005. All 59 birds successfully ingested the fish, and 56 (95%) returned to the colony to resume breeding behaviors within 6 hours of release. Five of the 59 terns (8.4%) already had PIT tags in their digestive tract at the time of capture (i.e., from a PIT-tagged salmonid caught in the wild by the tern prior to our capture of the tern). The capture and handling of terns at Crescent Island resulted in some tern egg loss. In total, 26 eggs were damaged during this research activity, the majority due to depredation by California gulls. No adult terns, however, were injured during this experiment and all but one of the captured terns were repeatedly resighted on the Crescent Island colony throughout the nesting season. Interestingly, the one bird that was not repeatedly resighted on Crescent Island was subsequently observed at a tern breeding colony on Potholes Reservoir (Tom Good, NOAA Fisheries, personal communication). Of the 59 force-fed terns, 32 of them deposited tags on-colony. On-colony detection efficiency was estimated to be 74.2% (DE) during this time period, based on a sample of test tags (n = 240) released on-colony that same day. Based on this DE, we estimated that 73.1% of the force-fed PIT tags were deposited on the Crescent Island tern colony; conversely, 26.9% of the force-fed PIT tags were egested off-colony.

Thirty-one terns from East Sand Island were captured and subsequently force-fed PIT-tagged trout in 2005. All 31 terns successfully ingested the fish, and 29 (94%) returned to the colony within 6 hours of release. None of the terns captured on East Sand Island had previously-consumed PIT tags in their digestive tracts. A total of 46 tern eggs were lost as a result of this research activity, the majority (40 eggs) due to depredation by glaucous-winged/western gulls. No adult terns captured on East Sand Island were injured and all of the captured terns were repeatedly resighted on the colony throughout the nesting season. Of the 31 force-fed terns, 20 of them deposited PIT tags on-colony. On-colony detection efficiency was estimated to be 75.3% (DE) during this time period, based on a sample of test tags (n = 300) released on-colony that same day. Based on this DE, we estimated that 85.6% of the force-fed PIT tags were deposited on the East Sand Island tern colony; conversely, 14.4% of the force-fed PIT tags were egested off-colony.

1.4.4. Predation Rate Estimates

Methods: In collaboration with NOAA Fisheries (POC, Brad Ryan), we have been using PIT tag recoveries on bird colonies to evaluate the relative vulnerability of various salmonid species and stocks to bird predation. Preliminary analyses of the tags recovered from the Crescent Island and East Sand Island Caspian tern colonies in 2005 are presented here. These data will be analyzed in greater depth in the project's Final Report, in NOAA Fisheries' Annual Reports, and in articles published in peer-reviewed scientific journals that are currently in preparation in collaboration with NOAA Fisheries.

We queried the regional PIT tag database (PTAGIS) on 12 November 2005 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 interrogations for all PIT-tagged fish released into the Columbia River Basin in 2005. We measured predation rates on different salmonid species, run types, and stocks (as defined by NOAA Fisheries' Evolutionarily Significant Units or ESUs). For Caspian terns nesting on Crescent Island, ESU or stock-specific predation rates were generated for PIT-tagged fish migrating in-river past Crescent Island (i.e., excludes all PIT-tagged smolts captured at dams on the lower Snake River and transported past Crescent Island). For Caspian terns nesting on East Sand Island, predation rates are provided for both in-river migrants and PIT-tagged fish that were transported from up-river dams to below Bonneville Dam. Predation rate estimates do not account for mortality that took place between the fish's release location and the detection site (i.e., Crescent or East Sand islands) and, as such, under-estimate tern predation rates because the numbers of smolts susceptible to tern predation were inflated.

A more direct or reach-specific measure of tern predation rates was calculated by limiting the analysis to actively-migrating smolts that were last detected within the foraging range of the Crescent Island or East Sand Island tern colonies. For the Crescent Island tern colony, this was done by calculating a predation rate for just those PIT-tagged smolts that were interrogated at Lower Monumental Dam (located on the Snake River, 80 Rkm above Crescent Island), Rock Island Dam (located on the Upper Columbia River; 210 Rkm above Crescent Island), and PIT-tagged smolts smolts released on the Middle Columbia River between McNary Dam (located on the Columbia River, 39 Rkm below Crescent Island) and the confluence of the Snake and Upper Columbia rivers. For the East Sand Island tern colony, this was done by calculating a predation rate for just those PIT-tagged smolts that were interrogated at Bonneville Dam (located 227 Rkm above East Sand Island), plus those PIT-tagged smolts that were transported and released below Bonneville Dam. These reach-specific estimates are still minimum predation rates because they do not account for in-river mortality of PIT-tagged fish between the interrogation site and the vicinity of the tern colony.

All predation rate estimates presented here for Crescent Island and East Sand Island terns were corrected for on-colony PIT tag detection efficiency, based on the results of PIT tag detection efficiency studies presented above (see Section 1.4.2). We used the weighted monthly average derived from the passage timing of smolts at each interrogation site to calculate on-colony detection efficiency based on the linear fit of detection efficiency as a function of deposition date. This approach ensured that the detection efficiencies used to correct PIT tag recovery rates for particular smolt runs were adjusted for the differences in timing of peak out-migration among various runs. Because no temporal trend was evident from test tags planted on East Sand Island, however, we used the average detection efficiency estimate of 83.3% for all runs, regardless of timing.

Results and Discussion: Approximately 1.85 million PIT-tagged fish were released into the Columbia River basin in 2005. The majority of these fish were released into the Upper Columbia River (0.72 million) or the lower Snake River (0.71 million), followed by the Middle Columbia River (0.1 million). The smallest numbers of PIT-tagged fish were released into the lower Columbia River (0.02 million) and the Willamette River (0.01 million), which limits the usefulness of PIT tag recoveries on tern colonies for determining the relative vulnerability of fish originating on the lower Columbia River below Bonneville Dam to tern predation in the estuary. Of the 1.85 million tagged fish in the Columbia basin, 40.9% were steelhead, 54.4% chinook, 3.8% coho, 0.5% sockeye, and remaining 0.2% other salmonids species. Most of the tagged fish were of hatchery origin (82.3%).

Crescent Island Caspian terns – Of the 1.85 million PIT-tagged fish released into the Columbia River basin in 2005, 0.9% (n = 16,003) were recovered on the Crescent Island tern colony. In-river migrants from the Snake River steelhead ESU were the most vulnerable to predation by Crescent Island terns in 2005, with estimated predation rates of 7.1% and 3.3% for all in-river steelhead of hatchery and wild origin, respectively (Table 4). Snake River steelhead included in this analysis were from five different spawning populations; predation rates ranged from as low as 0.8% to as high as 9.6%, indicating high stock-specific variability within this ESU (Table 5). Hatchery-raised steelhead from the Snake River were particular vulnerable to predation by Crescent Island terns, with predation rates more than double that of their wild counterparts (Table 4). The next most vulnerable ESU to predation by Crescent Island terns was the Middle Columbia River and the Upper Columbia River steelhead ESUs, with estimated predation rates of 2.3% and 1.4%, respectively (Table 4). Estimated predation rates by Crescent Island terns on all other listed/protected ESUs in 2005 were negligible, ranging from 0.1% for Upper Columbia River Summer Chinook to 0.8% for Snake River sockeye (Table 4).

Similar to the above results based on ESU-specific analysis, predation rates based on reach-specific analysis of PIT tag data indicate that steelhead from the Snake, Upper Columbia River, and Middle Columbia River ESUs were particular vulnerable to Crescent Island terns in 2005, compared to other ESUs (Table 6). Reach-specific predation rates indicate that 10.6%, 2.7%, 2.7% of the steelhead smolts belonging to the Snake River, Upper Columbia River, and Middle Columbia River ESUs, respectively, were consumed by Caspian terns nesting on Crescent Island (Table 6). These same predation rates, once corrected for the proportion of ingested PIT tags not deposited on the tern colony, increase to 16.7%, 4.0%, and 4.1% for Snake River, Upper Columbia River, and Middle Columbia River steelhead ESUs, respectively. After steelhead, coho and sub-yearling chinook salmon smolts from the Snake River were the most vulnerable to predation by Crescent Island terns, but predation rates for these species were considerably less than for Snake River steelhead (Table 6).

Predation rates by Crescent Island terns on PIT-tagged smolts were considerably lower in 2005 than in 2004. For example, estimated predation rates in 2004 were 22.5%, 3.9%, and 4.1% for steelhead from the Snake River, Upper Columbia River, and Middle Columbia River, respectively (CBR 2005). The smaller size of the Crescent Island tern colony in 2005 relative to 2004 is one factor that contributed to lower overall predation rates on salmonids. In addition, it appears that the bulk of the steelhead – particularly fish originating from the Snake River – may have passed Crescent Island unharmed in 2005 due to a predator swamping or prey density effect. Passage data from Lower Monumental Dam indicates that a large number of steelhead smolts passed the dam during a relatively short period in 2005; predation rates were lowest when the number of PIT-tagged smolts passing the dam peaked in early May (Figure 9). A simple linear regression model of the number of PIT-tagged steelhead smolts interrogated at the dam as a function of the proportion subsequently recovered on the tern colony was highly significant ($R^2 = 0.8183$, $P < 0.001$), with predation rates negatively correlated with numbers of out-migrating smolts. Although a predator swamping effect is one potential explanation for this trend in 2005, other hypotheses (e.g., smolts migrating during the peak are more fit than those migrating earlier or later) are currently being investigated in collaboration with NOAA Fisheries. Results of this multi-year (2004 to 2006) and multivariate analysis will be presented in the project's Final Report.

Some of the estimated predation rates by Crescent Island terns on salmonid ESUs are unexpectedly high and cause for concern, especially for the Snake River steelhead ESU. It is important to consider, however, that these predation rates apply only to the in-river component of each ESU, and do not include the component that was transported past Crescent Island. For Snake River ESUs, the in-river migrants were only a small fraction of the overall ESU, because the vast majority of smolts are transported around McNary Pool in barges and trucks each spring and therefore are unavailable to Crescent Island terns. For example, 96.4% and 87.2% of all steelhead and yearling chinook smolts, respectively, arriving at Lower Granite Dam (the uppermost dam on the lower Snake River) were collected for transportation around the McNary Pool in 2004 (FPC 2005). Unlike fish from the Snake River, smolts originating from the Upper Columbia River are not transported around McNary Pool, making a much larger proportion of Upper Columbia River runs susceptible to avian predators in McNary Pool. As such, the overall impact of predation by Crescent Island terns on survival of smolts from particular ESUs was likely greatest for the Upper Columbia River steelhead ESU, and not the Snake River steelhead ESU (Antolos et al. 2005; CBR 2005), as implied by reach-specific predation rates on in-river migrants.

East Sand Island Caspian terns – Of the 1.85 million PIT-tagged fish released into the Columbia River basin in 2005, 1.6% (n = 29,184) were recovered on the East Sand Island tern colony. As with the Crescent Island tern colony, steelhead were the most vulnerable salmonid to predation by Caspian terns from the East Sand Island colony in 2005 (Table 7). On average, one out of every 10 PIT-tagged steelhead smolts detected at or below Bonneville Dam ended up on the East Sand Island tern colony. Hatchery-raised coho smolts were the next most vulnerable to predation by East Sand Island terns (5.5%), after steelhead. Predation rates on other salmonid species and run types (< 2%) were much less than for steelhead (Table 7). As was the case for predation by Crescent Island terns, hatchery-raised smolts were generally more vulnerable to predation by East Sand Island terns than their wild counterparts (Table 7).

Finally, it is worth noting that estimates of predation rates based solely on PIT tag recovery data (i.e., the proportion of available PIT-tagged fish consumed by terns nesting at a particular colony) are not the same as estimates of the number of smolts belonging to a particular ESA-listed ESU that are taken by terns nesting at a particular colony. Accurate data on the abundance of smolts belonging to particular salmonid ESUs in a given river segment are needed to derive consumption estimates from predation rates based on PIT tag recoveries. We are currently working with NOAA Fisheries to generate abundance estimates for smolts in the Snake River. Until such estimates are available, predation rates based on PIT tag recoveries on-colony can indicate the relative vulnerability of various salmonid species and stocks, but do not provide precise estimates of the numbers of ESA-listed smolts that are annually consumed by populations of Caspian terns or other avian predators.

1.5. Dispersal and Survival

Methods: In 2005, adult and fledgling Caspian terns were banded at two breeding colonies in the Columbia Basin, and fledglings were banded at two colonies outside the Columbia Basin (see Roby et al. 2005 for banding results at Dungeness National Wildlife Refuge). 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. Each fledgling tern was banded with a federal numbered metal leg band and a unique color combination of five plastic leg bands that allows for the identification of individual terns at a distance (i.e., at roosts or on colonies). Adult 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 an alphanumeric code on the other. This new banding protocol for adults was used to evaluate an alternative method for individually marking Caspian terns that is potentially longer lasting than the five-band color combination method.

As part of this study, tern chicks that were near fledging were banded at East Sand Island, (n = 250) and Crescent Island (n = 164). Tern chicks were captured on-colony by herding flightless young into holding pens. Adult terns were captured 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 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 (2000–2004) were re-sighted on various breeding colonies by researchers throughout the 2005 breeding season. Re-sightings of banded terns at other locations were reported to us through our project web page (www.columbiabirdresearch.org), by phone, or by e-mail.

Results and Discussion: In 2005, 130 and 37 previously-banded Caspian terns were resighted at the East Sand Island colony and the Crescent Island colony, respectively. All 167 banded terns were identified such that the banding year, age class when banded (i.e., adult or chick), and banding location were known. Of the 130 banded individuals that were resighted at East Sand Island, 95 (73%) were banded in the Columbia River estuary (56 as adults and 39 as chicks), 33 (25%) were banded at the former ASARCO colony in Commencement Bay, WA (29 as adults and 4 as chicks; see Map 2), and 2 (2%) were banded at Crescent Island (one as an adult and one as a chick). All of the 37 banded terns that were resighted at the Crescent Island colony were banded at Crescent Island as adults.

In addition to these resightings, there were 31 banded terns that had been banded at either Rice Island, East Sand Island, Crescent Island, or ASARCO that were resighted at colonies in San Francisco Bay (7) or at the colony on Dungeness National Wildlife Refuge in Washington (24). Of these, 8 were banded as adults and 23 were banded as chicks.

Efforts to band significant numbers of fledgling Caspian terns began in earnest in 2001. The low resighting numbers of terns banded as fledglings indicates that (1) immature terns have lower than expected survival rates between fledging and recruitment into the breeding population, (2) most subadult terns are not recruiting into the breeding population until after their fourth year, and/or (3) most terns banded as fledglings are losing at least one colored plastic leg band before they recruit into the breeding population. The relatively high proportion of terns banded as fledglings that were resighted at the Dungeness NWR colony indicates that this relatively new breeding colony (first occupied in 2003) may be attractive to subadults attempting to recruit into the breeding population.

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. These predictions have not been met; the East Sand Island tern colony has instead remained stable in size. Together with stable or slowly declining breeding populations of Caspian terns in the Columbia Plateau and San Francisco Bay, this result suggests that the paucity of banded subadult terns recruiting into the East Sand Island colony is due to poor subadult survival. The cause of poor subadult survival is not known.

Analysis of the band re-sighting data is on-going and will allow us to estimate adult survival, juvenile survival, 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 between colonies, either within or between years, we can better assess the consequences of various management strategies.

1.6. Monitoring and Evaluation of Management

1.6.1. Nesting Distribution

All Caspian terns that nested at the former colony site on Rice Island shifted to the restored colony site on East Sand Island during the three-year period 1999–2001. Because of active management, all Caspian terns nesting in the Columbia River estuary have used East Sand Island during 2001-2005 (Figure 10). Habitat restoration/improvement, social attraction (tern decoys and audio playback systems), and gull control at the East Sand Island colony site were successful in attracting terns to breed there and provided suitable nesting habitat for all terns that formerly nested on Rice Island. Efforts to reduce available nesting habitat on Rice Island were successful in gradually reducing the area used by nesting terns (Figure 11). Furthermore, efforts to dissuade prospecting terns at other dredge disposal sites (e.g., Miller Sands Spit, Pillar Rock Sands) have prevented the formation of incipient tern colonies in the upper estuary, where predation impacts on smolts are known to be high. The number of Caspian terns nesting in the Columbia River estuary has remained relatively constant since 1998 (Figure 10).

The successful restoration of the Caspian tern colony on East Sand Island is partly a reflection of the species' nesting ecology. Caspian terns prefer to nest on patches of open, unvegetated habitat covered with sand (Quinn and Sirdevan 1998), at a safe elevation above the high tide line, and on islands that are devoid of mammalian predators (Cuthbert and Wires 1999). These habitats are typically ephemeral, particularly in coastal environments, and can be created or destroyed during winter storm events. Breeding Caspian terns must be able to adapt to these changes in available nesting habitat. Consequently, Caspian terns are in a sense pre-adapted to shifting their nesting activities from one site to another more so than most other colonial seabirds.

1.6.2. Diet and Salmonid Consumption

Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply (Table 1, Figure 12), even in 2005 when availability of marine forage fishes declined due to poor ocean conditions. Caspian terns nesting on East Sand Island in 2004 had the lowest average percentage of salmonids in their diet (17%) and terns nesting on Rice Island in 2000 had the highest percentage of salmonids in their diet (90%; Table 1). In general, juvenile salmonids were more prevalent in the diets of Caspian terns during April and May, and salmonids declined in the diet during June and July. The one exception to this trend was at Rice Island in 2000, when the proportion of salmonids in the diet remained high (over 80%) for the entire breeding season.

The major difference in diets of Caspian terns nesting at colonies separated by only 26 km suggests that the terns foraged primarily in proximity to their nesting colonies in the estuary, instead of commuting longer distances to favored or traditional foraging sites. The success of tern colony relocation as a means to reduce consumption of juvenile salmonids was contingent on the terns foraging opportunistically and adapting their foraging behavior to local conditions near the colony.

Compared to the estimate of total consumption of juvenile salmonids in 1998 (12.4 million), when all Caspian terns nested on Rice Island, consumption of juvenile salmonids by all Caspian terns nesting in the Columbia River estuary was lower by approximately 34%, 53%, 48%, 66%, 72%, and 71% in 2000, 2001, 2002, 2003, 2004, and 2005, respectively (Figure 13). Per capita smolt consumption has also declined since the study began in 1997 (Figure 14); in 2005 per capita smolt consumption (203 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$) declined 74% from the highest rate previously measured (777 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$ in 1999). These declines in losses of juvenile salmonids to Caspian tern predation coincided with the shift of breeding terns from Rice Island to East Sand Island and improved ocean conditions, which enhanced the availability of marine forage fish near East Sand Island.

Caspian terns nesting on East Sand Island in 2005 still consumed an estimated 3.6 million juvenile salmonids (95% c.i. = 3.0 – 4.2 million smolts), with some ESA-listed stocks suffering significant losses to tern predation (Ryan et al. 2001a; Ryan et al. 2001b; Ryan et al. 2003). Nevertheless, a conservative estimate of the reduction in losses of juvenile salmonids to Caspian tern predation in the estuary due to this management action is at least 36 million smolts over the last 6 years. This large reduction in smolt losses was primarily due to a reduction in the number of sub-yearling chinook salmon consumed, although reductions in the consumption of steelhead and coho salmon smolts also occurred (Figure 15). To achieve further reductions in consumption of juvenile salmonids by Caspian terns in the estuary, however, it will be necessary to reduce the size of the East Sand Island tern colony by relocating a portion of the colony to alternative sites outside the estuary.

1.6.3. Nesting Success

Our results indicate that relocating the tern colony from Rice Island to East Sand Island enhanced the nesting success of Caspian terns nesting in the Columbia River estuary. Average nesting success of Caspian terns on East Sand Island in 1999–2005 (0.94 young raised per breeding pair) was consistently higher than for terns nesting on Rice Island, both prior to tern management (0.06 and 0.45 young raised per breeding pair in 1997 and 1998, respectively) and post-management (0.55 and 0.15 young raised per breeding pair in 1999 and 2000, respectively; Figure 16). Nesting success at the Rice Island colony was also considerably lower than at other well-studied Caspian tern colonies along the Pacific Coast (average of 1.1 young raised per breeding pair; Cuthbert and Wires 1999), suggesting that nesting success at Rice Island during 1997–2000 may not have been adequate to compensate for annual adult and subadult mortality. Average nest density, which ranged from 0.25 to 0.78 nests/m^2 on Rice Island, and from 0.26 to 0.62 nests/m^2 on East Sand Island (Figure 17), was not apparently related to nesting success at either colony.

The relatively high nesting success of Caspian terns on East Sand Island in 2001–2004 was reflected in similarly high nesting success among double-crested cormorants and glaucous-winged/western gulls nesting on East Sand Island. These piscivorous colonial waterbirds all benefited from strong coastal up-welling and associated high primary and secondary productivity along the coast of the Pacific Northwest, particularly in 2001 (R. Emmett, NOAA Fisheries, pers. comm.). The favorable ocean conditions have been linked to the regime shift associated with the Pacific Decadal Oscillation (PDO) and may ensure relatively high availability of marine forage fishes near the mouth of the Columbia River for several years to come, although other climatic events (e.g., El Nino/Southern Oscillation) will also influence marine fish populations in the short term.

In 2005, East Sand Island terns experienced the lowest productivity we have measured since terns first started nesting there in 1999, productivity that was comparable to that observed on Rice Island in 1998 and 1999. This agrees with reports of poor ocean conditions and widespread seabird nesting failure along the coast of the Pacific Northwest in 2005.

SECTION 2: DOUBLE-CRESTED CORMORANTS

2.1. Nesting Distribution and Colony Size

2.1.1. Columbia River Estuary

Methods: In order to estimate double-crested cormorant colony size at East Sand Island in 2005, high resolution aerial photos of the colony were taken late in the incubation period. Counts of the number of stick nests within delineated boundaries of the breeding colony were conducted by staff in the Survey, Mapping, and Photogrammetry Department at the Bonneville Power Administration. In addition, researchers from Oregon State University proofed this count of stick nests in the photographs to confirm the estimate of the number of breeding pairs in 2005. Counts from aerial photos also provided an assessment of habitat use and distribution of nesting cormorants on East Sand Island in 2005.

Boat-based surveys of eight navigational markers near Miller Sands Spit (river km 38; see Map 2) were conducted 4-9 times monthly from early April through late July in 2005. Because nesting chronology varies 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 chicks was considered active. To minimize impacts to nesting cormorants (i.e., chicks sometimes jump from nests into the water when disturbed), we did not climb the navigational markers and check nests to estimate productivity.

Monthly boat-based surveys of the Astoria-Megler Bridge (see Map 1) were conducted from May through July in 2005. 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.

In 2005, frequent boat-, land-, and air-based surveys were also conducted to monitor the social attraction sites at Miller Sands Spit and Trestle Bay (see below), as well as other former cormorant colony sites (i.e., Rice Island), looking for indications of nesting activity by double-crested cormorants.

Results and Discussion: In 1989, fewer than 100 pairs of double-crested cormorants nested on East Sand Island. But growth in the breeding population from 1989 to 2004 resulted in the East Sand Island colony becoming the largest known colony of double-crested cormorants in North America by 2004 (Anderson et al. 2004; L. Wires, University of Minnesota, pers. comm.). We estimate that 12,287 breeding pairs (95% c.i. = 10,361–14,213 breeding pairs) attempted to nest at East Sand Island in 2005, very similar to the estimate of colony size in 2004 (12,480 breeding pairs). 2005 is the first year that there has not been a significant increase in the size of this colony since counts began in 1989. The lack of an increase in colony size was likely associated with poor ocean conditions during much of the 2005 nesting season, and associated lower availability of marine forage fish. Nevertheless, the East Sand Island cormorant colony was nearly three times larger in 2005 than when we first estimated the size of this colony in 1997 (Figure 18). 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 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.

During 2001-2004, increases in the size of the East Sand Island cormorant colony were associated with increases in colony area, as opposed to increases in nest density. In 2005, double-crested cormorants nesting on East Sand Island used less total area for nesting (Figure 19) and nested at higher densities (Figure 20) compared to 2004. The smaller area of the cormorant colony and the higher nesting density in 2005 was apparently caused by increased disturbance and predation pressure from bald eagles (*Haliaeetus leucocephalus*). Prior to 1999, cormorants on East Sand Island nested exclusively amongst the boulder riprap and driftwood on the southwest shore of the island, after which they began nesting in satellite colonies in the adjacent low-lying habitat (see Map 4 for distribution of nesting cormorants in 2005). 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 may limit the size of the colony in the future.

In 2005, 208 pairs of double-crested cormorants nested on eight channel markers located in the upper estuary near Miller Sands Spit. The previous year, 194 cormorant pairs nested on seven different channel markers in the same area. Peak nest counts on individual markers were recorded during 17 May - 9 June in 2005. The asynchrony in nesting chronology among the different channel marker colonies was likely due to differences in disturbance and predation by bald eagles among the channel markers used by nesting cormorants.

In 2005, we again observed double-crested cormorants nesting on the Astoria-Megler Bridge, immediately south of the southernmost portion of the established pelagic cormorant (*Phalacrocorax pelagicus*) colony on the bridge. During boat-based censuses on 25 May and 13 June, 14 nests were attended by double-crested cormorants. In 2004, the first year double-crested cormorants were documented to nest on this bridge, 6 double-crested cormorant nests were attended in the same area.

In late May, 2005, double-crested cormorants attempted to nest at Miller Sands Spit, where social attraction techniques (arrangement of nesting habitat, placement of old nests and decoys, and playback of vocalizations) were employed. On 31 May, at least 4 nests were confirmed to contain eggs. Within a few days of laying eggs, cormorants had abandoned the site, however, presumably due to human, eagle, or other disturbance. See below for more details on the social attraction efforts and the attempted breeding at Miller Sands Spit.

Double-crested cormorants did not attempt to nest at Rice Island in 2005.

2.1.2. Columbia Plateau

Methods: To estimate the size of the double-crested cormorant colony on Foundation Island in 2005 (see Map 3), periodic boat-based and land-based counts of attended nest structures were conducted off the east shore of the island. 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 weekly from the observation blind in 2005.

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”; see Map 2). 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 of the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, searching for new double-crested cormorant colonies.

Results and Discussion: In 2005, the double-crested cormorant colony on Foundation Island consisted of ca. 315 pairs, the largest cormorant colony on the Mid-Columbia River. The estimated size of the colony was slightly more than our estimate in 2004. As was the case in previous years, all cormorant nests at this colony were in trees at the south end of the island.

The largest cormorant colony in the entire Columbia Plateau Region was on Potholes Reservoir in the North Potholes Reserve (ca. 800 breeding pairs). Cormorants at this colony nest in trees that are flooded for much of the nesting season. This colony has also been slowly increasing in size over the last decade. There is little evidence, however, that these birds commute to the Columbia River to forage on juvenile salmonids.

Based on our counts of cormorant nests at the Okanogan colony, we estimate that there were 38 nesting pairs at that colony in 2005, up slightly from the previous year (20-30 nesting pairs).

Aerial surveys of the lower and mid-Columbia River did not reveal any previously unknown cormorant breeding colonies. Islands in the mid-Columbia River near Pasco and at the mouth of the Yakima River are used regularly by roosting cormorants, and may be incipient cormorant nesting colonies.

2.1.3. Coastal Washington

Methods: In 2005 we counted cormorant nests on channel markers in Grays Harbor, WA (Map 1) during two aerial survey flights at the beginning and end of May. No boat-based surveys of nesting habitat were conducted in Grays Harbor in 2005.

Results and Discussion: We counted a total of 121 double-crested cormorant nests during the 30 May aerial survey of Grays Harbor. These cormorant nests were on channel markers located in the western and northeast portions of the estuary. The number of nests counted in Grays Harbor in 2005 was lower than in 2004 (190 nests).

We saw no evidence of cormorant nesting attempts on Sand Island in Grays Harbor in 2005, a site where double-crested cormorants have nested in previous years.

2.2. Nesting Chronology and Productivity

2.2.1. Columbia River Estuary

Methods: Two elevated blinds located at the periphery of the East Sand Island cormorant colony were used to observe nesting cormorants in 2005 (see Map 4 for blind locations). The blinds were accessed via above-ground tunnels to prevent disturbance to nesting cormorants, gulls, and roosting California brown pelicans (*Pelecanus occidentalis californicus*). In 2005, 249 individual cormorant nests in seven 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 28 days post-hatching. Cormorant chicks older than 28 days are capable of leaving their nest.

Monitoring of nesting cormorants on channel markers in the upper estuary and on the Astoria-Megler Bridge was conducted periodically (1–4 times each month) from a boat.

Results and Discussion: The first cormorant eggs on East Sand Island were observed on 22 April in 2005, 1 day earlier than in 2004. The first hatchlings were observed on the colony on 23 May in 2005, 2 days later than in 2004.

We estimate that 16,969 fledglings (95% c.i. = 13,821–20,117 fledglings) were produced at the East Sand Island colony in 2005. This corresponds to an average productivity of 1.38 young raised per breeding pair (95% c.i. = 1.26–1.50 fledglings/breeding pair), which was lower than the estimate of productivity for the East Sand Island cormorant colony in 2004 (2.05 fledglings/breeding pair, 95% c.i. = 1.91–2.19 fledglings/breeding pair; Figure 21). Productivity at the East Sand Island cormorant colony in 2005 falls towards the lower end of the typical range (1.2–2.4 young per nest) reported for other North American colonies of this species (Hatch and Weseloh 1999).

Confirmation of eggs in nests on the channel markers in the upper Columbia River estuary was not possible from our vantage on the water, but small chicks (7-10 days) were observed on markers by late May in 2005, roughly synchronous with the nesting chronology of cormorants on East Sand Island. Nests on the Astoria bridge were likely initiated a bit later than nests on East Sand Island or the upper estuary channel markers; no chicks were observed during our boat survey on 13 June. There were no successful nests at the social attraction study site on Miller Sands Spit. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for either the nests on upper estuary channel markers or on the Astoria bridge.

2.2.2. Columbia Plateau

Methods: In 2005, we monitored 50 nests on Foundation Island each week from the observation blind (see Map 3). Productivity was estimated from the number of chicks in monitored nests at 28 days post-hatching. Because of our distance 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: In 2005, nest initiation was earlier at the Foundation Island cormorant colony compared to the cormorant colonies in the Columbia River estuary. At the end of April, more than three weeks before the first chick was observed on East Sand Island, researchers collecting cormorant diet samples at the Foundation Island colony heard chicks vocalizing in the nests overhead. Productivity on Foundation Island (2.30 ± 0.13 fledglings/nest) was significantly greater ($P < 0.001$) than at East Sand Island (1.38 ± 0.06 fledglings/nest) in 2005. In successful nests, brood size on Foundation Island at 36 days post-hatch was greater ($P = 0.02$) in 2005 (2.18 ± 0.11 fledglings/nest) than in 2004 (1.86 ± 0.11 fledglings/nest).

2.2.3. Coastal Washington

Methods: In 2005 we counted cormorant nests on channel markers in Grays Harbor, WA (Map 1) during two aerial survey flights at the beginning and end of May (121 nests were counted during the survey on 30 May). No boat-based surveys of cormorant nesting success were conducted in Grays Harbor during 2005.

Results and Discussion: Because we did not visit Grays Harbor by boat later in the breeding season (after hatch and near the fledging period), we were unable to assess nesting success for the nests on channel markers in Grays Harbor in 2005.

2.3. Diet Composition and Salmonid Consumption

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 was 6-10 adult fore-gut (stomach and esophagus) samples per week. Immediately after collection, the 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, stored, and 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. The diet composition results for 2005 are preliminary because they are based only on identifiable fish soft tissues, not diagnostic bones. Fish were identified to genus and species, whenever possible. Intact salmonids in fore-gut samples will be identified as chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on otolith and/or genetic analyses. Unidentifiable fish soft tissue samples will be artificially digested (work that is ongoing) according to the methods of Peterson et al. (1990, 1991). Once digested, diagnostic bones (i.e., otoliths, cleithra, dentaries, pharyngeal arches, and opercles) will be removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish soft tissue samples that do not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) will not be included 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 two-week period throughout the nesting season. The diet composition of cormorants over the entire breeding season was based on the average of these two-week percentages.

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

Results and Discussion: The diet composition of double-crested cormorants nesting on East Sand Island and their consumption of juvenile salmonids in 2005 are not available because of the unexpected termination of project funding from the Portland District, USACE on 30 September 2005. Once funding for this task is reinstated, we will complete the laboratory analysis necessary to estimate diet composition and smolt consumption by double-crested cormorants nesting on East Sand Island in 2005.

2.3.2. Columbia Plateau

Methods: During the 11-week period (late April to early July) when nestlings were being fed at the Foundation Island cormorant colony, we collected diet samples from the ground below active nests, samples that were spontaneously regurgitated by nesting adults and their young. A total of 89 regurgitations were collected from the ground during this period. Additionally, 10 adult cormorants were lethally collected on 5 May, and contents of their fore-gut and other tissues were sampled. All diet samples were analyzed in our laboratory at Oregon State University to investigate the diet composition of cormorants nesting on Foundation Island in 2005.

No samples to determine diet composition were collected early in the nesting season (March and most of April) in order to avoid disturbing breeding pairs early in nesting and potentially causing nest abandonment. Collection of diet samples was initiated soon after the first eggs hatched on the Foundation Island colony.

Results and Discussion: In 2005, the regurgitation samples collected from late April through early July indicated that centrarchids (bass and sunfish) and cyprinids (minnows) were the most prevalent prey types in the diet of Foundation Island cormorants during chick-rearing (Table 8). Salmonids were a relatively minor component of the diet (10.1%) during this period, based on the percent biomass of identifiable prey in regurgitations. Salmonids were only detected in regurgitations collected on two dates, 22 April (100% salmonids, n = 3 regurgitations) and 8 May (75.0% salmonids, n = 8 regurgitations). Salmonids made up 59.5% of identifiable prey biomass in the fore-gut contents of the 10 adults collected on 5 May. As in 2004, salmonids appeared to be more prevalent in the diet of Foundation Island cormorants early in the 2005 nesting season. These diet composition data suggest that, unlike Caspian terns nesting on nearby Crescent Island, double-crested cormorants nesting on Foundation Island do not rely on juvenile salmonids as a primary food source throughout the nesting season.

2.4. Salmonid Predation Rates: PIT Tag Studies

2.4.1. Columbia River Estuary

Methods: In comparison to Caspian tern colonies, the recovery/detection of smolt PIT tags on cormorant colonies is more difficult. Unlike Caspian terns, which nest primarily on bare sand, cormorants nest in a wide array of habitat types (i.e., in trees, on the ground amongst vegetation and woody debris, on rip-rap). This poses significant challenges for the recovery or detection of PIT tags egested by nesting cormorants on-colony. To enhance our ability to recover PIT tags from the cormorant colony on East Sand Island, we constructed cormorant nesting platforms on the colony and used social attraction techniques (see Section 2.5 for details on social attraction) to encourage cormorant nesting on the platforms. We hypothesized that if we could attract cormorants to nest on platforms we would improve the detection efficiency for smolt PIT tags. Furthermore, if we knew how many cormorant breeding pairs nested on each platform, we could calculate a per-capita PIT tag consumption rate for these cormorants, which could be used, along with our estimate of colony size, to estimate total consumption of PIT-tagged smolts by cormorants nesting on East Sand Island.

Prior to the 2005 nesting season two plywood nesting platforms (each measuring 6 m x 6 m) were constructed near the observation tower at the west end of East Sand Island. Silt fencing material was placed on the surface of each platform to retain PIT tags, and a 30-cm high railing was secured around the perimeter of each platform to prevent tags from blowing off the platforms during the nesting season. A 4-m wide trench was dug around each platform to prevent birds from nesting directly adjacent to the platforms. Each platform was top-dressed with sand and 36 truck tires were placed on the sand. Old cormorant stick nests from the 2004 nesting season were then placed on each truck tire, providing nest sites for up to 36 nesting pairs on each platform. The nesting chronology, number of breeding pairs, and nesting success of cormorants on each platform was recorded throughout the nesting seasoning (8 April to 12 August 2005). Detection efficiency for PIT tags on the platforms (a parameter needed to adjust/correct PIT tag recovery results) was measured by intentionally spreading 400 PIT tags on each platform at four different times during the nesting season: before nest building (30 March), during incubation (14 and 20 May), during chick-rearing (16 and 25 June), and immediately following fledging (5 and 11 August). PIT tags were then recovered from each platform on 17 November 2005 by a combination of electronic detection and hand removal methods (see Section 1.4 for more details).

Results and Discussion: PIT tag results and other analyses pertaining to this pilot experiment at the East Sand Island cormorant colony are not available due to an unexpected termination of funding from the Portland District, USACE on 30 September 2005. If funds become available, we will complete the analyses and prepare results for inclusion in the 2006 Season Summary.

2.4.2. Columbia Plateau

Methods: Data on PIT tag detection efficiency and predation rates on PIT-tagged smolts for double-crested cormorants nesting on Foundation Island were collected in 2005. The methods used to generate these estimates are the same as those described for Crescent Island terns (see Section 1.4). Unlike the Crescent Island tern colony, however, test tags used to evaluate detection efficiency were not spread on discrete plots because double-crested cormorants on Foundation Island nest in trees. Instead, test tags (n = 100 per release) were spread randomly under nesting trees on four different occasions: prior to arrival of birds on the colony (16 March), early in the chick-rearing period (16 May), during fledging (3 July), and after the birds had left the colony following nesting (26 July).

Tags were detected at the Foundation Island cormorant colony by NOAA Fisheries using specially designed hand-held electronic equipment (see Ryan et al. 2003 for a detailed description of NOAA Fisheries' PIT tag recovery methods). Smolt predation rates by Foundation Island cormorants were based on the number of PIT-tagged fish interrogated/tagged at Lower Monumental Dam that were subsequently recovered on the colony; these predation rates were corrected for detection efficiency. Comparison of the relative impacts of predation by cormorants, terns, and pelicans nesting in McNary Pool on PIT-tagged smolts are based on minimum predation rates (uncorrected for the proportion of ingested PIT tags that were not deposited on-colony) at each colony.

Results and Discussion: Of the 400 test tags intentionally spread on Foundation Island in 2005, 271 or 67.8% were subsequently recovered on-colony by NOAA Fisheries. Detection efficiency ranged from as low as 58.0% for tags spread early in the chick-rearing period to 79% for tags spread before the nesting season. There was no evidence of an association between test tag release date and detection efficiency (R^2 = 0.2897, P = 0.4617), indicating that tags deposited early in the nesting season were just as likely to be recovered as tags deposited late in the nesting season. These detection efficiency results pertain to tags deposited and recovered on the ground directly underneath nesting cormorants, and may not be representative of PIT tags ejected in arboreal nests. It is not known what proportion of PIT tags ejected by cormorants while on their nest are retained in the nest vs. deposited on the ground. Researchers noted, however, that many of the cormorant nests had deteriorated and fallen to the ground prior to PIT tag recovery efforts in 2005, suggesting that the bulk of PIT tags deposited on-colony by cormorants were subsequently recovered. In 2006, we plan to place some test tags in cormorant nests prior to the breeding season and then remove these nests following the nesting season (of those that remain in trees) to scan for PIT tags.

A total of 4,101 PIT tags from 2005 migration year smolts were recovered by NOAA Fisheries at the Foundation Island cormorant colony in 2005. These tags represent 0.22% of the 1.85 million PIT-tagged fish released into the Columbia River basin in 2005. Of the 4,101 tags recovered, 55% were from steelhead (n = 2,252), 16% from spring chinook (n = 659), and 15% from fall chinook (n = 633). These salmonid species were also the most heavily tagged, representing 43%, 31%, and 15% of all tagged, in-river smolts, respectively. Overall, Foundation Island cormorants consumed an estimated 1.18% of the PIT-tagged smolts interrogated at Lower Monumental Dam from 1 April to 31 July (Table 9), including 2.01% of hatchery-reared Snake River steelhead smolts and 1.83% of wild Snake River steelhead smolts. These predation rates are minimums because they were not corrected for the proportion of ingested PIT tags that were not deposited on the colony.

A comparison of PIT tag recoveries between the Foundation Island cormorant colony and the Crescent Island tern colony indicates that the cormorants consumed about 1/4th as many PIT-tagged Snake River smolts as did the terns in 2005 (625 vs. 2,384; Table 9). Snake River steelhead were the most vulnerable salmonid ESU to Foundation Island cormorants in 2005, similar to the results from the Crescent Island tern colony (Table 9). Although uncertainties remain regarding PIT tag detection efficiency and deposition rate on the Foundation Island cormorant colony, results provide a valid comparison of predation rates by two different colonies of avian predators – colonies that are separated by just a few kilometers – on the same group of tagged fish. As such, we recommend that these comparisons be continued in 2006 and strengthened by utilizing predation rate data from a telemetry study proposed in McNary Pool by NOAA Fisheries (POC, Gordon Axel).

Table 11 examines predation rates on groups of PIT-tagged fall chinook smolts by the Crescent Island tern colony, the Foundation Island cormorant colony, and the Badger Island white pelican colony. Cormorants nesting on Foundation Island consumed similar numbers of PIT-tagged fall chinook smolts as terns nesting on Crescent Island, despite the finding that upriver cormorants consumed 25% fewer PIT-tagged fish as upriver terns in 2005. Cormorant predation rates on PIT-tagged fall chinook were highest, however, for release groups of non-listed smolts from the Yakima River and Upper Columbia River, while tern predation rates were highest for releases of Snake River fall chinook. Predation rates by Badger Island pelicans on PIT-tagged fall chinook were lowest among the three avian predators, but were much higher on Yakima River fall chinook than on fall chinook from the Snake and Middle Columbia rivers (Table 11). There is considerable variation in avian predation rates among release groups of PIT-tagged fall chinook, suggesting that fall chinook from particular river reaches and release groups may be more vulnerable than others. This is likely a result of differences in bird foraging efficiencies among release groups, but may be partly attributable to differences in smolt mortality from other factors prior to predation by piscivorous birds nesting on islands in McNary Pool.

2.5. Management Feasibility Studies

Methods: In 2005, we continued management feasibility studies to determine whether social attraction techniques can be used to induce double-crested cormorants to nest in areas where they have not previously nested and, if so, whether these techniques can be used to manage cormorants nesting in the Columbia River estuary. We employed social attraction techniques (decoys and audio playbacks; Kress 2000, Kress 2002, Roby et al. 2002) and enhanced nesting habitat at three different sites in the Columbia River estuary in 2005: (1) on East Sand Island in areas adjacent to previously established nesting areas; (2) on a small rock island in Trestle Bay, approximately 5 km south of the East Sand Island cormorant colony; and (3) at the west end of Miller Sands Spit, approximately 24 km east of the East Sand Island cormorant colony (see Map 2).

Two elevated nesting platforms (5 x 5 m) were constructed on East Sand Island near the active cormorant breeding colony to investigate whether cormorants could be induced to nest on an artificial structure at a specific site where they had not previously nested (Map 4). The platforms were also designed to facilitate recovery of smolt PIT tags from cormorant nesting areas in order to generate better estimates of cormorant predation rates based on PIT tag recoveries on-colony (see above). The platforms were covered with silt fencing material and then sand, and old tires (n = 36) filled with old cormorant nests were placed on each platform. A total of 12 cormorant decoys and two speakers broadcasting audio playbacks of the cormorant colony were placed on each platform.

Nesting chronology and productivity data from the nesting platforms were collected by direct observation from the nearby observation tower. A total of 30 and 33 active cormorant nests were monitored on platforms 1 and 2, respectively. Visual observations of nest contents were recorded each week from mid-April through July. Productivity was expressed as the number of nestlings remaining in each monitored nest 28 days post-hatch.

Social attraction techniques were also tested on Miller Sands Spit (see Map 1), a dredged material disposal site in the upper Columbia River estuary (river km 34). Approximately 10 pairs of double-crested cormorants attempted to nest at the west (downstream) end of Miller Sands Spit in 2001, but all nests were abandoned prior to eggs hatching. Nest depredation by gulls, perhaps facilitated by human disturbance, was the most likely cause of abandonment at this site. In April of 2004, we set up an experimental plot on the western tip of the upland portion of the island, near the area where cormorants had attempted to nest in 2001. On a number of occasions, aggregations of cormorants were observed roosting on the beach below the experimental plot, but only once were cormorants observed in the upland area near the experimental plot. In 2005, we repeated our efforts to attract cormorants to nest on Miller Sands Spit. Large and small pieces of driftwood were placed in an 8 x 5 m plot and the area was filled in with smaller sticks and reeds that could be used as nesting material. A total of 24 cormorant decoys and 25 old tires were placed throughout the plot. Each tire was filled with small sticks as nesting material, and some of the decoys were placed on the tires. Two speakers broadcasting audio playbacks of a cormorant colony were also placed in the plot. Boat-based or aerial surveys of the island were conducted twice each week from mid-April through June and each week in July in order to monitor potential nesting activity at the site.

An experimental social attraction plot for double-crested cormorants was also set up on a small rock island at the mouth of Trestle Bay in April 2005. Double-crested cormorants nested on some old trestles in Trestle Bay during the 1980s; however, there have been no records of cormorants nesting there since then. A total of 26 decoys, 24 old tires, and two speakers broadcasting audio playbacks of a cormorant colony were secured to the large rocks within an area of about 10 x 20 m. The tires were filled with small sticks as nesting material, and some of the decoys were placed on the tires. Boat- and land-based surveys of the rock island were conducted once or twice each week from April through early-July in order to monitor potential nesting activity at the site.

Results and Discussion: On East Sand Island, cormorants were observed on both nesting platforms carrying nesting material and engaging in courtship displays within 4 days of completing construction. Nest initiation on the platforms was synchronous with the rest of the East Sand Island cormorant colony. A total of 31 and 33 breeding pairs nested on platforms 1 and 2, respectively. Productivity was slightly higher on the nesting platforms (1.94 ± 0.11 fledglings/breeding pair, n = 64 nests) than elsewhere on the East Sand Island cormorant colony (1.50 ± 0.07 fledglings/breeding pair; n = 169 nests).

Based on relatively similar nesting chronology and higher productivity, it appears that we were able to create nesting habitat that was similar to or higher in quality than the surrounding habitat available on East Sand Island. Preparation of suitable nesting habitat, in conjunction with social attraction techniques, appears to be an effective technique for inducing nesting cormorants to colonize new nesting sites short distances from previously used nesting areas.

Double-crested cormorants attempted to nest in the experimental plot on Miller Sands Spit in 2005. Cormorants were first observed carrying nesting material to the plot on 15 May, 24 days after completion of setting up the plot (21 April). A total of 21 nests were partially or completely built on the plot, and six eggs were laid in four nests; all nests subsequent failed prior to hatching, presumably due to gull predation. The west end of Miller Sands Spit is subject to disturbance from both recreational fisherman and bald eagles, and gulls may have removed all the cormorant eggs from the incipient colony during one such disturbance.

Double-crested cormorants did not attempt to nest on the experimental plot on the small rock island in Trestle Bay. This attempt at inducing double-crested cormorants to nest at a location removed from East Sand Island may have been unsuccessful for several reasons. First, cormorants prospecting for nest sites in the lower Columbia River estuary are not likely to look beyond East Sand Island because there appears to be ample unused nesting habitat available there, and the large and well-established nesting colony on East Sand Island likely provides strong social attraction to that site. Second, there may be greater disturbance rates for cormorants prospecting for nest sites at Trestle Bay as compared to East Sand Island. Bald Eagles are commonly seen roosting in Trestle Bay and recreational boaters are often seen just offshore at the site. Social attraction of nesting cormorants from East Sand Island to an alternative nesting island may have a greater probability of success if the alternative site is more protected from disturbance and if the available nesting habitat on East Sand Island is reduced through management.

SECTION 3: OTHER COLONIAL WATERBIRDS

3.1. Distribution

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

Gulls: During land-based surveys, breeding colonies of glaucous-winged/western gulls and ring-billed gulls (*L. delawarensis*) were confirmed at several sites in the Columbia River estuary in 2005 (Table 10). Glaucous-winged/western gulls nested on three islands in 2005: East Sand Island, Rice Island, and Miller Sands Spit (see Map 1), with the East Sand Island gull colony being by far the largest of the three (ca. several thousand nesting pairs; Table 10). Ring-billed gulls, which previously nested on Miller Sands Spit (Collis et al. 2002), now nest solely on East Sand Island within the Columbia River estuary (ca. hundreds of pairs; Table 10).

California Brown Pelicans: East Sand Island has been identified as the largest known post-breeding roost site for California brown pelicans, and is the only known night roost for this ESA-listed endangered species in the Columbia River estuary (Wright 2004). In 2005, the first California brown pelicans were observed roosting on East Sand Island on 8

April and no pelicans were observed on the island during the last island-wide census of the season on 16 November. The number of brown pelicans roosting on East Sand Island peaked at 5,445 on 8 August. 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 disturbance to brown pelicans roosting East Sand Island in 2005.

Brandt's and Pelagic Cormorants: Small numbers of Brandt's cormorants (*P. penicillatus*; 62 nesting pairs) and pelagic cormorants (*P. pelagicus*; 159 nesting pairs) nested on structures (i.e., pile dikes and the Astoria–Megler Bridge, respectively) in the Columbia River estuary in 2005 (see Map 1 and Table 10). The first documented breeding record for Brandt's cormorants in the Columbia River estuary was in 1997, when a few pairs were found nesting on a pile dike at the west end of East Sand Island (Couch and Lance 2004). 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 lower and middle Columbia River, gulls, primarily California and ring-billed gulls, were confirmed to be nesting on six different islands in the river between The Dalles Dam and Rock Island Dam in 2005: Miller Rocks (river km 333), Three Mile Canyon Island (river km 413), Rock Island (river km 445), Crescent Island (river km 510), and on two islands near Richland, Washington (Fencepost Island [river km 545] and Island 18 [river km 553]; see Map 2 and Table 10). The California gull colony on Little Memaloose Island (river km 315), which was active in 1998 (Collis et al. 2002), has not been active for several years (see Map 2). The gull colonies on Crescent Island, Fencepost Island, and Island 18 were the largest colonies identified along the mid-Columbia River in 2005 (Table 10). When last censused in 1997 and 1998, gull colonies in the Richland area totaled over 30,000 nesting birds (Collis et al. 2002).

An unknown number of ring-billed and California gulls were also confirmed to be nesting in Potholes Reservoir, Sprague Lake, and Banks Lake in 2005 (see Map 2 and Table 10).

American White Pelicans: Each week, we conducted boat-based counts of American white pelicans (*P. erythrorhynchos*) at the colony on Badger Island in 2005 (see Map 3) in order to assess seasonal pelican activity on the island. The only known nesting colony of American white pelicans in the State of Washington is on Badger Island, and the species is listed as endangered by the State. Consequently, the island is closed to the public and researchers in order to avoid human disturbance to nesting pelicans that might cause the colony to be abandoned. An aerial photograph was taken of the colony on 16 May during the incubation period in order to estimate colony size. Complete counts of the number of active pelican nests on Badger Island were not possible from the water because most nests were concealed amidst the thick, brushy vegetation on the island.

Most, but probably not all, pelicans present on the island were visible in the aerial photo; however, we could not correct aerial photo counts 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. As it was only possible to obtain index counts of adults and juveniles at the Badger Island pelican colony, it was not possible to precisely estimate nesting success (number of young raised per breeding pair).

A total of 1057 adult American white pelicans were counted in the aerial photograph taken on 16 May. This is a minimum count of adults present on the colony at the time of the photograph. The pelicans were divided between two nesting areas on the island: 703 were counted in a nesting area in the middle of the eastern bank of the island, and 354 were counted in a nesting area near the northern (upriver) end of the island. Counts from aerial photographs have increased significantly in the years since 2001, when only 263 pelicans were counted on Badger Island, suggesting a corresponding increase in the actual number of breeding pairs. The average annual growth rate (?) in the number of pelicans counted on aerial photos during 2001-2005 was 1.42. Our boat-based counts resulted in a maximum count of 204 adults on 10 May, and a maximum count of 296 juveniles on 26 July. Maximum counts of juvenile pelicans during boat-based surveys were 238 in 2002, 141 in 2003, and 329 in 2004. The relatively high maximum count of juveniles in 2005 suggests that nesting success was relatively good.

Other species: In addition to gulls and pelicans, other colonies of piscivorous waterbirds were recorded by our field crews in 2005, including colonies of great blue herons, black-crowned night-herons, great egrets, and Forster's terns (Table 10).

3.2. Diet Composition

3.2.1. Columbia River Estuary

Gulls: As part of the current study, we have not collect diet data from gulls nesting in the Columbia River estuary for several years. Our previous research indicated that, in contrast to the gulls nesting at upriver locations (see below), glaucous-winged/western gulls nesting in the Columbia River estuary consumed primarily fish (Collis et al. 2002). 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 from Caspian terns, which nested at the nearby colony on Rice Island (Collis et al. 2002).

California Brown Pelicans: As part of this study, we do not collect diet data on brown pelicans roosting on East Sand Island. Brown pelicans feed primarily on schooling marine forage fish 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 fish near East Sand Island (R. Emmett, NOAA Fisheries, pers. comm.), and presumably these fish species comprise the majority of the diet of brown pelicans at East Sand Island.

Brandt's and Pelagic Cormorants: As part of this study, we do 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 know 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 diet preferences of Brandt's and pelagic cormorants, the impacts of these birds on juvenile salmonids from the Columbia River basin are expected to be negligible.

3.2.2. Columbia Plateau

Gulls: As part of the current study, we have not collected diet 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 1997 and 1998. 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 diet mass; this colony is no longer active) and Miller Rocks (3% of total diet mass). 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, but our previous data suggest that at the level of the breeding colony, juvenile salmonids were a minor component of the diet. Current efforts to limit avian predation on smolts at the lower Columbia River dams (Jones et al. 1996) and salmon hatcheries (Schaeffer 1991, 1992) have apparently been effective in reducing gull predation as a source of mortality to juvenile salmonids from levels that were previously reported (Ruggerone 1986).

More recent studies that use PIT tag recoveries on gull colonies (Ryan et al., in prep.) corroborate our previous finding that gulls nesting at up-river colonies are having a negligible impact on survival of juvenile salmonids.

American White Pelicans: Data regarding PIT tag detection efficiency and predation rates on PIT-tagged salmonids were generated for American white pelicans nesting on Badger Island in 2005. The methods used to generate these estimates are similar to those described for Crescent Island terns (see Section 1.4). One notable difference is that test tags used to determine detection efficiency could not be spread on Badger Island throughout the nesting season, as white pelicans are very sensitive to human disturbance on the colony. Test PIT tags (n = 100) were spread on only the southern nesting area (the larger of the two nesting areas on Badger Island) on 16 March, prior to the nesting season.

For the first time in three years, NOAA Fisheries recovered PIT tags on Badger Island in December 2005 using handheld electronic equipment (see Ryan et al. 2003 for a detailed description of NOAA Fisheries' PIT tag recovery methods). Hand removal of tags was also conducted on a smaller sub-section of the colony to determine if PIT tag densities were resulting in collision, a finding that would warrant a full-scale hand removal effort in the future. This was done by first scanning for PIT tags with handheld transceivers and then using magnets and rakes (as described above) to physically remove tags. Lastly, similar to the analytical approach used for Crescent Island terns and Foundation Island cormorants, predation rate data from the Badger Island pelican colony were corrected/adjusted for potential bias due to tag detection efficiency, but not for the proportion of ingested PIT tags that were deposited off-colony.

Of the 100 test tags intentionally spread on the Badger Island white pelican colony in 2005, 58.0% were subsequently recovered on-colony by NOAA Fisheries. Because only one pre-season release of test tags occurred, data regarding detection efficiency as a function of date were not available. As such, a detection efficiency of 58% may not accurately represent tags naturally deposited by pelicans during the nesting season but likely represents a minimum value. A comparison between the numbers of tags detected by handheld scanners versus the number physically removed suggests that PIT tag collision had little effect on tag detection efficiency in 2005. In total, handheld scanners detected 100% (18/18) of the tags that were subsequently physically removed from a sub-section of the colony; indicating that tag densities are not resulting in excessive tag collision on the Badger Island pelican colony.

A total of 611 PIT tags from 2005 migration year smolts were recovered from the Badger Island pelican colony following the 2005 nesting season. These tags represent only 0.03% of the 1.85 million PIT-tagged fish released into the Columbia River basin in 2005. Of the 611 tags recovered, 41% were from steelhead (n = 252), 30% were from fall chinook (n = 184), and 16% were from spring chinook (n = 95). Overall, Badger Island pelicans consumed only 29 (0.07%) of the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July (Table 9); 1% and 5% of the numbers consumed by Crescent Island terns and Foundation Island cormorants, respectively. In regards to PIT-tagged fish from the Snake River, steelhead smolts - especially hatchery-reared smolts - were the most vulnerable to Badger Island white pelicans (Table 9). Data collected from all in-river PIT-tagged smolts (not just those interrogated at Lower Monumental) suggest that fall chinook originating from the Upper and Middle Columbia rivers (not listed) and coho from the Yakima River (also not listed) were the most vulnerable to white pelicans nesting on Badger Island (Table 11; data on Yakima River coho not presented, but available upon request), with these two ESUs comprising 42% of all PIT-tagged smolts recovered on-colony yet comprising only 17% of all in-river PIT-tagged smolts. Taken as whole, the 611 PIT tags recovered from Badger Island provides evidence that the overall impact of white pelicans on survival of juvenile salmonids smolts in the McNary Pool is negligible, especially when compared to that of Caspian terns and double-crested cormorants.

SECTION 4: SYSTEM-WIDE OVERVIEW

4.1. Avian Predator Population Trajectories

Although numbers of Caspian terns nesting in the Columbia River basin have remained relatively stable over the past 8 years, the numbers of double-crested cormorants nesting on East Sand Island have nearly tripled during the same period to ca. 12,500 pairs, the largest known breeding colony of double-crested cormorants (Figure 22). Based on the habitat preferences of nesting cormorants, there currently exists ample unused habitat on East Sand Island that could support continued expansion of that colony in future years. Productivity at the East Sand Island cormorant colony has also been consistently greater than productivity for Caspian terns nesting in the estuary and up-river (Figure 23). Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is imminent; the Final EIS for Caspian tern management in the Columbia River estuary lists the redistribution of approximately two-thirds of the East Sand Island colony to alternative colony sites in Washington, Oregon, and California as the preferred alternative (USFWS 2005). Substantial increases in the numbers of nesting Caspian terns along the mid-Columbia River is unlikely due to the paucity of suitable nesting habitat for terns in that region. Based on these results, it is possible that the cormorant breeding population will continue to expand for the foreseeable future, while numbers of Caspian terns nesting in the estuary and up-river will not increase and may decline as the EIS is implemented. The trajectories of other colonial waterbird populations along the Columbia River (e.g., gulls and pelicans) is less clear, but monitoring of these colonies has not been deemed a priority by the agencies funding this work because of the relatively low impact of these avian predators on survival of juvenile salmonids from the Columbia River basin (see below).

4.2. Relative Impact of Predation

In 2004, double-crested cormorants nesting on East Sand Island probably consumed more juvenile salmonids than Caspian terns nesting at both East Sand Island and Crescent Island combined. This was due in part to the larger colony size and greater food requirements of double-crested cormorants relative to Caspian terns. Management options to reduce or limit smolt losses to double-crested cormorants in the Columbia River estuary have yet to be considered and will require additional research and NEPA analysis.

In 2005, Caspian terns nesting at East Sand Island consumed 8-fold more salmonids than did Caspian terns nesting on Crescent Island. The large disparity in smolt consumption between the estuary and mid-Columbia River tern colonies was primarily due to differences in colony size, with the East Sand Island tern colony (8,822 breeding pairs) being more than an order of magnitude larger than the Crescent Island tern colony (476 breeding pairs). Despite the much smaller numbers of salmonid smolts consumed annually by the Crescent Island tern colony, predation rates on particular salmonid stocks have been unexpectedly high, particularly predation rates on certain steelhead stocks in low flow years. For example, data collected in 2004 and 2005 indicate that predation rates by Crescent Island terns on in-river Snake River steelhead smolts were 34% and 17%, respectively (based on the number of PIT-tagged fish interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony). In-river steelhead smolts from the Snake River were more vulnerable to Crescent Island tern predation than in-river steelhead smolts from the Upper Columbia River ESU (predation rates in 2004 and 2005 of ca. 6% and 4%, respectively, based on PIT-tagged smolts interrogated at Rock Island Dam and subsequently recovered on the Crescent Island tern colony). The high predation rate on in-river migrants from the Snake River, however, is offset by the transportation of most Snake River steelhead around the McNary Pool. Conversely, juvenile salmonids from the Upper Columbia River are not transported past Crescent Island, resulting in the entire run being susceptible to predation by Crescent Island terns. Predation rates on salmonids by Crescent Island terns are unlikely to increase appreciably considering constraints on tern colony expansion, limited capacity for increased per capita smolt consumption by terns, and current high transportation rates for Snake River smolts.

A system-wide assessment of avian predation using the available data from recent years indicates that the most significant impact to survival of juvenile salmonids occurs in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combining to consume ca. 10 million smolts in 2004 (CBR 2005). Additionally, when compared to impacts of avian predation 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 compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids from every 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 terns and 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 bird populations. The Caspian tern colony on Crescent Island may be an exception to this rule; management of this small, up-river colony may benefit certain salmonid stocks, particularly in low flow years.

LITERATURE CITED

Anderson, C.D., D.D. Roby, and K. Collis. 2004. Conservation implications of the large colony of double-crested cormorants on East Sand Island, Columbia River estuary, Oregon, USA. Waterbirds 27:155-160.

Antolos, M., D.D. Roby, and K. Collis. 2004. Breeding ecology of Caspian terns at colonies on the Columbia Plateau. Northwest Science 787:303-312.

Antolos, M., D.D. Roby, D.E. Lyons, K. Collis, A.F. Evans, M. Hawbecker, and Brad A. Ryan. 2005. Caspian tern predation on juvenile salmonids in the Mid-Columbia River. Transactions of the American Fisheries Society 134:466-480.

CBR (Columbia Bird Research). 2005. Caspian Tern Research on the Lower Columbia River: 2004 Final Season Summary. Real Time Research, Bend, Oregon. Available on-line at http://columbiabirdresearch.org/.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Collis, K., D.D. Roby, D.P. Craig, S. Adamany, J. Adkins, and D.E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537–550.

Couch, S.L.L., and M.M. Lance. 2004. Diet composition and breeding success of Brandt's cormorants in the Columbia River estuary. Northwestern Naturalist 85:62-66.

Cuthbert, F., and L. Wires. 1999. Caspian tern (*Sterna caspia*). in A. Poole and F. Gill, editors. The Birds of North America, no. 403. The Birds of North America, Inc., Philadelphia, Pennsylvania.

FPC (Fish Passage Center). 2004. Available www.fpc.org (accessed December 2004).

Hansel, H. C., S. D. Duke, P. T. Lofy, and G. A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Hatch, J.J. and D.V. Weseloh. 1999. Double-crested Cormorant (*Phalacrocorax auritus*). *In* The Birds of North America, No. 441 (A. Poole and F. Gill, Eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

Hodder, J. 2003. Pelagic Cormorant (*Phalacrocorax pelagicus*). Pp. 58-59 *in* Birds of Oregon: A General Reference. D.B. Marshall, M.G. Hunter, and A.L. Contreras, Eds. Oregon State University Press, Corvallis, OR.

Jones, S. T., G. M. Starke, and R. J. Stansell. 1996. Predation by birds and effectiveness of predation control measures at Bonneville, The Dalles, and John Day dams in 1995. U.S. Army Corps of Engineers, Portland District, Operations Division, CENPP-CO-SRF. 10 pp.

Kress, S.W. 2000. Colony site management techniques. Issue Report in the Managers Toolbox, North American Waterbird Conservation Plan. Available through the Internet at http//www.nawcp.org/plan/toolbox.html.

Kress, S.W., and C.S. Hall. 2002. Tern management handbook: Coastal Northeastern United States and Atlantic Canada. Draft Report submitted to U.S. Fish and Wildlife Service, Migratory Bird Division, Hadley, MA.

Quinn, J.S., and J. Sirdevan. 1998. Experimental measurement of nesting substrate preference in Caspian terns, *Sterna caspia*, and the successful colonization of human constructed islands. Biological Conservation 85:63–68.

Roby, D. D., D. P. Craig, K. Collis, and S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report of the Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon, USA.

Roby, D.D., K. Collis, D.E. Lyons, D.P. Craig, J. Adkins, A.M. Myers, and R.M. Suryan. 2002. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management 66: 662–673.

Roby, D.D., D.E. Lyons, D.P. Craig, K. Collis, and G.H. Visser. 2003. Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81:250-265.

Roby, D.D., K. Collis, A. Evans, S.K. Nelson, K. Bixler, and D.E. Lyons. 2005. Caspian tern nesting ecology and diet on the Olympic Peninsula, Washington. Draft 2005 Annual Report. USGS-Oregon Cooperative Fish and Wildlife Research Unit, Corvallis, OR. 17 pp.

Ruggerone, G. T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115:736-742.

Ryan, B.A., S.G. Smith, J.M. Butzerin, and J.W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with Passive Integrated Transponders in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society 132:275-288.

Ryan, B. A., J. H. Glabek, J. W. Ferguson, E. P. Nunnallee, and R. D. Ledgerwood. 2001a. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River basin, 2000. Report of Research, Northwest Fisheries Science Center, NMFS/NOAA, Seattle, WA.

Ryan, B. A., E. P. Nunnallee, J. H. Glabek, and J. W. Ferguson. 2001b. Recovery of passive integrated transponder tag codes from piscivorous bird colonies in the Columbia River basin. 2001 Annual Research Review, Anadromous Fish Evaluation Program, U.S. Army Corps of Engineers, Portland, OR. (abstract only).

Ryan, B.A., B.P. Sanford, K. Collis, A.F. Evans, and D.D. Roby. In prep. Predation on juvenile salmonids by colonial waterbirds in the Columbia River basin: System-wide assessment of avian predation based on PIT tag recoveries.

Schaeffer, L. 1991. Predation study: Salmon hatchery smolts and survival. Oregon Department of Fish and Wildlife, Technical Report. 33 pp.

Schaeffer, L. 1992. Avian predators at ODFW hatcheries: Their identification and control. Oregon Department of Fish and Wildlife, Technical Report 92-1. 19 pp.

Tyler, W.B., K.T. Briggs, D.B. Lewis, and G. Ford. 1993. Seabird distribution and abundance in relation to oceanographic processes in the California system. Pp. 48-60 *in* The status, ecology, and conservation of marine birds in the North Pacific. K. Vermeer, K.T. Briggs, K.H. Morgan, and D. Siegel-Causey, Eds. Canadian Wildlife Service Special Publication, Ottawa.

USFWS (U.S. Fish and Wildlife Service). 2005. Caspian tern management to reduce predation of juvenile salmonids in the Columbia River estuary: Final Environmental Impact Statement, January 2005. Migratory Birds and Habitat Program, Portland OR.

Wright, S.K. 2005. Disturbance and roosting ecology of California brown pelicans (*Pelecaus occidentalis californicus*) on East Sand Island in the Columbia River estuary. Unpubl. M.Sc. Thesis, Oregon State University, Corvallis, OR. 106 Pp.

PUBLICATIONS AND SUBMITTED MANUSCRIPTS

Anderson, C.D., D.D. Roby, and K. Collis. 2004. Conservation implications of the large colony of double-crested cormorants on East Sand Island, Columbia River estuary, Oregon, USA. Waterbirds 27:155-160.

Anderson, C.D., D.D. Roby, and K. Collis. 2004. Foraging patterns of male and female double-crested cormorants nesting in the Columbia River estuary. Canadian Journal of Zoology 82:541-554.

Anderson, S.K., D.D. Roby, D.E. Lyons, and K. Collis. 2004. Factors affecting chick provisioning by Caspian terns nesting in the Columbia River estuary. Waterbirds 28:95-105.

Antolos, M., D.D. Roby, and K. Collis. 2004. Breeding ecology of Caspian terns at colonies on the Columbia Plateau. Northwest Science 787:303-312.

Antolos, M., D.D. Roby, D.E. Lyons, K. Collis, A.F. Evans, M. Hawbecker, and Brad A. Ryan. 2005. Caspian tern predation on juvenile salmonids in the Mid-Columbia River. Transactions of the American Fisheries Society 134:466-480.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of different species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385–396.

Collis, K., D.D. Roby, D.P. Craig, S. Adamany, J. Adkins, and D.E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537–550.

Collis, K., D.D. Roby, C.W. Thompson, D.E. Lyons, and M. Tirhi. 2002. Barges as temporary breeding sites for Caspian terns: Assessing potential sites for colony restoration. Wildlife Society Bulletin 30:1140–1149.

Lyons, D.E., D.D. Roby, and K. Collis. 2005. Foraging ecology of Caspian terns in the Columbia River Estuary. Waterbirds 28:280-291.

Lyons, D.E., D.D. Roby, and K. Collis. In review. Foraging patterns of Caspian terns and double-crested cormorants in the Columbia River estuary. Journal of Field Ornithology.

Matthews, S.E., D.P. Craig, K. Collis, and D.D. Roby. 2003. Double-crested Cormorant (*Phalacrocorax auritus*). Pp. 56-58 *in* Birds of Oregon: A General Reference. D.B. Marshall, M.G. Hunter, and A.L. Contreras, Eds. Oregon State University Press, Corvallis, OR.

Roby, D.D., K. Collis, D.E. Lyons, D.P. Craig, J. Adkins, A.M. Myers, and R.M. Suryan. 2002. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management 66: 662–673.

Roby, D.D., K. Collis, D.E. Lyons, M. Antolos, and D.P. Craig. 2003. Caspian Tern (*Sterna caspia*). Pp. 277-279 *in* Birds of Oregon: A General Reference. D.B. Marshall, M.G. Hunter, and A.L. Contreras, Eds. Oregon State University Press, Corvallis, OR.

Roby, D.D., K. Collis, and D.E. Lyons. 2003. Conservation and management for fish-eating birds and endangered salmon. Proceedings of the Third International Partners In Flight Conference, Asilomar, California.

Roby, D.D., D.E. Lyons, D.P. Craig, K. Collis, and G.H. Visser. 2003. Quantifying the effects of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81: 250–265.

Suryan, R.M., D.P. Craig, D.D. Roby, N.D. Chelgren, K. Collis, W.D. Shuford, and D.E. Lyons. 2004. Redistribution and growth of the Caspian tern population in the Pacific coast region of North America, 1981-2000. Condor 106:777-790.

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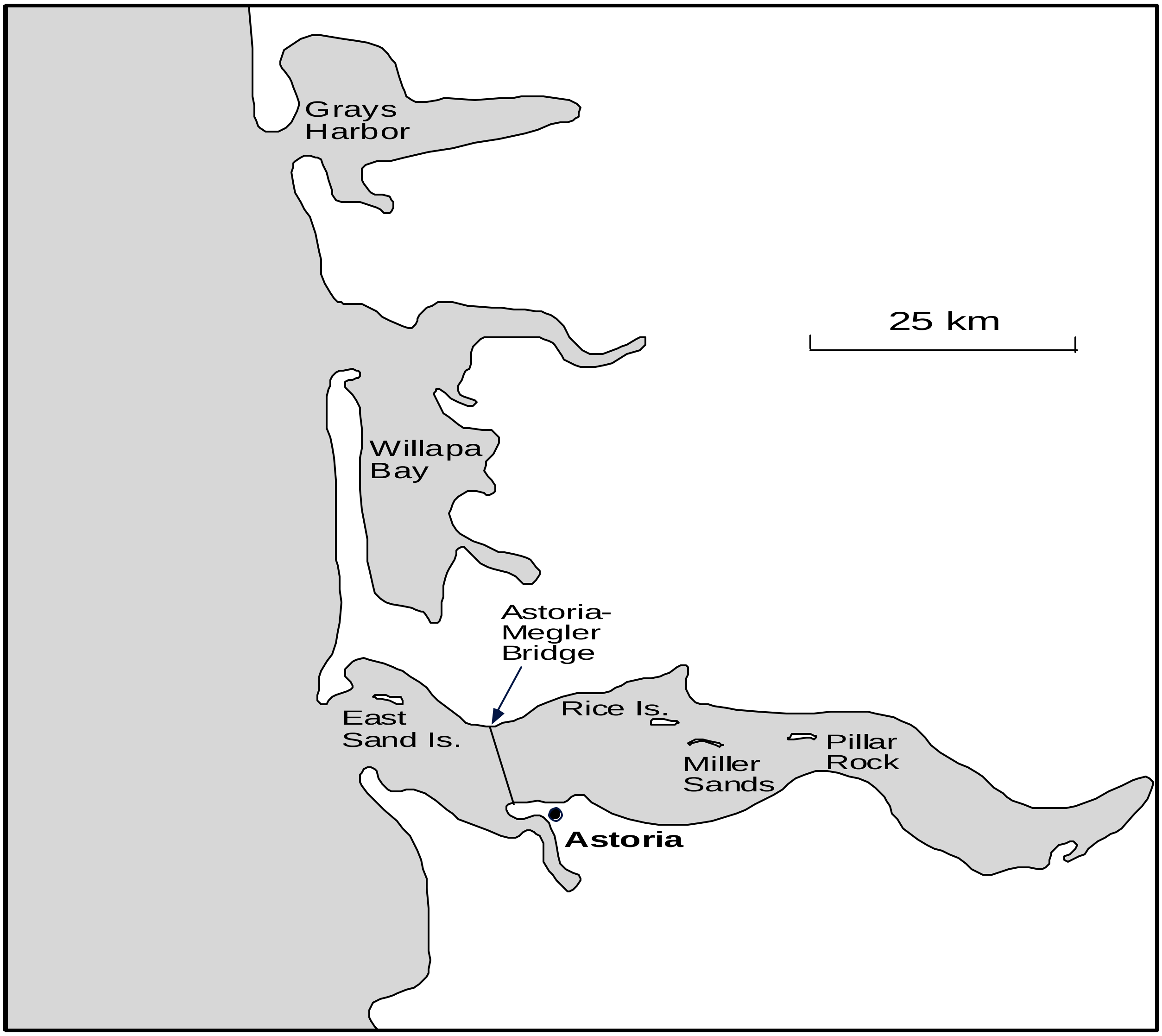
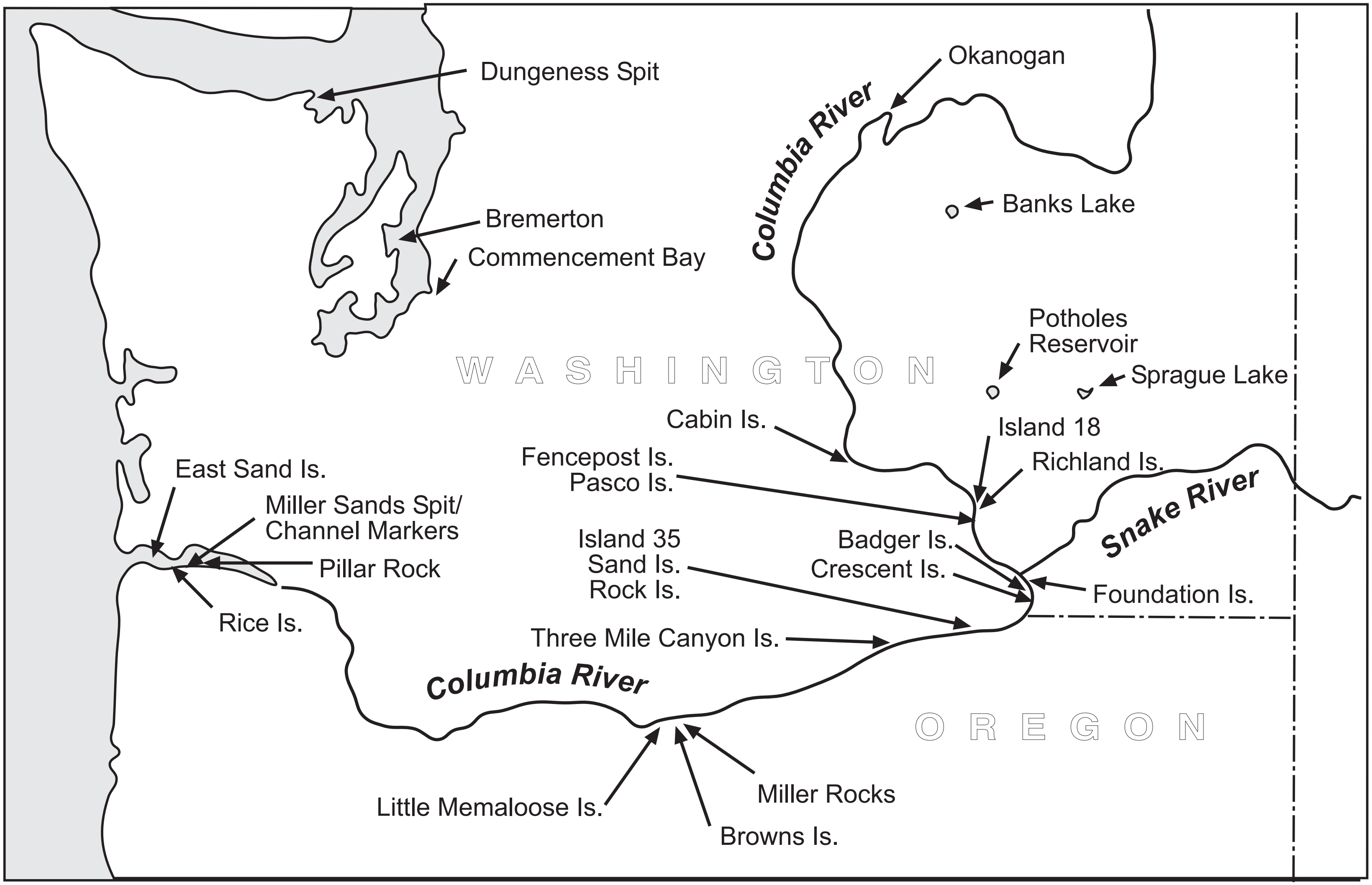
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian terns			
1.1. Preparation and Modification of Nesting Habitat			
1.1.1. Columbia River Estuary		x	
1.2. Colony Size and Productivity			
1.2.1. Columbia River Estuary	x	x	
1.2.2. Columbia Plateau	x		x
1.2.3. 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: PIT Tag Evaluations			
1.4.1. PIT Tag Collision			x
1.4.2. Detection Efficiency	x	x	x
1.4.3. Deposition Rate	x	x	x
1.4.4. Predation Rate Estimates	x	x	x
1.5. Dispersal and Survival		x	
1.6. Monitoring and Evaluation of Management			
1.6.1. Nesting Distribution	x	x	
1.6.2. Diet and Salmonid Consumption	x	x	
1.6.3. Nesting Success	x	x	

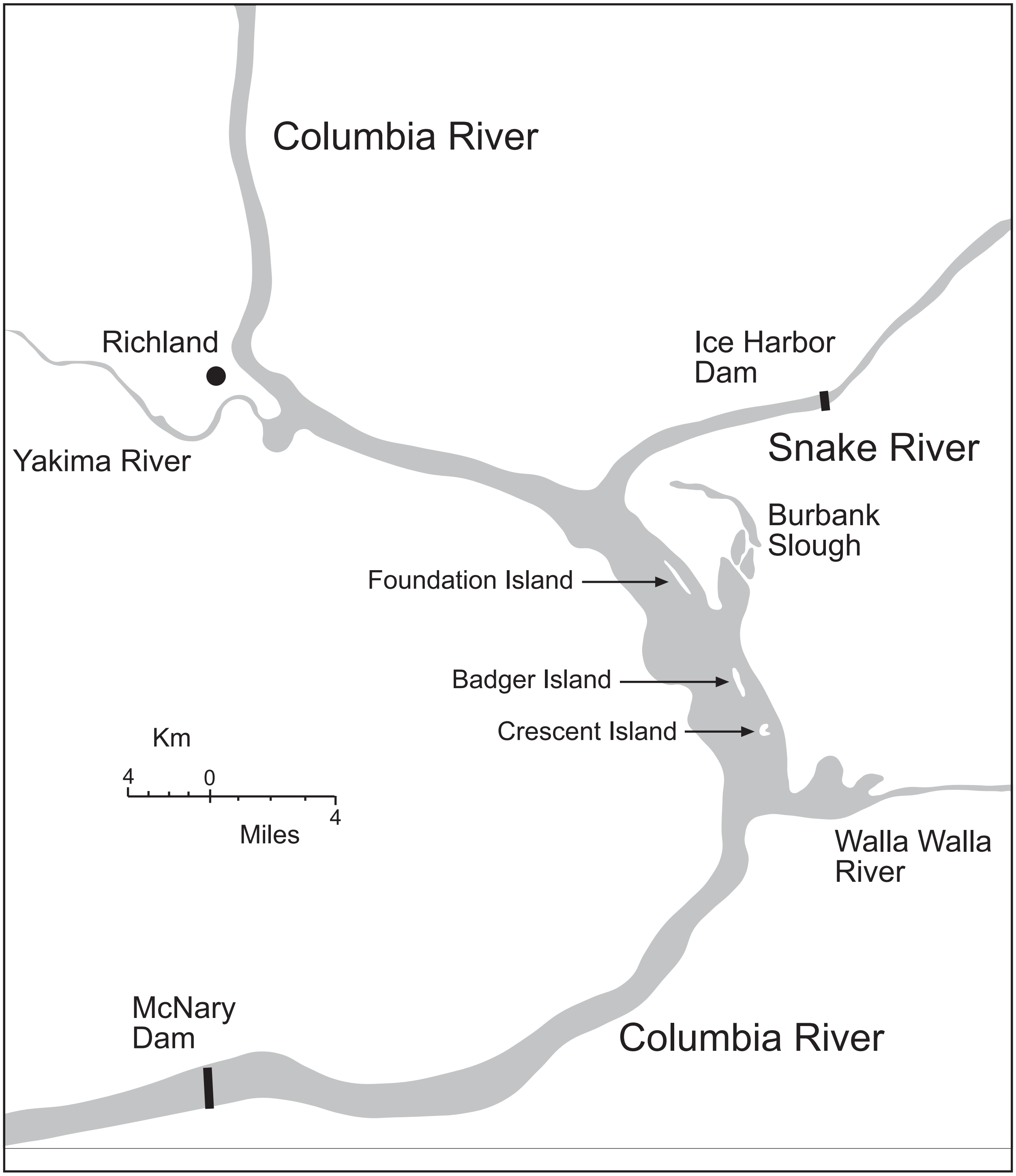
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Double-crested Cormorants			
2.1. Nesting Distribution and Colony Size			
2.1.1. Columbia River Estuary	x	x	
2.1.2. Columbia Plateau			x
2.1.3. Coastal Washington		x	
2.2. Nesting Chronology and Productivity			
2.2.1. Columbia River Estuary	x	x	
2.2.2. Columbia Plateau			x
2.2.3. Coastal Washington		x	
2.3. Diet Composition, Salmonid Consumption, and Predation Impacts			
2.3.1. Columbia River Estuary	x	x	
2.3.2. Columbia Plateau			x
2.4. Management Feasibility Studies	x	x	
Other Colonial Waterbirds			
3.1. Distribution			
3.1.1. Columbia River Estuary	x	x	
3.1.2. Columbia Plateau			x
3.2. Diet Composition			
3.2.1. Columbia River Estuary	x	x	
3.2.2. Columbia Plateau			x



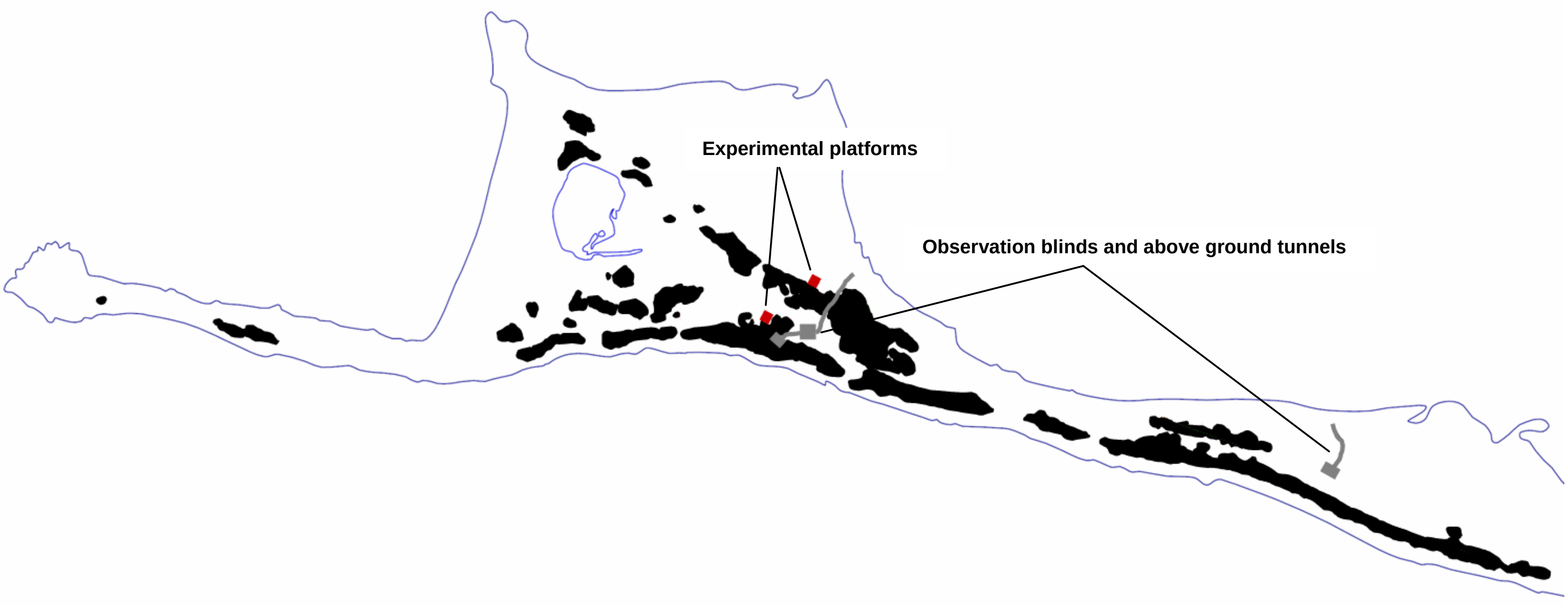
Map 1. Study area in the Columbia River estuary and along the southwest coast of Washington in 2005.



Map 2. Study areas along the Columbia River and the locations of active and historic bird colonies mentioned in this report.



Map 3. Study area in the Mid-Columbia River.



Map 4. The distribution of nesting double-crested cormorants (shown in black) on East Sand Island in 2005 and the location of the experimental nesting platforms (shown in red), observations blinds (shown in gray), and blind access tunnels (see text for details). Nesting cormorants were restricted to the western end on the island (shown here) and did not nest anywhere else on East Sand Island in 2005.

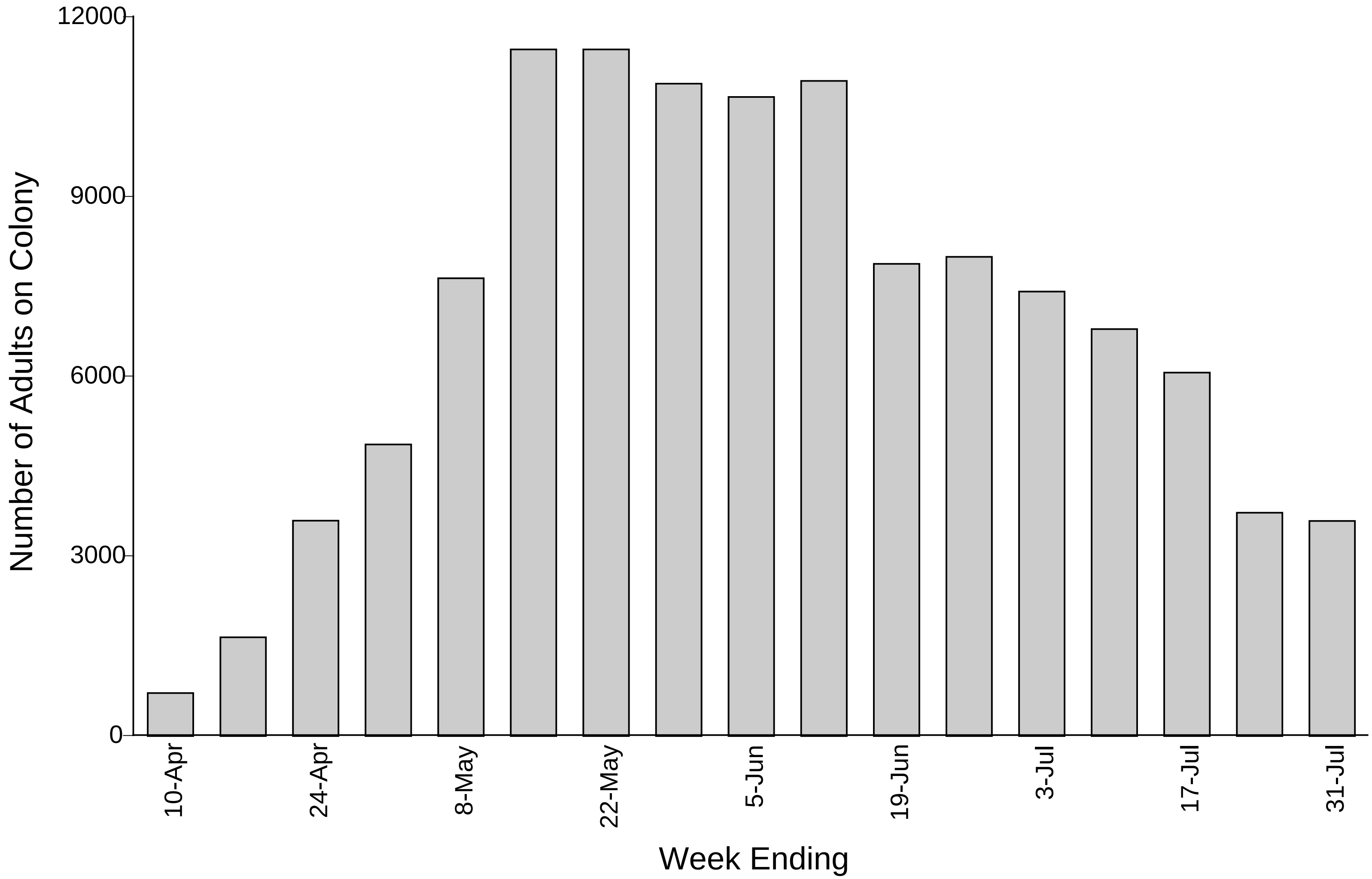


Figure 1. Weekly visual estimates of the number of adult Caspian terns on the East Sand Island colony during the 2005 breeding season.

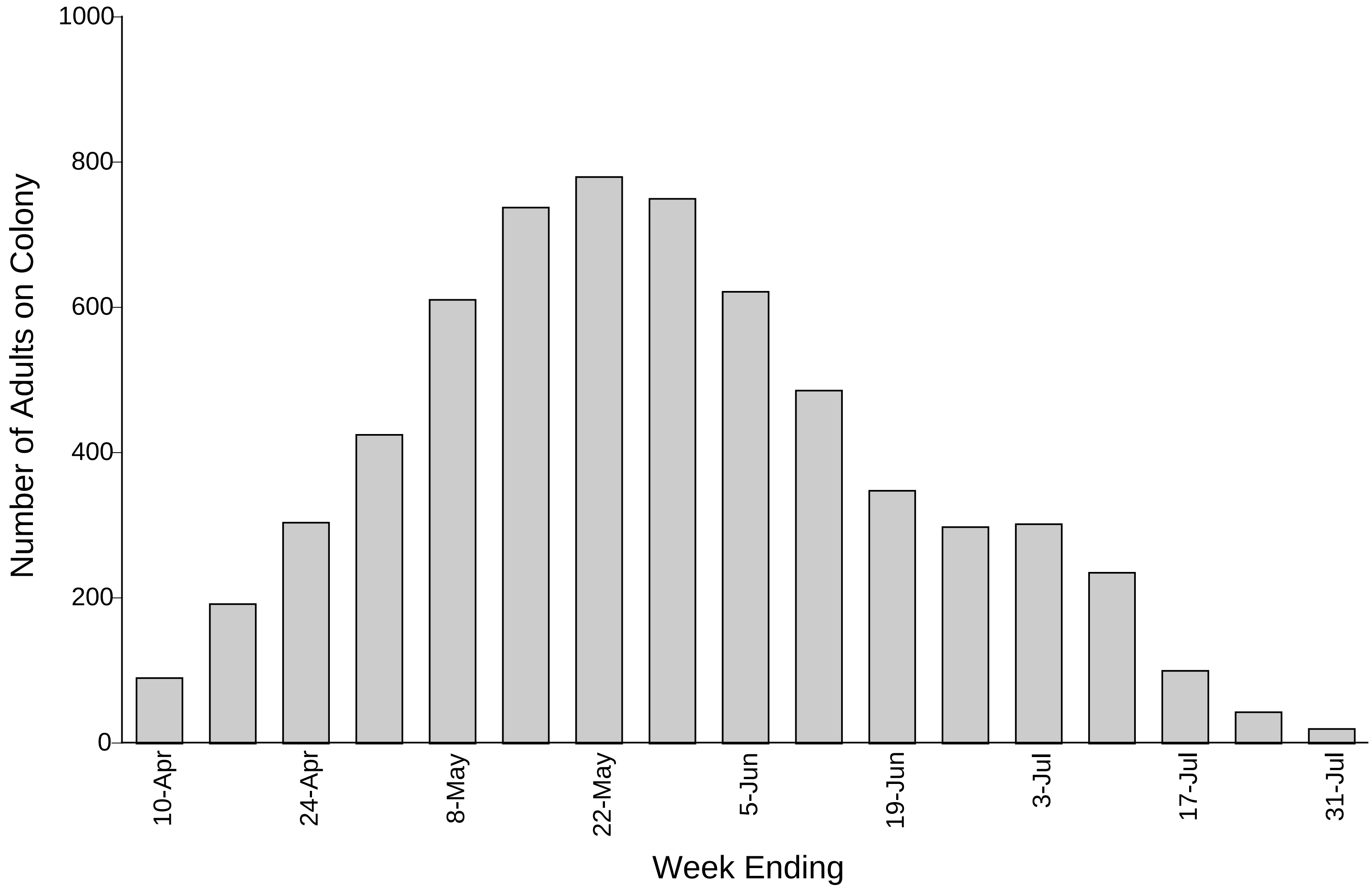


Figure 2. Weekly visual estimates of the number of adult Caspian terns on the Crescent Island colony during the 2005 breeding season.

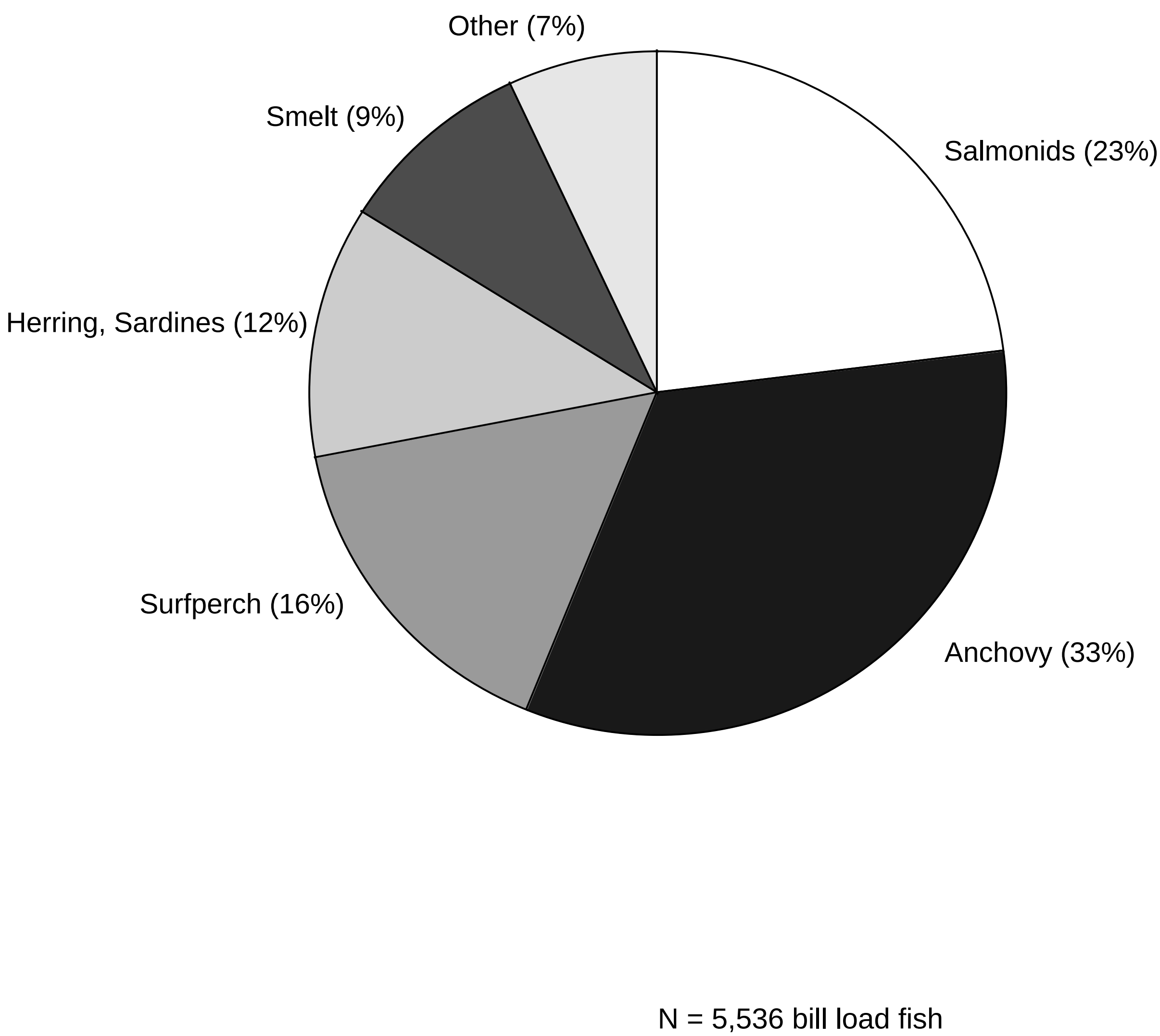


Figure 3. Diet composition of Caspian terns nesting on East Sand Island in 2005 (see text for methods of calculation).

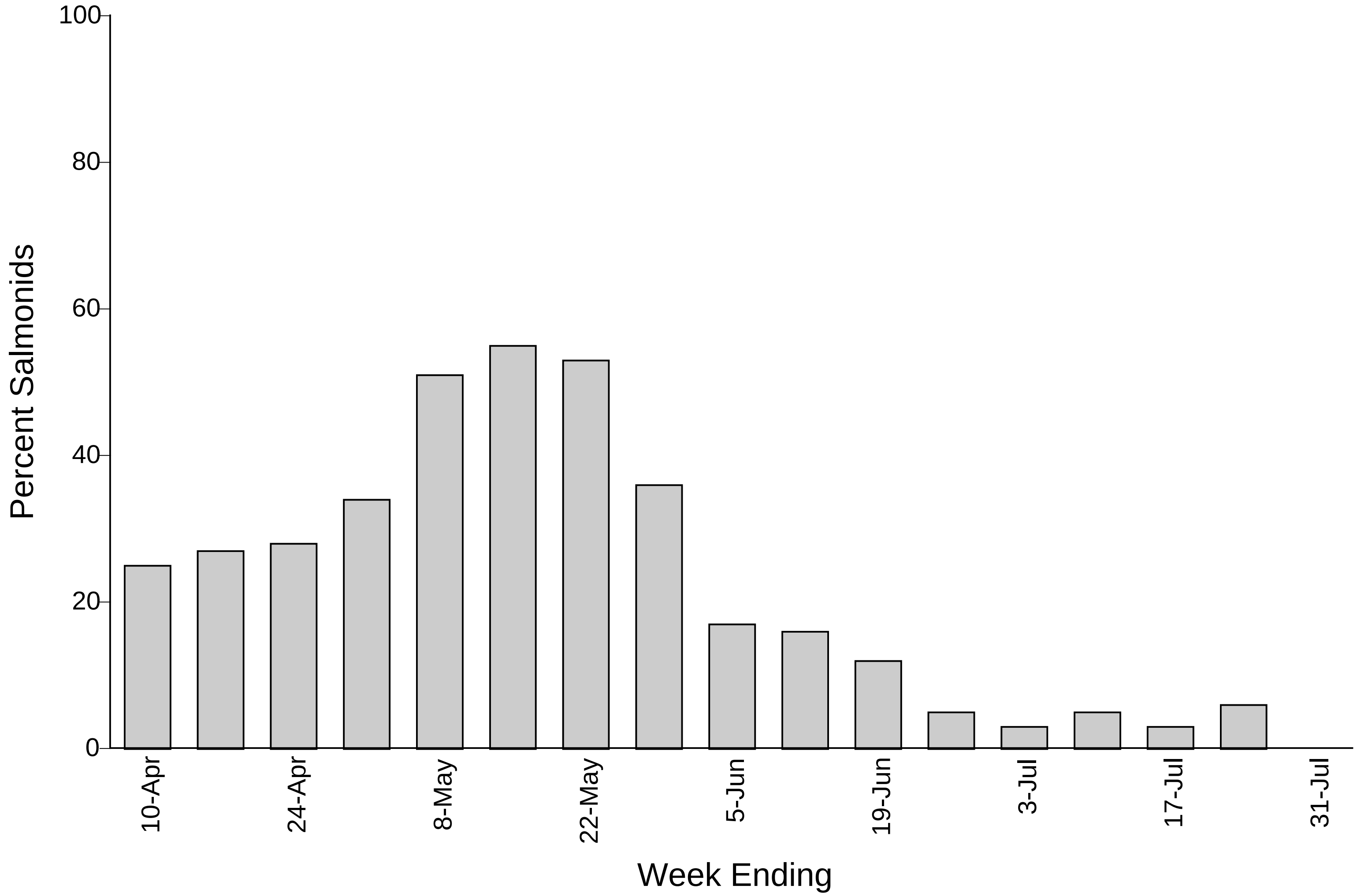


Figure 4. Weekly proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during the 2005 breeding season.

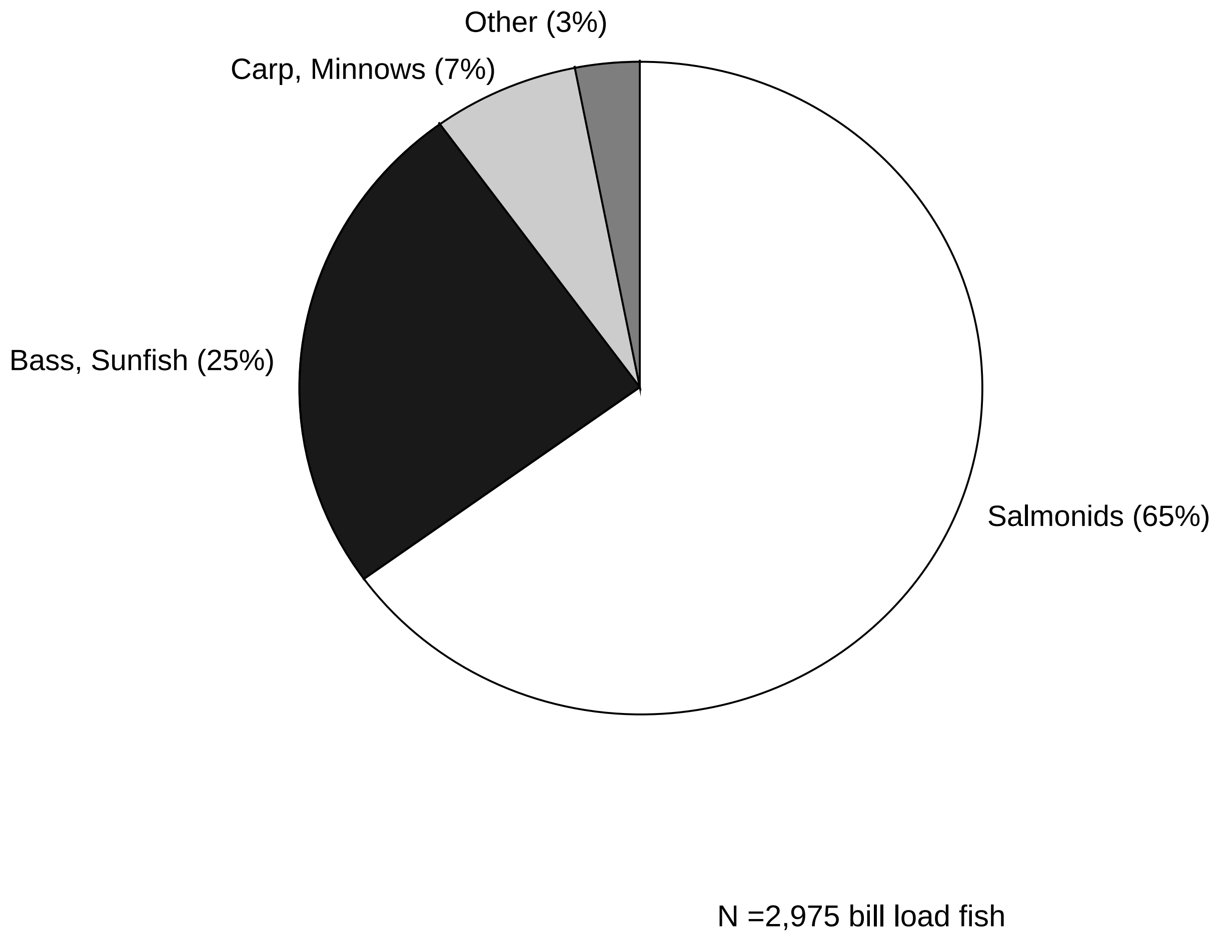


Figure 5. Diet composition of Caspian terns nesting on Crescent Island in 2005 (see text for methods of calculation).

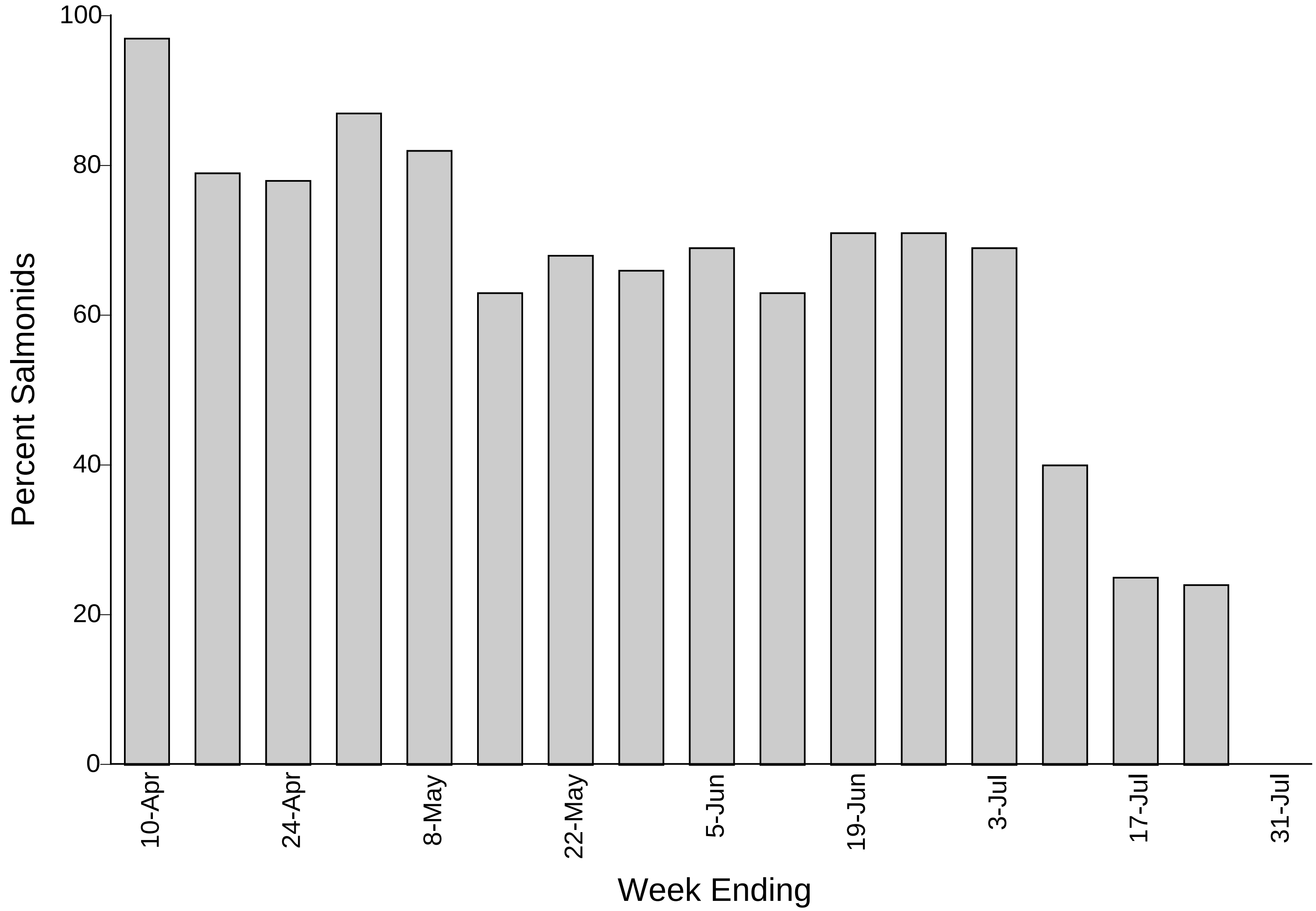


Figure 6. Weekly proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island during the 2005 breeding season.

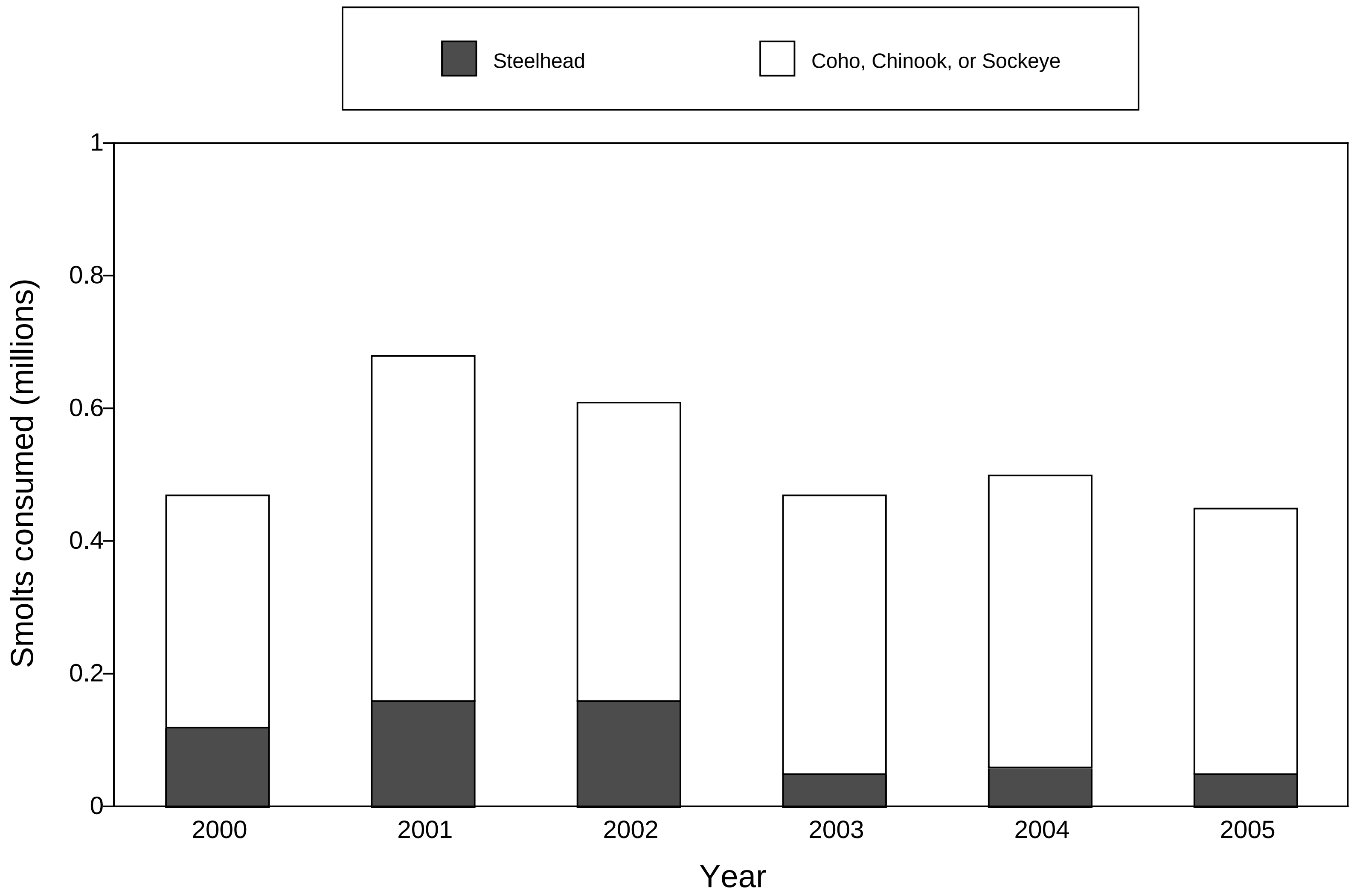


Figure 7. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island, 2000-2005.

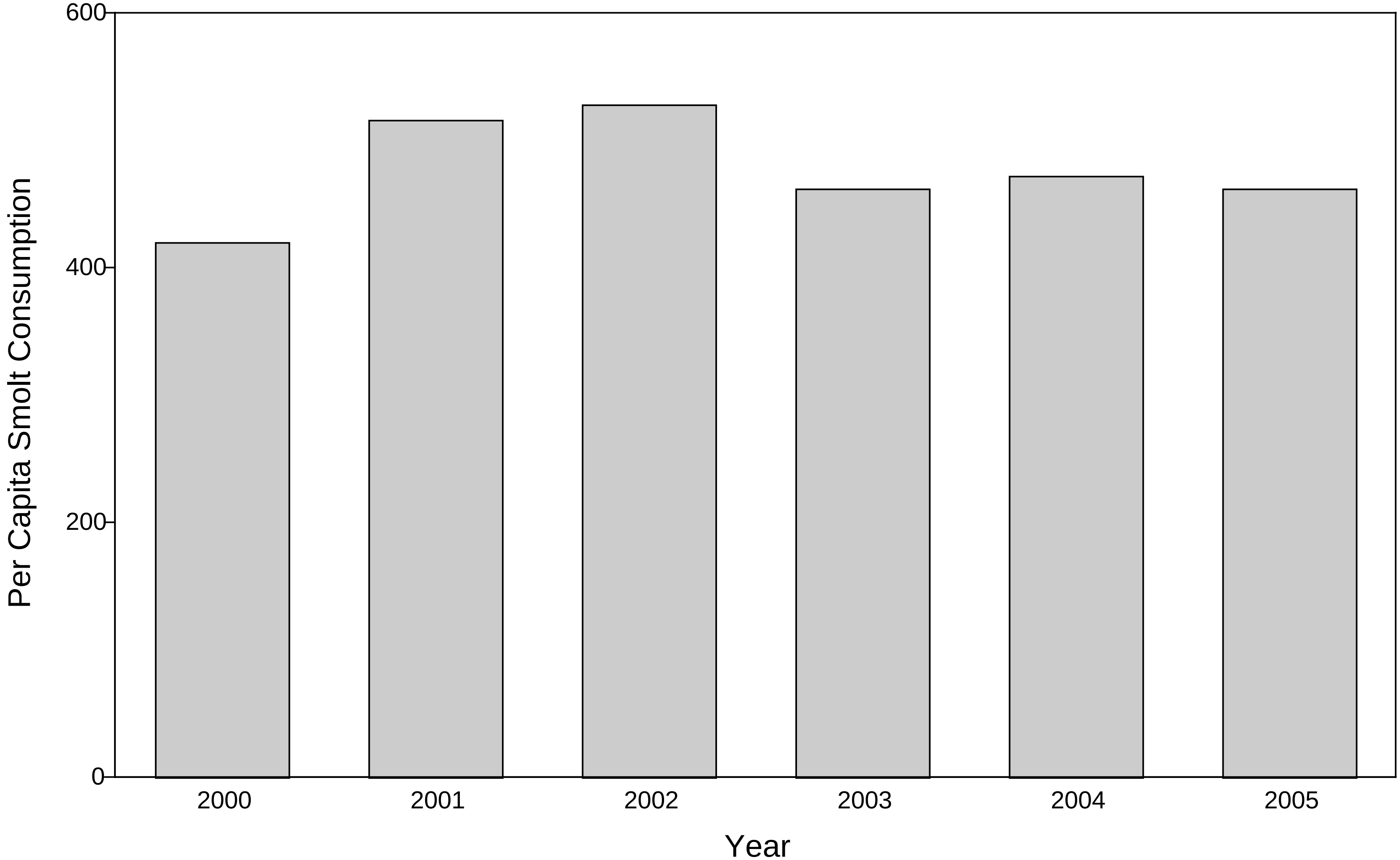


Figure 8. Estimated per capita annual smolt consumption by Caspian terns nesting on Crescent Island, 2000 - 2005.

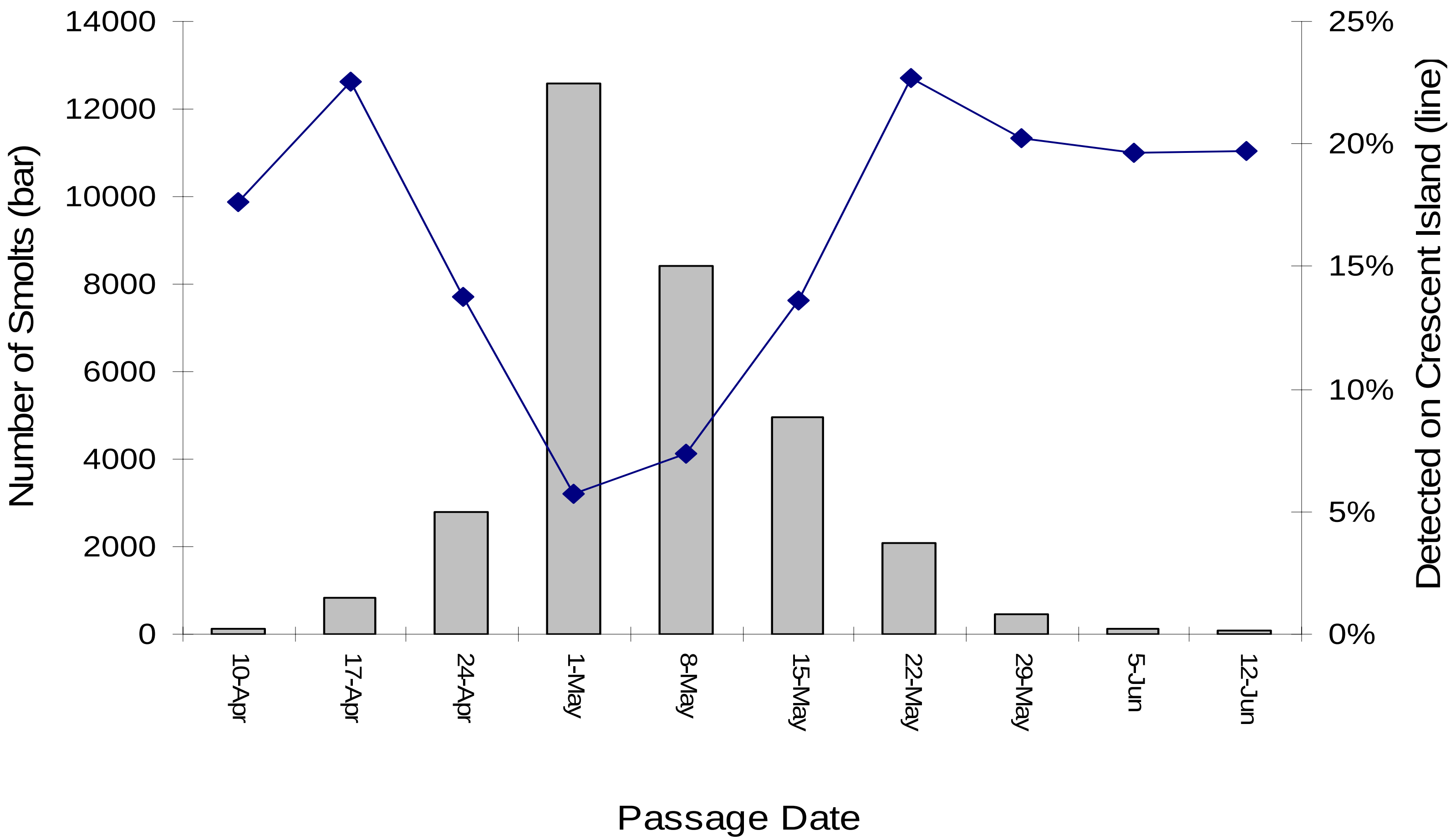


Figure 9. Numbers of PIT-tagged steelhead smolts interrogated passing Lower Monumental Dam (bar) in each of 10 weeks (Sunday to Saturday) during the peak out-migration and the percentage of these subsequently recovered on the Crescent Island tern colony (line) in 2005. The percentage of PIT tags recovered was corrected for bias due to on-colony PIT tag detection efficiency.

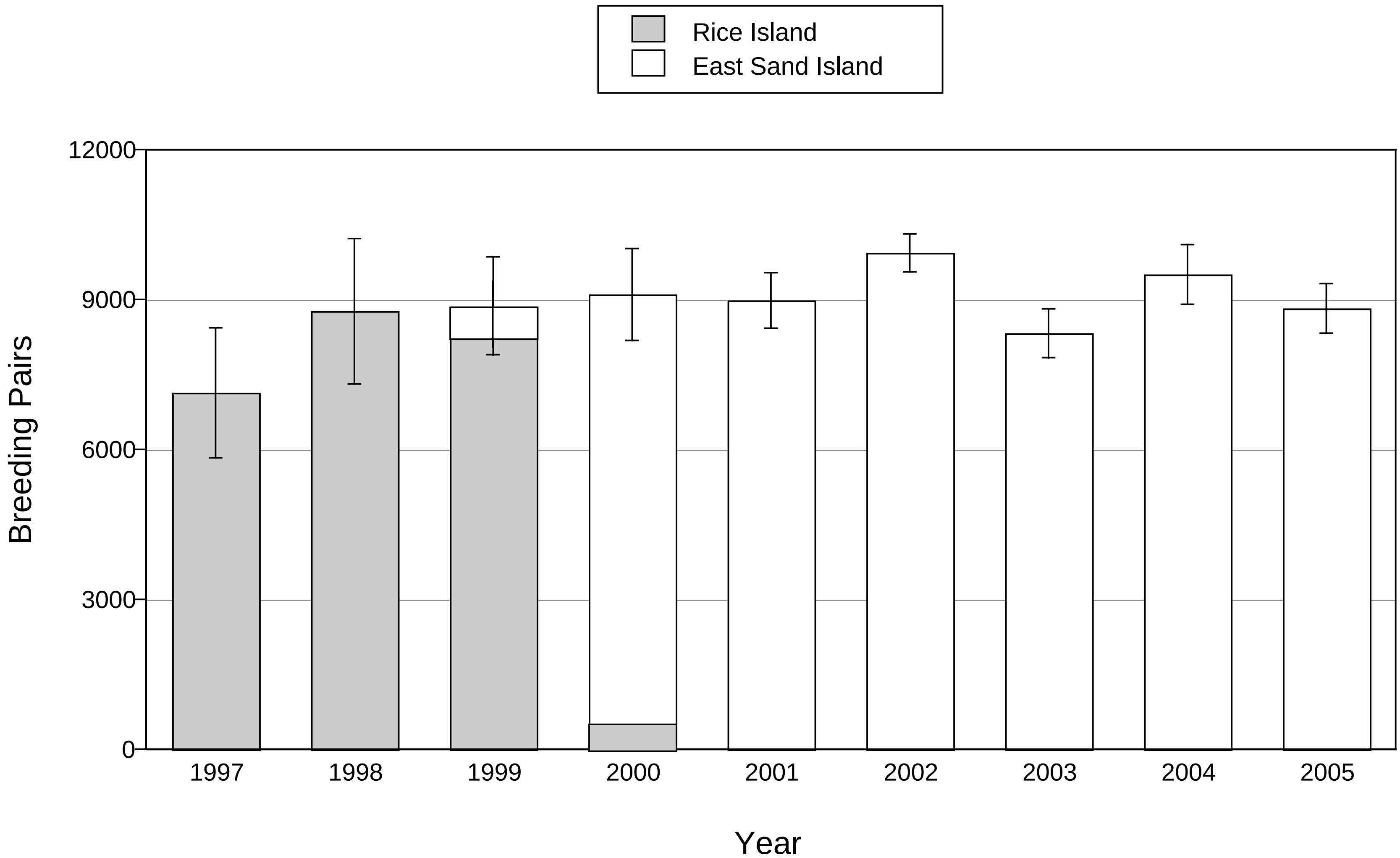


Figure 10. Numbers of breeding pairs of Caspian terns nesting at two colonies in the Columbia River estuary, 1997 - 2005.

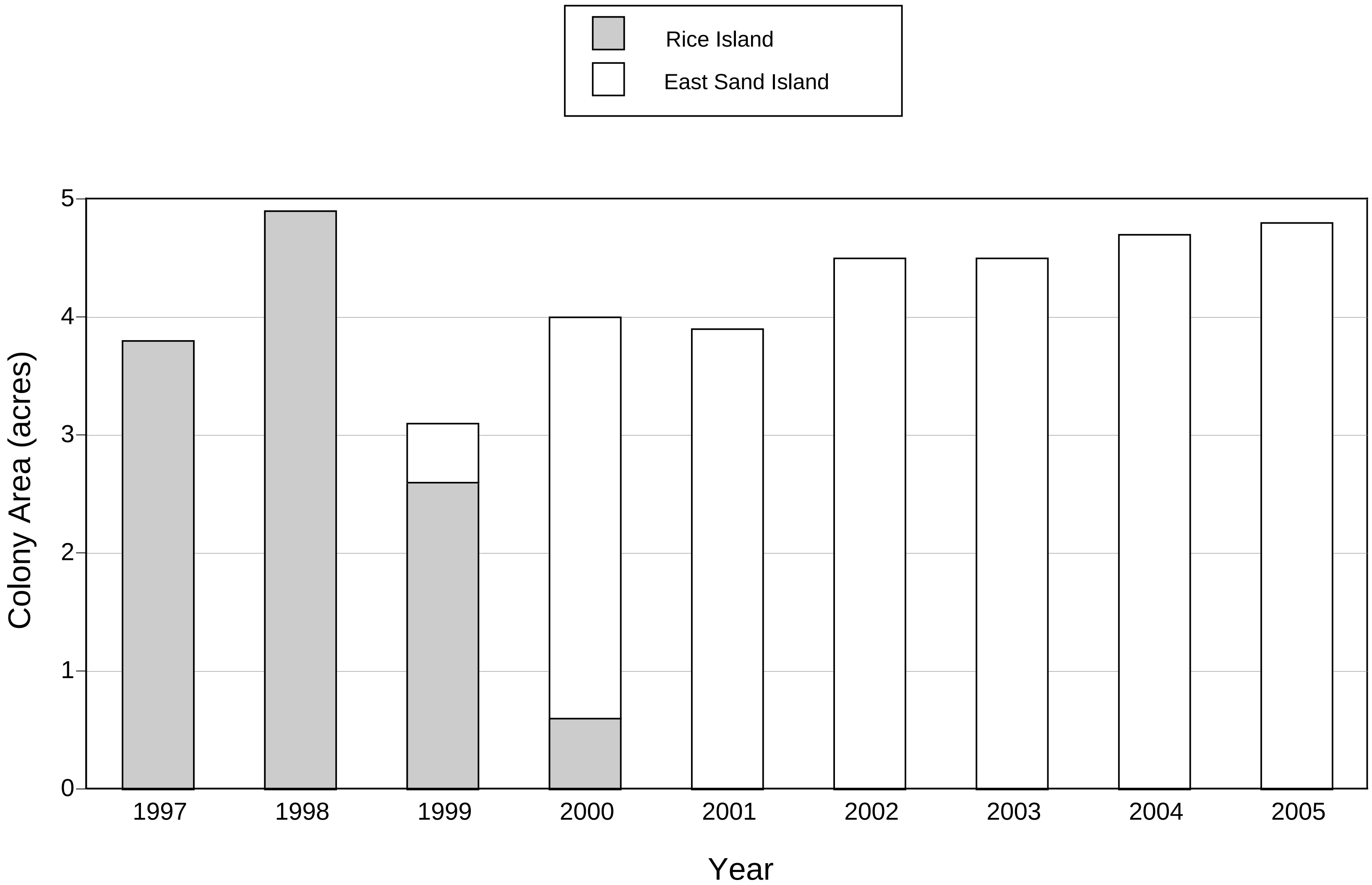


Figure 11. Area occupied by nesting Caspian terns at two colonies in the Columbia River estuary, 1997 - 2005.

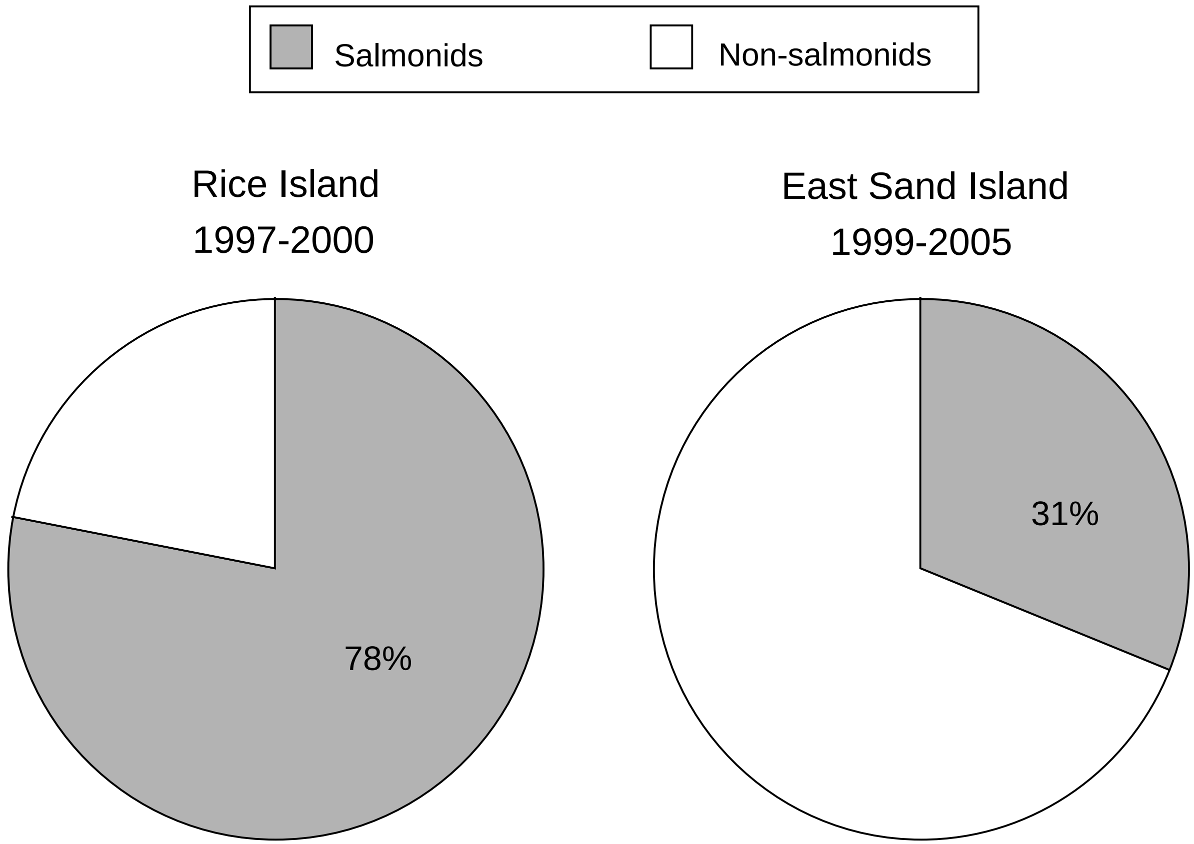


Figure 12. Mean annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Rice Island (n = 4 years) and on East Sand Island (n = 7 years) in the Columbia River estuary, 1997-2005.

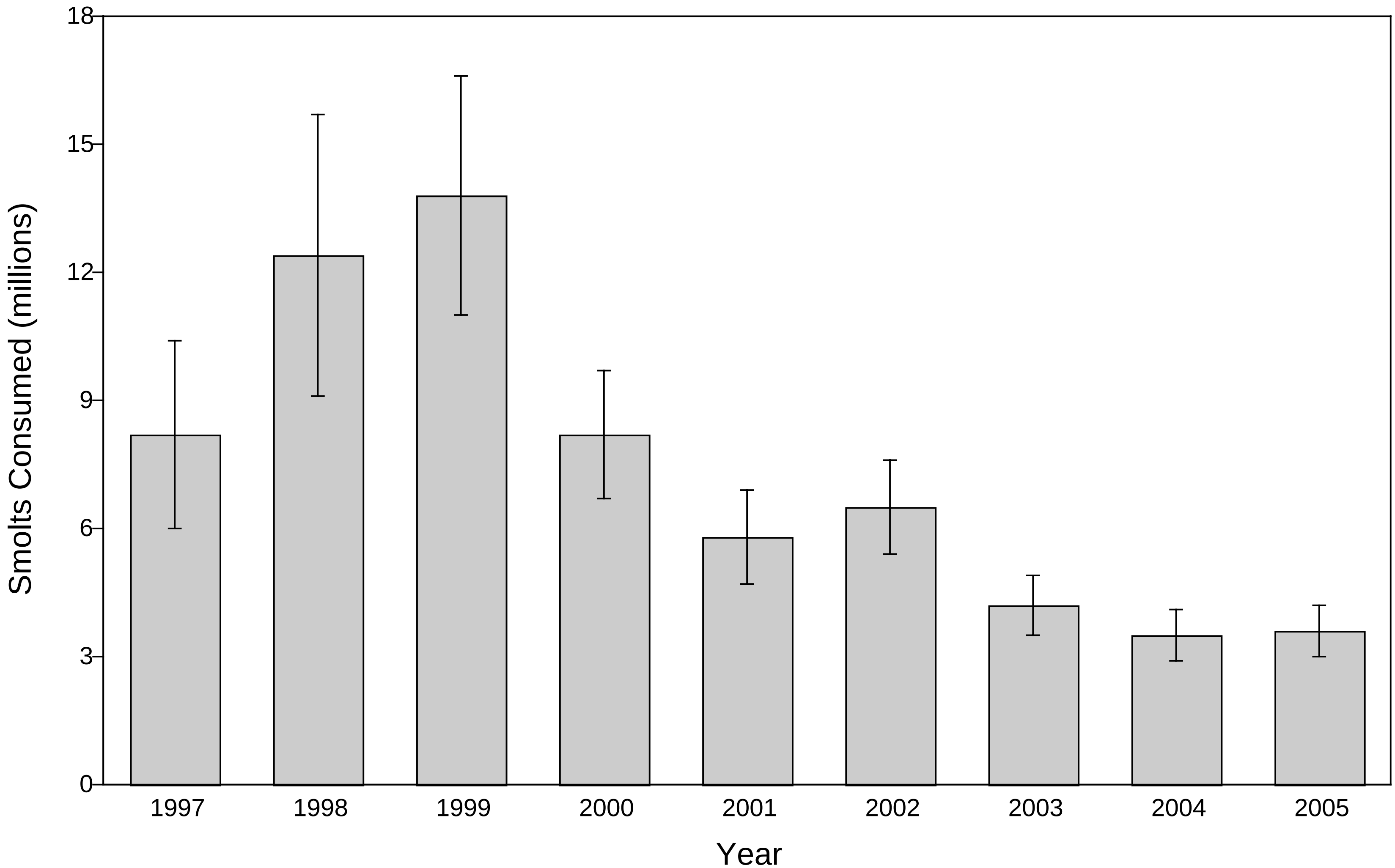


Figure 13. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary, 1997 - 2005.

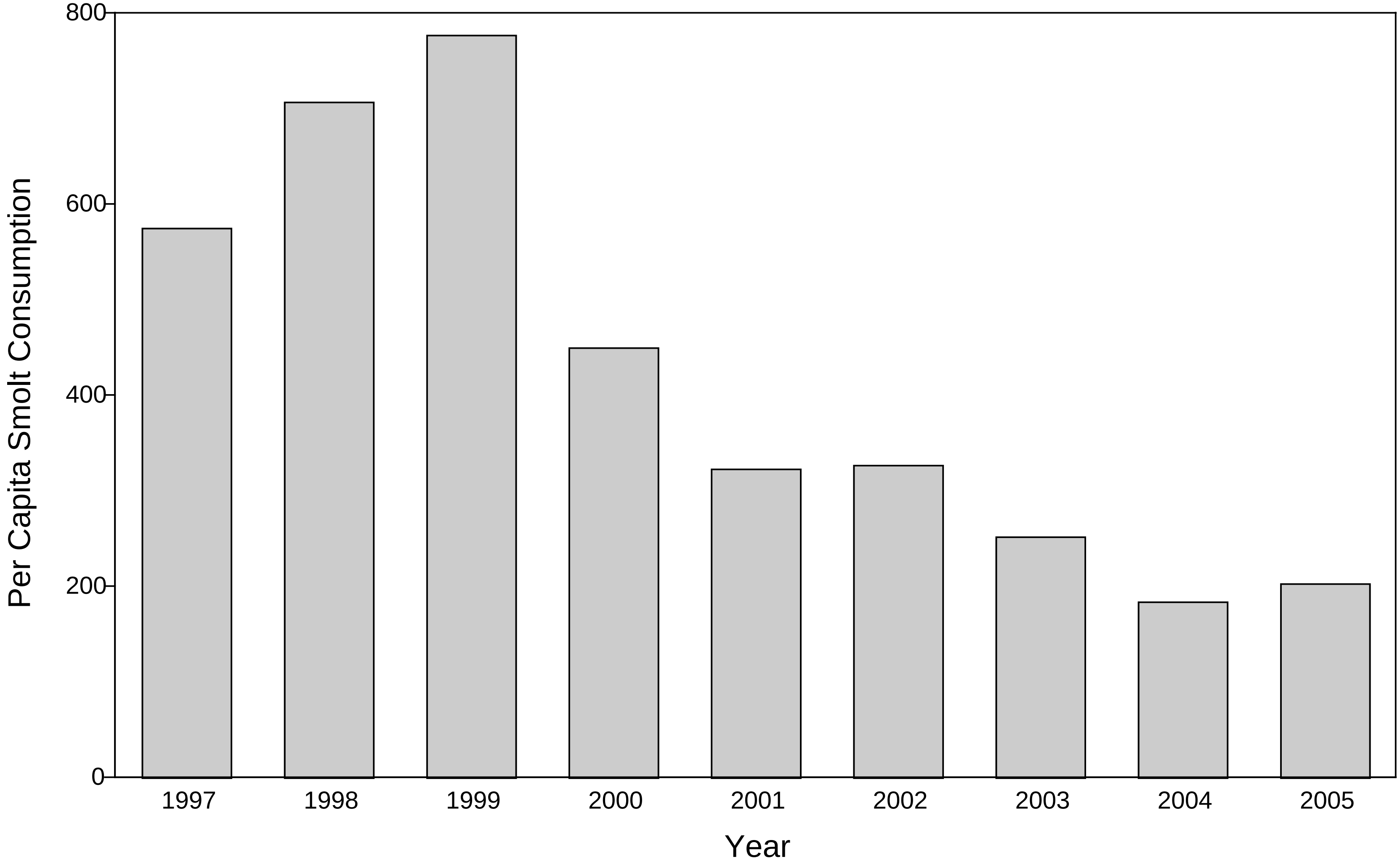


Figure 14. Estimated per capita annual smolt consumption by Caspian terns nesting in the Columbia River estuary, 1997 - 2005.

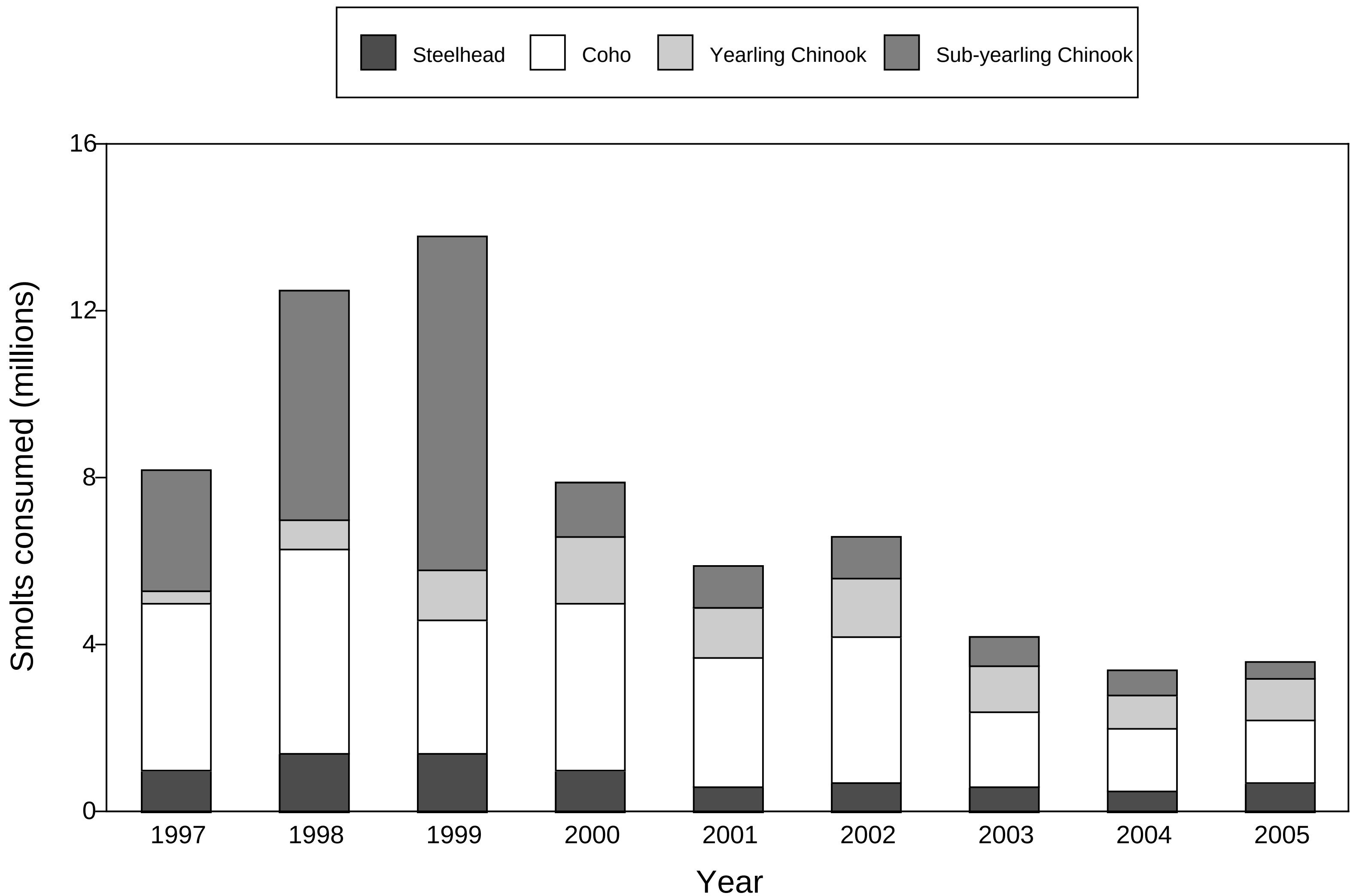


Figure 15. Estimated total annual consumption of three species of juvenile salmonids by Caspian terns nesting in the Columbia River estuary, 1997-2005.

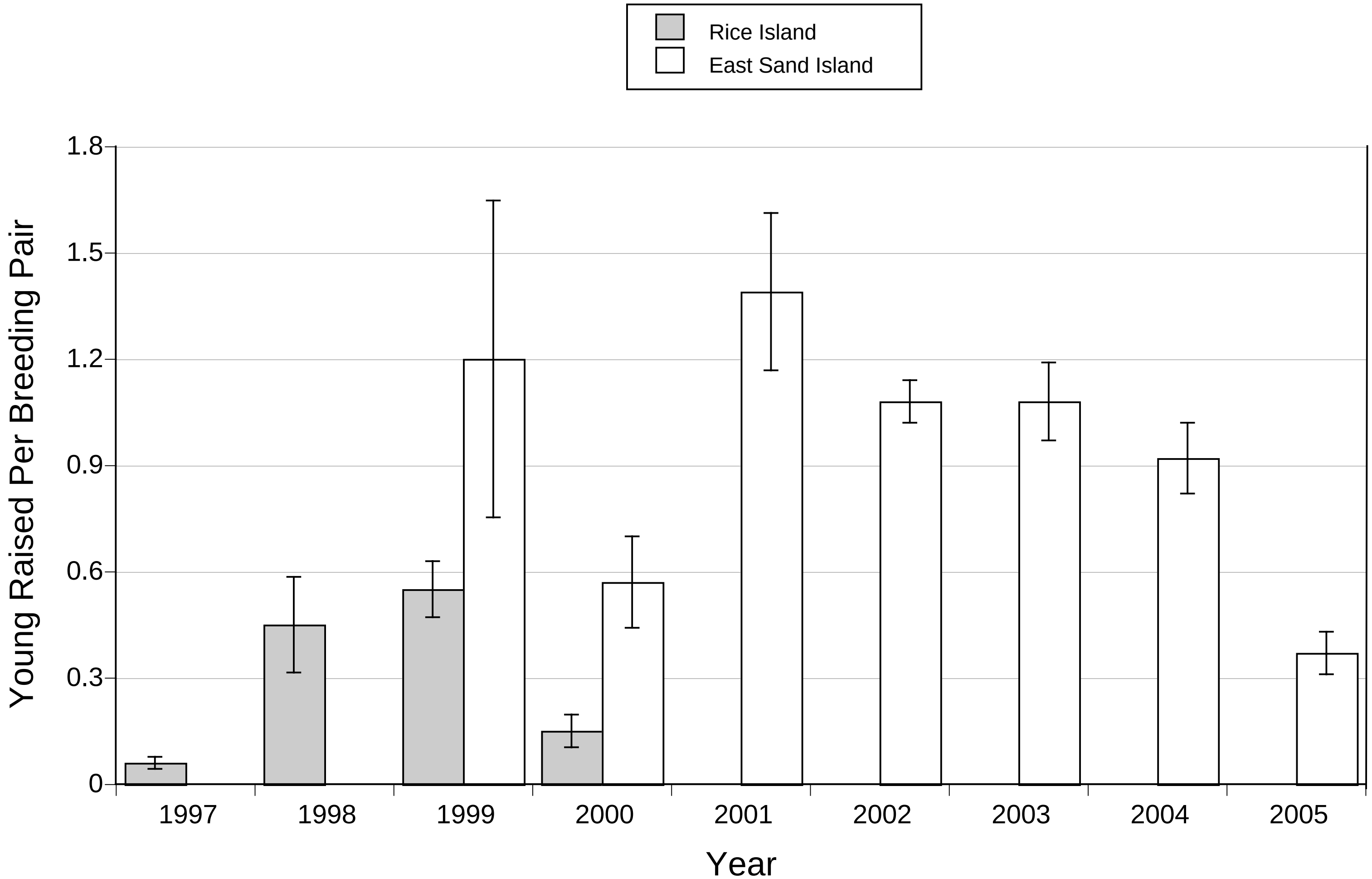


Figure 16. Average nesting success of Caspian terns nesting at two colonies in the Columbia River estuary, 1997 - 2005.

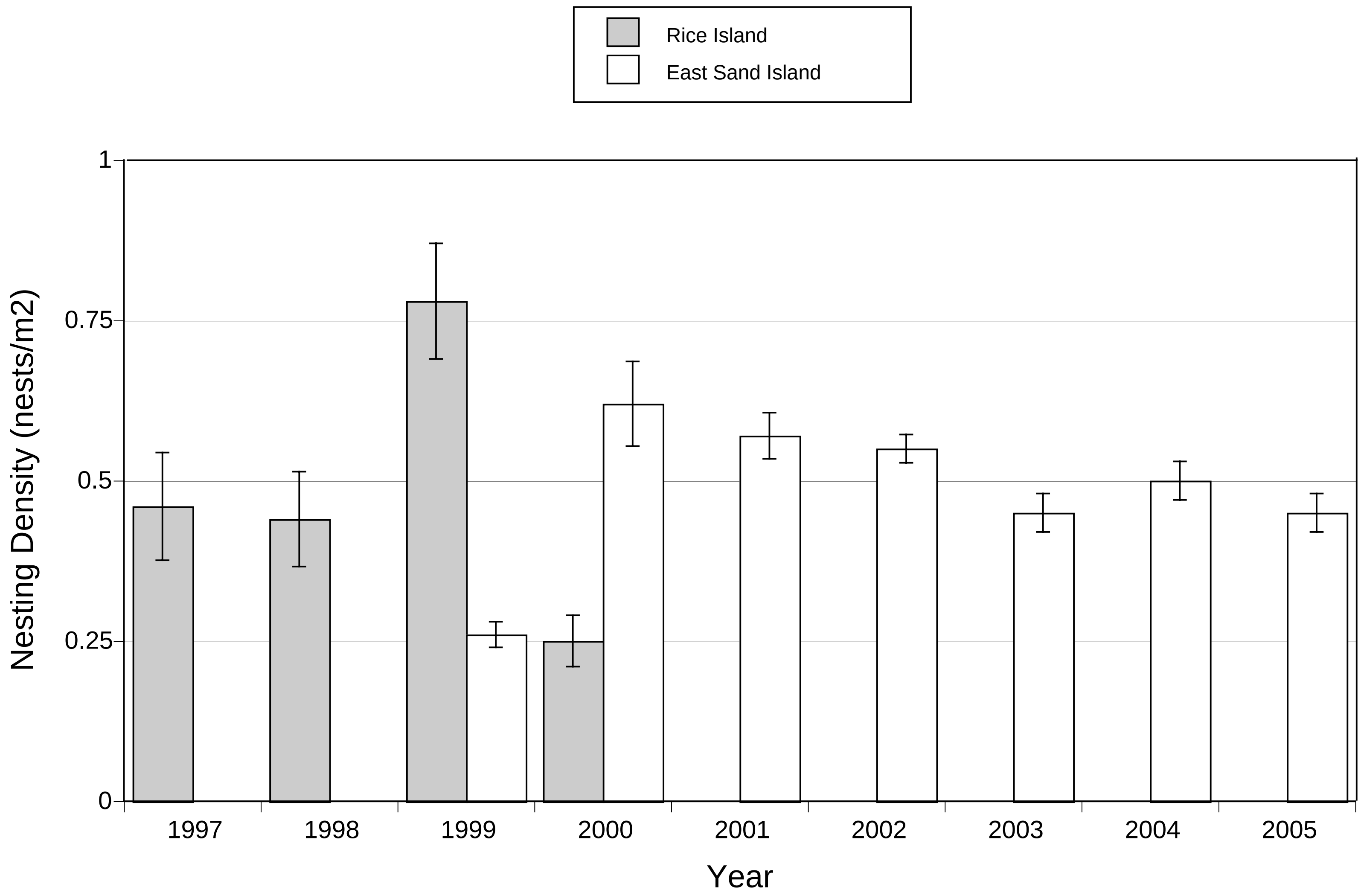


Figure 17. Average nest density for Caspian terns nesting at two colonies in the Columbia River estuary, 1997 - 2005.

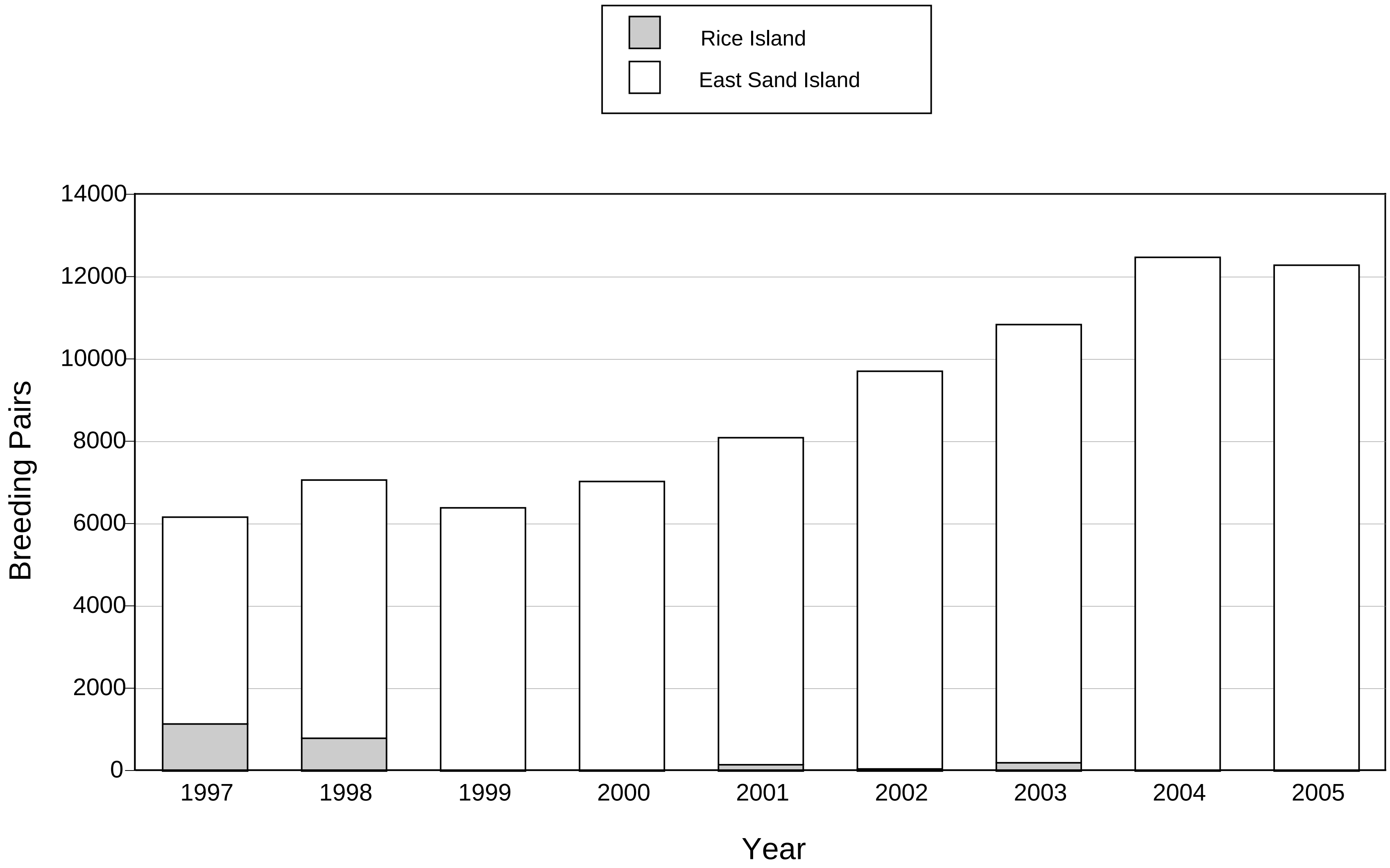


Figure 18. Numbers of breeding pairs of double-crested cormorants nesting at two colonies in the Columbia River estuary, 1997 - 2005.

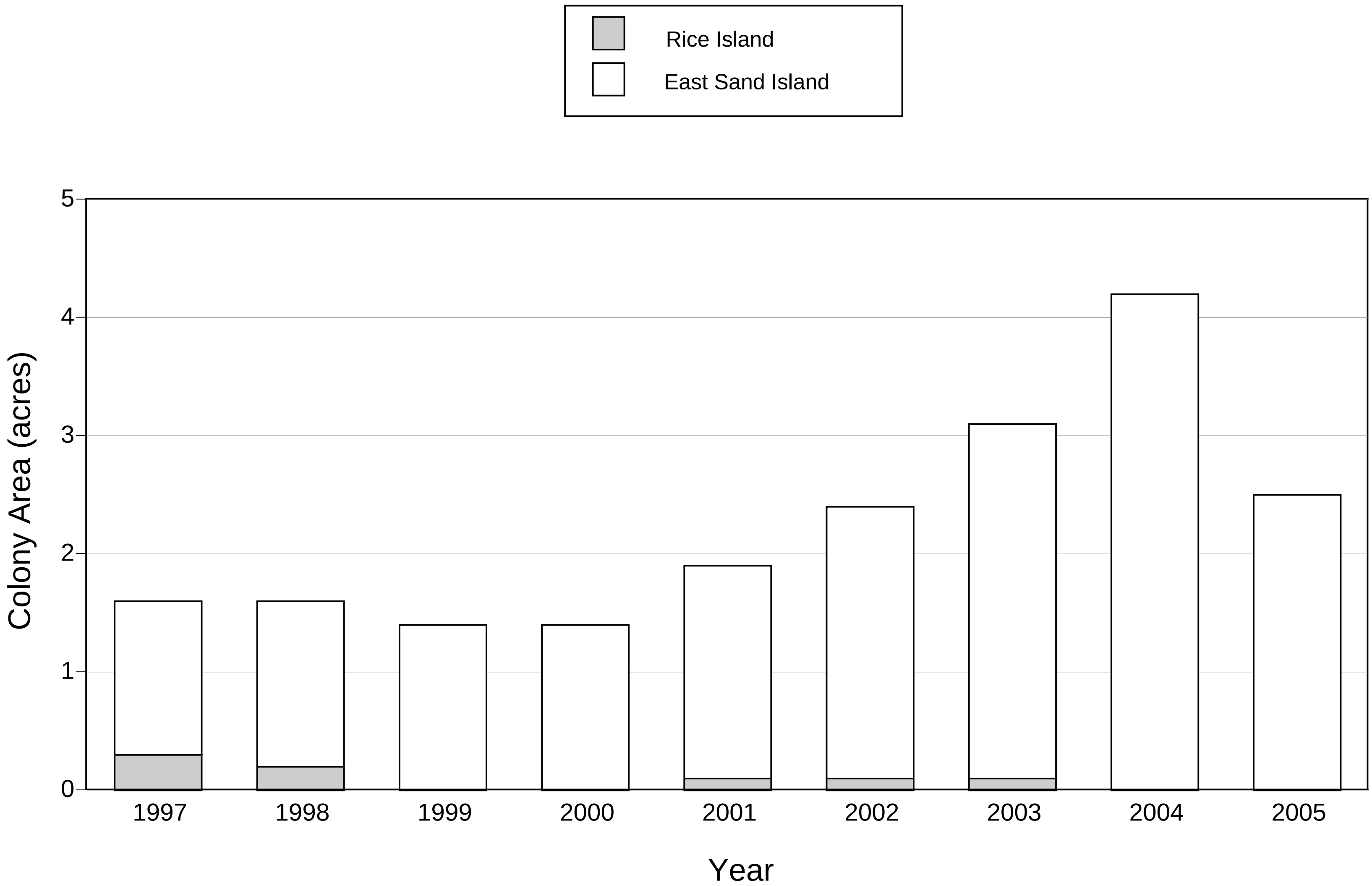


Figure 19. Area occupied by nesting double-crested cormorants at two colonies in the Columbia River estuary, 1997 - 2005.

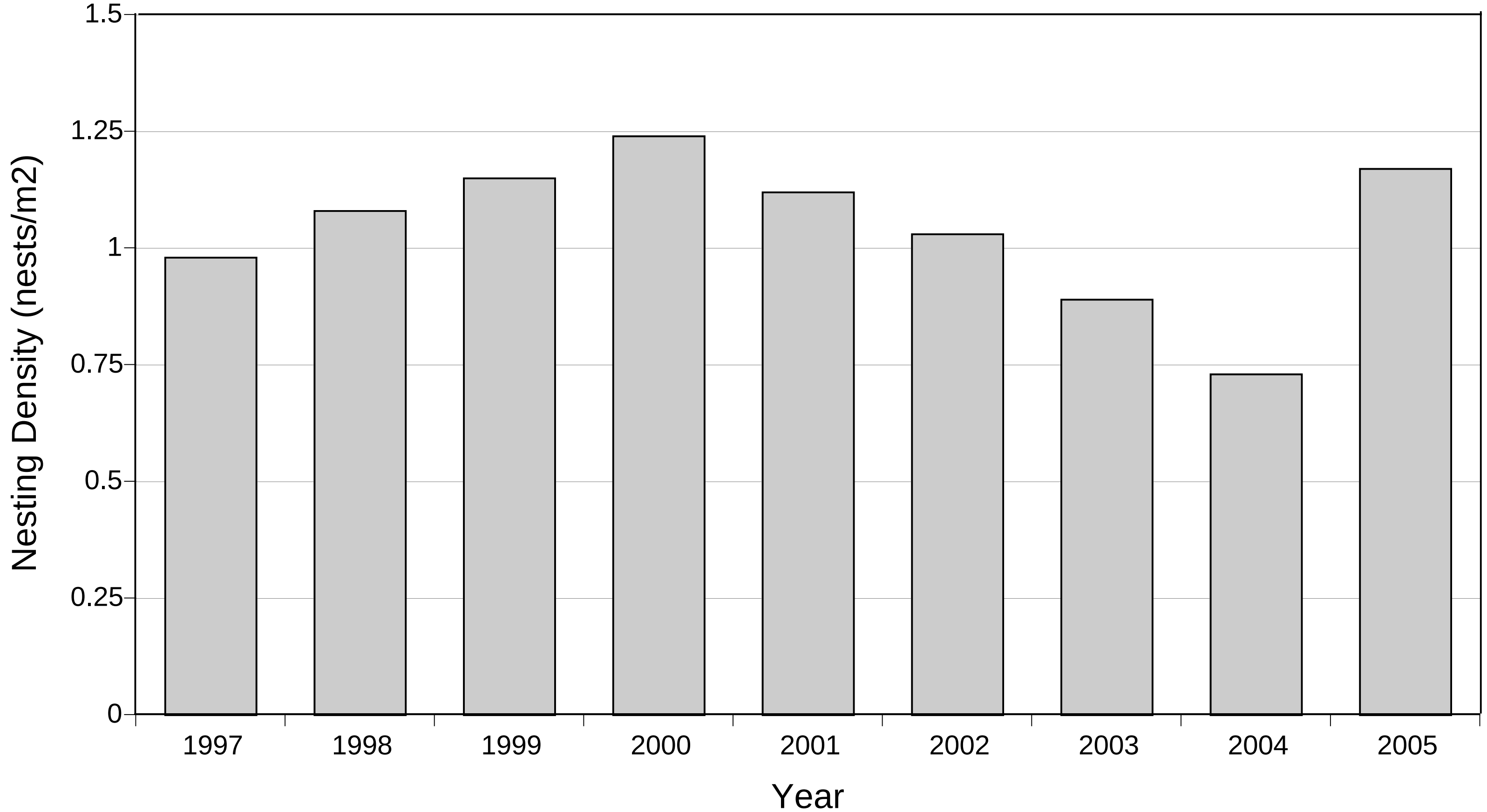


Figure 20. Average nest density for double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1997 - 2005.

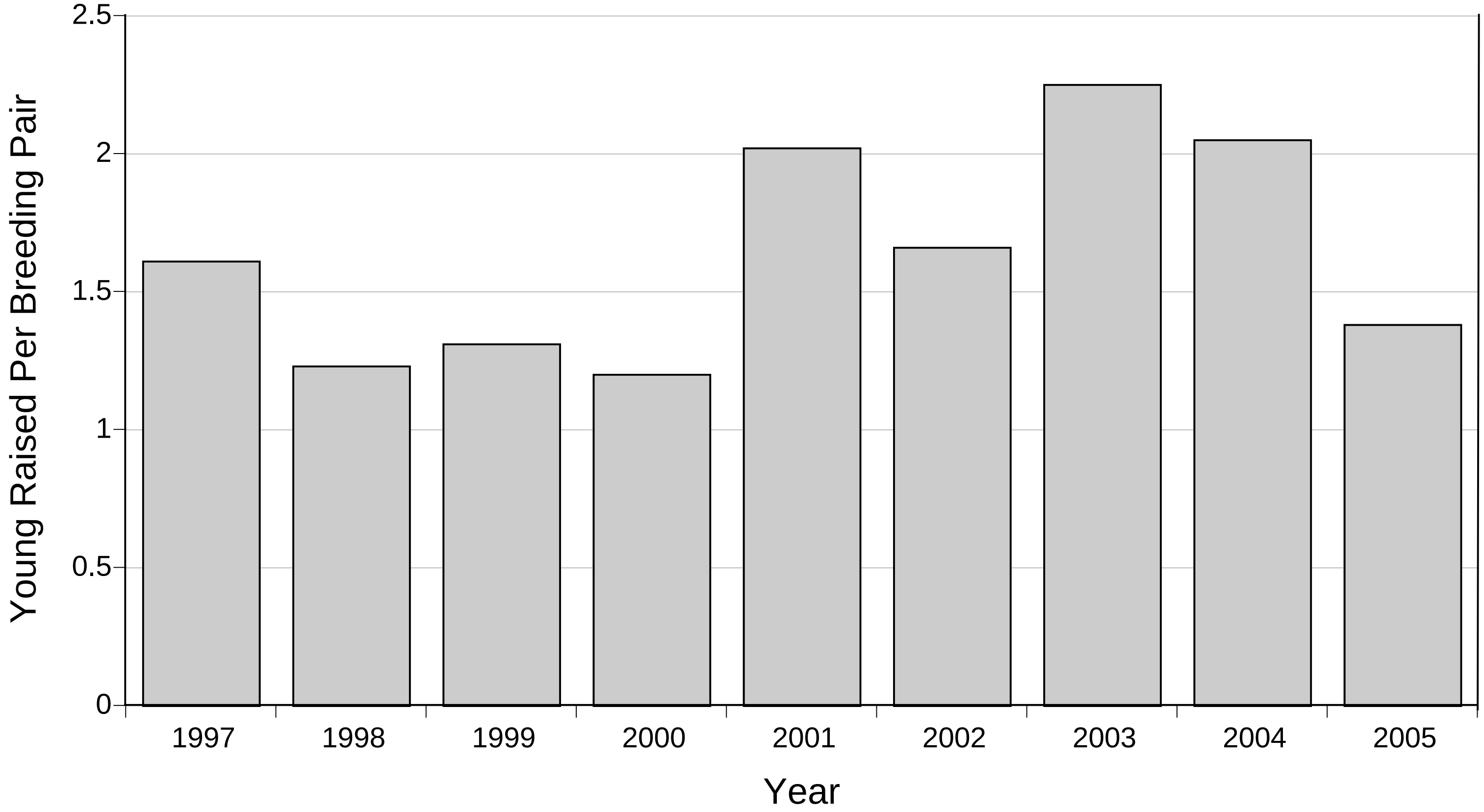


Figure 21. Average nesting success of double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1997 - 2005.

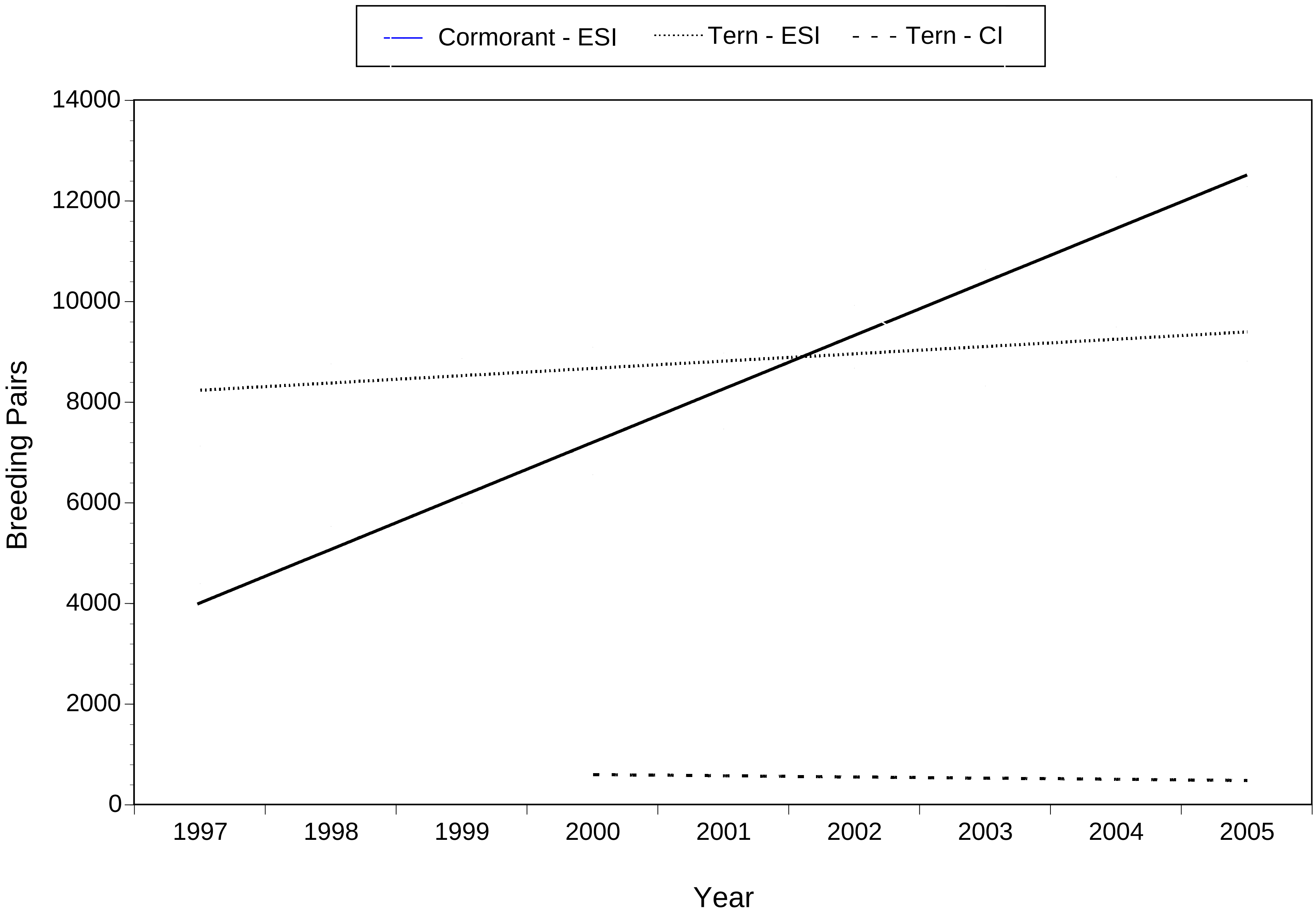


Figure 22. Trends in size of double-crested cormorant and Caspian tern colonies on East Sand Island (ESI) and the Caspian tern colony on Crescent Island (CI), 1997 - 2005.

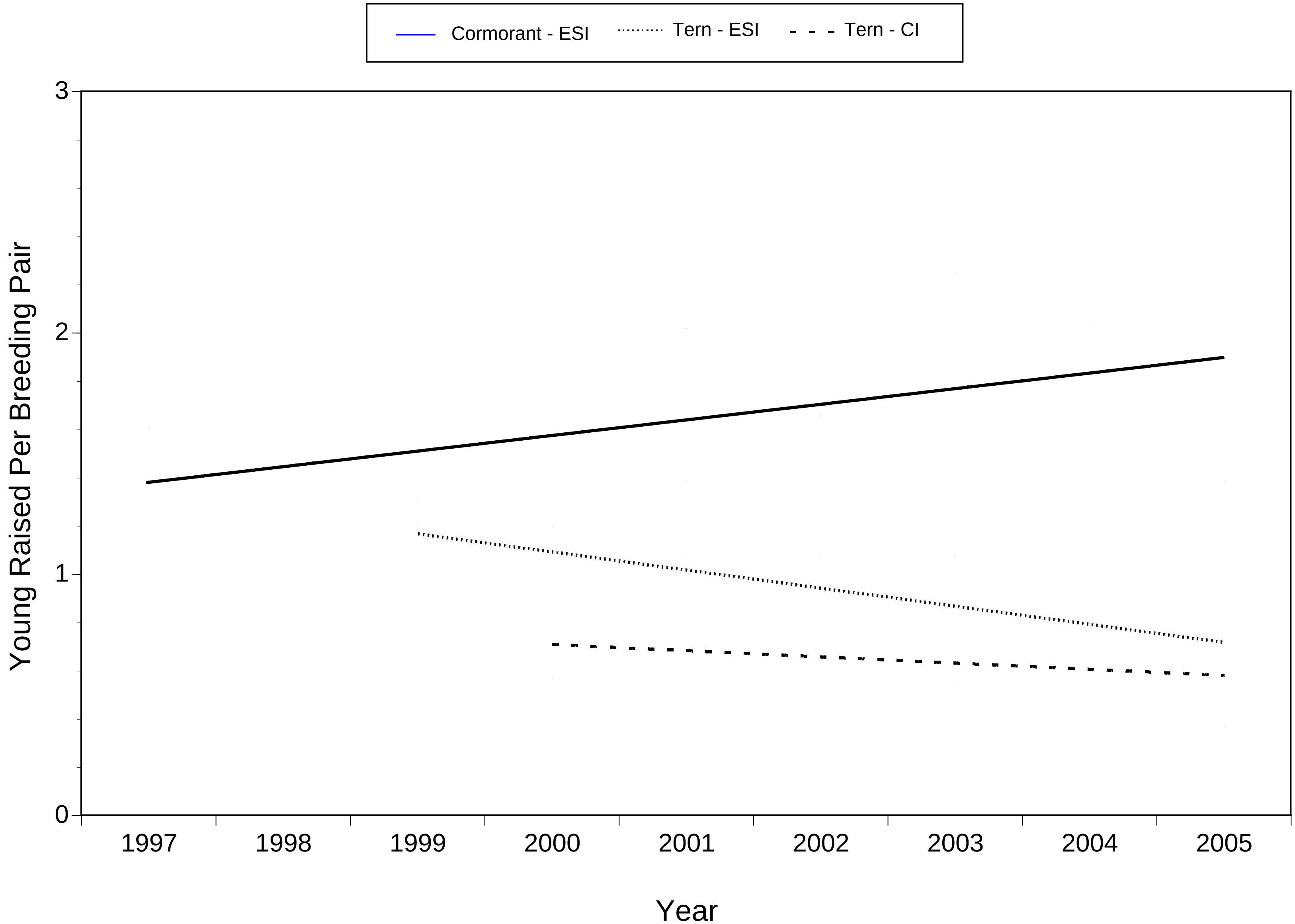


Figure 23. Trends in nesting success of double-crested cormorants and Caspian terns nesting on East Sand Island (ESI) and Caspian terns nesting on Crescent Island (CI), 1997 - 2005.

Table 1. Diet composition (% identifiable prey items) of Caspian terns nesting on Rice Island and East Sand Island in the Columbia River estuary, 1997-2005.

	1997-98	1999		2000		2001	2002	2003	2004	2005
Prey Type	Rice Is.	Rice Is.	East Sand Is.	Rice Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.
Herring, sardine, shad	10.7	1.8	8.2	1.7	10.1	20.3	18.4	18.5	29.3	12.3
Anchovy	0.0	6.5	15.9	0.5	11.6	22.4	14.1	23.7	25.2	33.4
Peamouth, pike minnow	2.0	1.0	0.5	0.9	0.8	0.6	0.5	0.1	0.7	0.1
Smelt	6.2	0.9	3.8	0.7	5.6	5.1	7.3	17.6	9.3	8.8
Salmonid	**72.7**	**76.5**	**45.6**	**89.6**	**46.5**	**32.5**	**31.1**	**24.1**	**16.8**	**22.6**
Cod	0.0	0.0	0.0	0.0	0.0	2.2	0.1	0.3	2.4	0.0
Sculpin	1.2	1.3	3.3	1.9	5.1	3.6	2.4	3.0	3.1	2.8
Surfperch	5.5	2.8	10.7	1.2	10.0	5.9	11.6	6.7	11.5	16.4
Pacific sand lance	0.1	0.1	5.9	0.1	5.6	3.1	2.5	4.5	0.2	1.7
Flounder	0.2	0.3	0.2	1.8	0.6	0.2	0.1	0.0	0.2	0.2
Other	1.4	8.7	5.8	1.6	3.9	3.9	11.9	1.5	1.4	1.7
Total no. identified prey	1,448	5,305	5,486	5,023	5,387	6,007	5,661	5,476	5,854	5,536

Table 2. Detection efficiency (DE) of test PIT tags intentionally released on the Crescent Island Caspian tern colony during four discrete time periods in 2005. Test tags were distributed evenly among four study plots. R indicates the number of test tags recovered.

	Plot 1		Plot 2		Plot 3		Plot 4		
Date	R	DE	R	DE	R	DE	R	DE	Average
16 March	12	20.0%	17	27.9%	14	23.0%	28	46.7%	29.3%
9 May	49	80.3%	43	72.9%	48	80.0%	38	63.3%	74.2%
30 June	57	95.0%	48	80.0%	56	87.5%	46	75.4%	84.5%
26 July	58	96.7%	56	93.3%	58	93.3%	56	93.3%	95.0%
TOTAL	176	73.0%	164	68.3%	176	71.8%	168	69.7%	70.8%

Table 3. Detection efficiency (DE) of test PIT tags intentionally released on the East Sand Island Caspian tern colony during four discrete time periods in 2005. Test tags were distributed evenly among three study plots. R indicates the number of test tags recovered.

	Plot 1		Plot 2		Plot 3		
Date	R	DE	R	DE	R	DE	Average
31 March	90	90.0%	87	87.0%	82	82.0%	86.3%
18 May	74	74.0%	76	76.0%	76	76.0%	75.3%
13 July	81	81.0%	92	92.0%	94	94.0%	89.0%
22 August	95	95.0%	74	74.0%	78	78.0%	82.3%
TOTAL	340	85.0%	329	82.3%	330	82.5%	83.3%

Table 4. Predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns in 2005. PIT-tagged smolts were from seven different ESA-listed Evolutionarily Significant Units (ESUs) of salmonid released upstream of McNary Dam. Analysis was limited to PIT-tagged fish of known origin. Predation rates are corrected for bias due to PIT tag detection efficiency on-colony (see Table 2), but not for the proportion of ingested smolt PIT tags that were not deposited on-colony; predation rates reported here are therefore minimums. Confidence intervals (±) based on the normal approximation and were derived from release groups of PIT-tagged smolts within the corresponding ESU (see Table 5).

ESU [b]	Released		Predation Rate [a]	
	Hatchery	Wild	Hatchery	Wild
SR steelhead	38,635	36,514	7.12% (±1.0)	3.33% (±1.4)
UCR steelhead	332,193	2,087	2.37% (±0.5)	1.43% (±1.1)
MCR steelhead	11,106	3,706	0.64% (±0.4)	2.29% (±2.0)
SR Fall chinook	197,417	1,850	0.39%	0.05%
UCR Spring chinook	72,026	3,570	0.34% (±0.1)	0.10% (±0.0)
SR Spr/Sum chinook	162,569	101,051	0.39% (±0.1)	0.24% (±0.1)
SR sockeye	5,357	981	0.34%	0.82%

[a] these predation rates are minimums because they do not include a correction factor for the proportion of ingested smolt PIT tags that were not deposited on the colony.

[b] SR = Snake River; UCR = Upper Columbia River; MCR = Middle Columbia River

Table 5. Stock-specific predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns in 2005. Assignment of each stock to an Evolutionarily Significant Unit (ESU) is based on genetic and geographic criteria developed by NOAA Fisheries. Only fish of known rearing type, origin, and release location are included. Sample sizes and predation rates are listed separately for hatchery (H) and wild (W) fish. Predation rates are corrected for bias due to PIT tag detection efficiency on-colony (see Table 2), but not for the proportion of ingested smolt PIT tags that were not deposited on-colony.

Species	ESU[b]	Stock	Released		Predation Rate[a]		
			H	W	H	W	Overall
Steelhead	SR						
		Imnaha River	6,989	4,191	9.77%	9.69%	9.74%
		Grande Ronde River	1,296	4,531	7.72%	2.85%	3.93%
		Clearwater River	12,260	15,381	7.81%	0.84%	3.93%
		Salmon River	9,639	8,884	7.53%	0.81%	4.13%
		Lower Snake	8,451	2,527	2.76%	2.45%	2.69%
		Average			**7.12%**	**3.33%**	**4.88%**
	UCR						
		Okanogan River	5,427	-	3.21%	-	3.21%
		Methow River	236,083	404	1.77%	0.25%	1.77%
		Entiat River	-	1,683	-	2.61%	2.61%
		Wenatchee River	90,683	-	2.14%	-	2.14%
		Average	**332,193**	**2,087**	**2.37%**	**1.43%**	**2.43%**
	MCR						
		Walla Walla & Touchet	9,995	857	1.09%	5.83%	1.47%
		Yakima	-	2,145	-	1.03%	1.03%
		Umatilla	1,111	704	0.18%	0.00%	0.11%
		Average	**11,106**	**3,706**	**0.64%**	**2.29%**	**0.87%**
Chinook	SR Fall						
		Mainstem Snake River	197,417	1,850	0.39%	0.05%	0.39%
	SR S/S						
		Salmon River	87,451	64,936	0.23%	0.18%	0.21%
		Grande Ronde/Imnaha	16,011	13,185	0.22%	0.33%	0.27%
		Lower Snake River	1,948	-	0.46%	-	0.46%
		Clearwater River	57,159	22,930	0.65%	0.21%	0.53%
		Average			**0.39%**	**0.24%**	**0.37%**
	UCR S						
		Methow River	6,808	428	0.26%	0.00%	0.25%
		Entiat River	47,493	1,606	0.28%	0.31%	0.28%
		Wenatchee River	17,725	1,536	0.49%	0.00%	0.45%
		Average			**0.34%**	**0.10%**	**0.32%**
Sockeye	SR						
		Redfish Lake	5,357	981	0.34%	0.82%	0.41%
TOTAL		**ALL STOCKS**	**1,435,832**	**296,687**	**0.75%**	**0.39%**	**0.69%**

[a] these predation rates are minimums because they do not include a correction factor for the proportion of ingested smolt PIT tags that were not deposited on the colony.[b] SR = Snake River; UCR = Upper Columbia River; MCR = Middle Columbia River

Table 6. Estimated predation rates on PIT-tagged salmonid smolts traveling through the McNary Pool by Crescent Island Caspian terns in 2005. Predation rates are based on the number of fish interrogated/tagged at Lower Monumental Dam (Snake River), Rock Island Dam (Upper Columbia River), and in the Middle Columbia River (only fish released below the confluence of the Snake and Columbia rivers and upstream of McNary Dam were included). Predation rates on hatchery (H) and wild (W) smolts are listed separately. Sample sizes of interrogated/tagged fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 2), but not for the proportion of ingested smolt PIT tags that were not deposited on-colony; predation rates reported here are therefore minimums.

	Snake R.		Upper Columbia R.		Mid-Columbia R.	
Species / Run Type	H	W	H	W	H	W
Steelhead	11.9%	9.3%	3.0%	2.3%	3.1%	2.2%
Yearling Chinook	1.0%	1.2%	0.2%	-	0.3%	0.8%
Sub-yearling Chinook	1.8%	-	-	-	0.2%	0.5%
Unknown Run Chinook	1.2%	0.6%	-	-	-	-
Coho	2.9%	-	-	-	0.1%	0.2%
Sockeye	-	-	-	0.2%	-	-

Table 7. Estimated predation rates (PR) on PIT-tagged salmonid smolts by East Sand Island Caspian terns in 2005. Predation rates are based on the number of PIT-tagged fish interrogated (I) while passing the Juvenile Bypass Facility at Bonneville Dam (In-river) or released (R) from transportation barges below Bonneville Dam (Transported). Predation rates on hatchery-raised and wild smolts are listed separately. Sample sizes of interrogated/tagged fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for the proportion of ingested smolt PIT tags that were not deposited on-colony; predation rates reported here are therefore minimums.

	In-river				Transported			
	Hatchery		Wild		Hatchery		Wild	
Species / Run Type	I	PR	I	PR	R	PR	R	PR
Steelhead	6,723	10.9%	655	8.3%	27,404	12.6%	17,513	9.2%
Yearling Chinook	12,526	1.7%	1,697	1.0%	82,598	1.8%	11,457	0.8%
Subyearling Chinook	1,338	0.6%	178	1.3%	14,948	1.4%		
Unknown Chinook	3,308	2.3%	1,160	1.2%	923	1.6%	19,350	0.8%
Coho	710	5.5%	221	0.6%	-	-	-	
Sockeye	-		-		1,322	0.6%	391	3.7%

Table 8. Percent biomass of identifiable prey in regurgitations of double-crested cormorants nesting at Foundation Island in the mid-Columbia River during 2-week sampling periods over the 2005 breeding season. All samples are regurgitations collected from beneath nesting trees.

Sample period	N	Salmonidae	Cyprinidae	Catastomidae	Petromyzontidae	Centrarchidae	Percidae	Ictaluridae
4/22-5/5	9	33.3%	32.2%	0.0%	0.0%	1.2%	11.1%	22.2%
5/6-5/19	17	35.3%	17.6%	5.9%	0.0%	35.3%	0.0%	5.9%
5/20-6/2	16	0.0%	25.0%	0.0%	0.0%	62.5%	0.0%	12.5%
6/3-6/16	30	0.0%	33.3%	10.0%	0.0%	46.7%	3.3%	6.7%
6/17-6/30	16	0.0%	12.5%	6.3%	6.3%	56.3%	6.3%	12.5%
7/1-7/14	1	0.0%	0.0%	0.0%	0.0%	100%	0.0%	0.0%
TOTAL[a]	89	10.1%	24.6%	5.6%	1.1%	45.1%	3.4%	10.1%

[a] these percentages are the average percent biomass for all regurgitations (n = 89) collected on Foundation Island during 2005

Table 9. Estimated minimum predation rates (PR) on juvenile salmonids from the Snake River based on PIT-tagged smolts that were interrogated while passing Lower Monumental Dam (N) and subsequently detected on either (1) the Crescent Island Caspian tern colony, (2) the Foundation Island double-crested cormorant colony, or (3) the Badger Island American white pelican colony during the 2005 migration year. The number of tags detected (D) on each bird colony is also provided. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency, but not for the proportion of ingested smolt PIT tags that were not deposited on-colony; predation rates reported here are therefore minimums.

		Crescent Island Caspian Terns		Foundation Island Double-crested Cormorants		Badger Island American White Pelicans	
Species / Run type	N	D	PR	D	PR	D	PR
Hatchery Steelhead	21,616	1,616	11.9%	293	2.01%	25	0.21%
Wild Steelhead	6,467	377	9.29%	80	1.83%	1	0.03%
Hatchery Spring Chinook	21,745	126	0.99%	116	0.78%	1	0.00%
Wild Spring Chinook	4,703	33	1.19%	23	0.72%	0	0.00%
Hatchery Fall Chinook	7,081	100	1.75%	7	0.15%	1	0.02%
Unknown Fall Chinook	35	2	5.73%	0	0.00%	0	0.00%
Unknown Run Chinook	16,038	115	1.20%	100	0.92%	1	0.02%
Coho	578	11	2.9%	6	1.54%	0	0.00%
Sockeye	79	4	7.59%	0	0.00%	0	0.00%
TOTAL	78,342	2,384	4.83%	625	1.18%	29	0.07%

Table 10. Counts of nesting piscivorous waterbirds at colonies throughout the Columbia River basin in 2005. Species include American white pelicans (AWPE), Caspian terns (CATE), Forster's terns (FOTE), double-crested cormorants (DCCO), Brandt's cormorants (BRCO), pelagic cormorants (PECO), California gulls (CAGU), ring-billed gulls (RBGU), glaucous-winged/western gulls (GWGU/WEGU), great blue herons (GBHE), black-crowned night-herons (BCNH), and great egrets (GREG). Counts of terns and cormorants are of the number of breeding pairs; all other counts are of the number of individuals on colony (rough estimate of the number of breeding pairs).

Water Body	Location	River km	Species	Colony Size
Columbia R. estuary				
	East Sand Island	8	CATE	8,822
			DCCO	12,287
			GWGU/WEGU	1,000-10,000
			RBGU	100-1,000
	Pile dikes	8	BRCO	62
	Astoria Bridge	16	PECO	159
	Rice Island	34	GWGU/WEGU	100-1,000
	Miller Sands Spit	37	GWGU/WEGU	100-1,000
Middle Columbia R.				
	Browns Island	318	GBHE	10-100
	Miller Rocks	333	RBGU/CAGU	1,000-10,000
	Three Mile Island	413	RBGU/CAGU	1,000-10,000
	Island 35	445	FOTE	< 10
	Sand Island	445	GBHE/GREG/BCNH	10-100
	Rock Island	445	RBGU	10-100
			CATE	< 10
			FOTE	10-100
	Crescent Island	510	CATE	476
			RBGU/CAGU	1,000-10,000
			GBHE/GREG	unknown
	Badger Island	511	AWPE	1,057
	Foundation Island	518	DCCO	> 315
Upper Columbia R.				
	Fencepost Island	545	CAGU	1,000-10,000
	Island 18	553	RBGU	1,000-10,000
			GBHE/GREG	10-100
			FOTE	< 10
	Okanogan Island	858	DCCO	38
Potholes Reservoir				
	Solstice Island	-	Unidentified gulls	unknown
	Goose Island	-	CATE	320-330
			RBGU/CAGU	unknown
	North Potholes		DCCO	800
Sprague Lake				
	Harper Island	-	CATE	< 10
			RBGU/CAGU	unknown
Banks Lake				
	Twining Island	-	CATE	< 10
			RBGU/CAGU	unknown
	Goose Island		CATE	< 10
			RBGU/CAGU	unknown

Table 11. Estimated avian predation rates (PR) in the mid-Columbia River on PIT-tagged fall chinook smolts of hatchery (H), wild (W), or unknown (U) origin, and released (R) into the Snake, Upper Columbia, or Middle Columbia rivers. Predation rates are presented separately for Crescent Island Caspian terns, Foundation Island double-crested cormorants, and Badger Island American white pelicans in 2005. The number of PIT tags detected (D) on each bird colony is also provided. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency, but not for the proportion of ingested smolt PIT tags that were not deposited on-colony; predation rates reported here are therefore minimums.

			Terns		Cormorants		Pelicans		Cumulative	
Release Group	Origin	R	D	PR	D	PR	D	PR	D	PR
Snake River										
Ice Harbor	H	1546	7	0.6%	40	3.8%	3	0.3%	50	4.5%
Ice Harbor Tailrace	U	5319	125	2.9%	15	0.4%	9	0.3%	149	3.9%
Lyons Ferry Hatchery	H	1454	24	2.1%	4	0.4%	1	0.1%	29	2.8%
Lower Monumental	U	1008	16	2.0%	2	0.3%	2	0.3%	20	2.8%
Salmon R.	H	9451	111	1.5%	6	0.1%	0	0.0%	117	1.7%
Captain Johns Accl.	H	3355	31	1.2%	2	0.1%	0	0.0%	33	1.4%
Pittsburg Landing Accl.	H	7161	47	0.8%	13	0.3%	1	0.0%	61	1.2%
Snake R. mainstem	H	3375	16	0.6%	3	0.1%	0	0.0%	19	0.8%
Clearwater to Salmon R.	H	111599	227	0.3%	38	0.1%	4	0.0%	269	0.3%
Clearwater R.	W	1847	1	0.1%	0	0.0%	0	0.0%	1	0.1%
Big Canyon Creek	H	52305	17	0.0%	11	0.0%	0	0.0%	28	0.1%
Lower Granite	U	840	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Sub-total		**199260**	**622**	**0.4%**	**134**	**0.1%**	**20**	**0.0%**	**776**	**0.5%**
Upper Columbia River										
Natches R.	U	1630	3	0.2%	77	7.0%	29	3.1%	109	9.4%
Lower Crab Creek	W	22612	123	0.7%	390	2.5%	91	0.7%	604	3.7%
Priest Rapids Hatchery	H	2993	20	0.8%	15	0.7%	5	0.3%	40	1.9%
Chandler Dam	U	1670	1	0.1%	4	0.4%	11	1.1%	16	1.3%
Natches R.	H	4200	2	0.1%	1	0.0%	17	0.7%	20	0.7%
Natches R.	H	13203	23	0.2%	3	0.0%	7	0.1%	33	0.3%
Natches R.	W	428	0	0.0%	0	0.0%	1	0.4%	1	0.3%
Sub-total		**46736**	**172**	**0.5%**	**490**	**1.5%**	**161**	**0.6%**	**823**	**2.5%**
Mid. Columbia River										
Umatilla R.	H	2481	0	0.0%	8	0.5%	4	0.3%	12	0.7%
Hat Rock State Park	U	1633	5	0.4%	0	0.0%	0	0.0%	5	0.4%
McNary Forebay	U	1448	4	0.3%	0	0.0%	0	0.0%	4	0.4%
Umatilla R.	W	458	0	0.0%	1	0.3%	0	0.0%	1	0.3%
McNary Bypass	U	2647	5	0.2%	0	0.0%	0	0.0%	5	0.3%
McNary Tailrace	U	1066	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Sub-total		**9733**	**14**	**0.2%**	**9**	**0.1%**	**4**	**0.1%**	**27**	**0.4%**
Grand Total		**255729**	**808**	**0.4%**	**633**	**0.4%**	**185**	**0.1%**	**1626**	**0.9%**

Predation on juvenile salmonids by Caspian Terns nesting in Potholes Reservoir

DRAFT 2005 Season Summary

This Draft 2005 Season Summary has been prepared for the Bonneville Power Administration and the U.S. Army Corps of Engineers for the purpose of assessing project accomplishments. This report is not for citation without permission of the authors.

Thomas P. Good, Principal Investigator
National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, WA 98112
tom.good@noaa.gov

Deborah Harstad, Christina Hall, Brad A. Ryan,
and Melissa Carper
National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, WA 98112

Christina J. Maranto
Department of Biology
Box 351800
University of Washington
Seattle, WA 98195-1800

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Introduction

Avian predation is one of the factors believed to currently limit recovery of *Oncorhynchus* salmonids throughout the Columbia River basin (Roby et al. 1998; IMST 1998). Piscivorous birds, particularly Caspian Terns (*Sterna caspia*), consume millions of juvenile Pacific salmonids annually (Roby *et al.* 1998, NMFS 2000, Collis *et al.* 2001), and their populations are managed in the Columbia River estuary. While relocating the Caspian Tern colony from Rice Island to East Sand Island during 1999-2001 reduced consumption of juvenile salmonids significantly, Caspian Terns still consume an estimated 3.5-6.5 million juvenile salmonids annually (Collis *et al.* 2002, 2003a,b). Based on life cycle modeling of reducing Caspian Tern predation on Columbia River steelhead ESUs (NMFS 2005), USFWS has proposed that the size of the East Sand Island colony be reduced by about two-thirds and the displaced birds dispersed to colony sites elsewhere in and out of the basin (USFWS 2005).

Losses of salmonid smolts from Columbia River and Snake River ESUs are also extensive at upriver Caspian Tern colonies, although the numbers of depredated smolts are at least an order of magnitude less (Antolos *et al*. 2005). However, the proportion of salmonids observed in the diet at these colonies can be 2-3 times that observed in the estuary (Collis *et al.* 2002, 2003a,b). On Crescent Island, PIT tag detection rates rival those found in the estuary for the Snake River steelhead ESU (13% of PIT-tagged fish in 2001; B. Ryan unpubl. data, Antolos *et al*. 2005). In the Potholes Reservoir, diet has been observed over portions of breeding seasons (Antolos 2004, T. Good and C. Maranto, unpubl. data), and thousands of PIT tags have been recovered from the Goose Island and Solstice Island colonies since 2000 (B. Ryan, unpubl. data).

Research at the Potholes Reservoir colonies was initiated to study these colonies in the context of Columbia River colonies upriver and in the estuary. By combining bioenergetics modeling and PIT tag recovery methodologies, which have proven useful (Ryan *et al.* 2001, 2003, Roby *et al.* 2003), we aim to quantify predation impact by off-river Caspian Tern colonies. The ultimate aim is to contribute to more effective management of avian predator populations, and to enhance salmon recovery in the Columbia River basin.

Study Sites

The field research was conducted on Caspian Tern breeding colonies located in the Potholes Reservoir in eastern Washington, ca. 50 km from the Columbia River (Fig. 1). Goose Island is in the lower (southern) reservoir, 1 km north of the O'Sullivan Dam. The island is composed of two hilltop islets (east Goose Island, west Goose Island) joined by a low-lying beach--the islet tops remain well above the waterline during the change in water level (5-6 m) over the course of the breeding season. A Caspian Tern colony lies atop the eastern islet and is surrounded by nesting Ring-billed and California Gulls. The colony substrate is a hard-packed mix of soil, volcanic ash from the 1980 eruption of Mount St. Helens, guano, and fish bones. Solstice Island is the upper (northern) reservoir ~8 km north of the O'Sullivan Dam. The island is low-lying and sandy, and the open area on the shallow-sloping south side of the island (where Caspian Terns nest) is prone to flooding during the seasonal changes in water level. This Caspian Tern colony has Ring-billed and California gulls nesting adjacent to it in the open area and in the willows to the north and west.

Colony Size and Productivity

Methods:

Prior to the breeding season of 2005, observation blinds were placed adjacent to the areas observed to have had Caspian Terns breeding in past years on Goose and Solstice islands in the Potholes Reservoir (Table 1). The blind on Goose Island was located at the highest point of east Goose Island, facing eastward and toward an area of previously known Caspian Tern breeding activity. The blind on Solstice Island was located on the southern portion of the island, facing a sandy clearing where Caspian Terns have attempted breeding in previous years. Tunnels were constructed from the boat landing area to the entrance of the blind so that the tern colonies would not be disturbed by researchers entering the blinds.

Observation of both colonies began April 12, 2005 and spanned the Caspian Tern breeding season until July 5, 2005 on Goose Island (observations lasted only until May 2, 2005 on Solstice Island, after it became apparent that terns were not using the island for breeding). The number of adults breeding on east Goose Island was estimated from daily observations of the maximum number of adults observed on and around the breeding colony. Counts were conducted hourly of all adults observed on the colony and loafing on nearby shores or islets.

Results and Discussion:

In contrast to past years in the Potholes Reservoir, all breeding by Caspian terns took place on Goose Island in 2005. The maximum number of Caspian Tern adults observed on the east islet breeding colony was 256 during the week of June 4 (Fig. 2). The maximum number of Caspian Terns observed on Solstice Island in 2005 was 41 during the week of May 7 (Fig. 3). While some adults were observed loafing, feeding, and copulating on Solstice Island, no nesting behavior was observed. The number of Caspian Terns observed on Solstice Island peaked after a major disturbance occurred on Goose Island on April 22, which caused them to abandon the breeding area, including at least one nest where an egg had been laid. On April 30, Caspian Tern decoys were placed on the east Goose Island colony to encourage reestablishment of the breeding colony. Once the decoys were in place, the number of Caspian Terns using east Goose Island increased and the number of terns using Solstice Island began to drop. After the disturbance, a colony also formed atop the western part of the island (West Goose colony).

We estimate that there were 320-330 breeding pairs for all of Goose Island (and hence the Potholes Reservoir) in 2005. Direct observation of the East Goose colony resulted in an estimate of 168 breeding pairs. These were all pairs that displayed incubating behavior, although eight of these nests were never confirmed to have eggs. Although we did not observe Caspian Terns breeding at the west Goose Island colony, we estimate from an aerial photograph taken on May 26, 2005 that another 160 breeding pairs were nesting there. We estimate the total number of Caspian Tern fledglings from both Goose Island colonies to be approximately 103. We estimate that 53 fledglings were produced at the east Goose colony, based upon the final observed chick count on July 4, corresponding to a nesting success of 0.32 fledglings/active nest. The total number of chicks documented on the east Goose colony was 153, while the daily number of chicks observed peaked on June 10 at 108 nestlings (Fig. 4). A total of 291 eggs were laid, for an average clutch size of 1.8 eggs/nest. We did not observe the west Goose colony, but we assumed that *ca*. 160 active nests on West Goose produced *ca*. 50 fledglings.

The number of breeding pairs on Goose Island in 2005 has increased from past years. Although accurate population counts for past years are lacking, we estimated from boat observations and nest cup surveys that approximately 200 breeding pairs produced 50 fledglings on the east Goose Island colony in 2004. The increase in breeding pairs on Goose Island may be due to terns nesting on the western islet in addition to the known breeding area on the eastern islet. Caspian Tern colonies have not been documented prior to 2005. The increased number of breeding pairs on Goose Island may be a result of terns not attempting to breed on Solstice Island in 2005. In addition, the Caspian Tern colony at Crescent Island in the mid-Columbia River declined by *ca*. 50-60 nesting pairs in 2005 compared to 2004.

Diet Composition and Salmonid Consumption

Methods:

During the field season of 2005, diet composition observations were made from blinds on the periphery of Caspian Tern colonies east Goose Island and Solstice Island. We visually identified all bill loads with binoculars and spotting scopes and documented taxonomic grouping and size of prey (in relation to tern bill length) along with date, time, nest number, recipient, and provider if known. Males and females of many nests were identified early in the breeding season by observing courtship behaviors and noting distinctive plumage, bill and leg patterns, as well as colored and aluminum USFWS leg bands. From the observation blind, we could distinguish salmonids from non-salmonids; while we could identify the vast majority of non-salmonids to species, we generally did not identify salmonids to species.

Results and Discussion:

All Bill Loads

Of the 3762 identifiable bill loads observed on the east Goose Island Caspian Tern colony in 2005, 17.0% of these were salmonids (Fig. 5, Table 2). The most prevalent family observed as prey at this breeding colony was the Centrarchidae (68%). The other taxonomic groups observed as prey were Perchidae (14.4%), Ictaluridae (0.4%), Catostomidae (0.03%), and Petromyzontidae (0.03%). There were two peaks of salmonid consumption during the 2005 field season (Fig. 6). During the first week of observation (April 16), 42.6% of observed prey brought back to the colony were salmonids; an unknown proportion of the smaller salmonids (< 1.5 bill lengths) may have been rainbow trout obtained from stocked lakes in the vicinity of Potholes Reservoir. The second peak of salmonid consumption occurred during the week of July 2 (28.2%), during the peak in chick numbers.

Observed Adult Diet

We detected no overall difference in diet composition by sex; males and females consumed Centrarchids, Percids, Salmonids, Ictalurids, and Catostomids in similar proportions (Fig. 7). There were some observed temporal differences in diet composition. The percentage of salmonids consumed by females peaked at 50% during the week of April 30, while the percentage of salmonids consumed by males peaked at 45% during the week of April 16 (Fig. 8).

Observed Chick Diet and Provisioning

Overall, chick diets were similar to that observed in adults, consisting primarily of Centrarchids, followed by Salmonids, Percids, Ictalurids, and Petromyzontids (Fig. 9). Salmonids formed a significant portion of the chick diet. This was reflected in the increasing proportion of salmonids in chick diet as chicks grew during the month of June (Fig. 10) as well as in increasing delivery rates by adults after chicks hatched out (Fig. 11).

On average, males and females differed in provisioning of salmonids to chicks. Of the chick feedings where the provider could be identified, females delivered 22.1% salmonids, as compared to 13.7% salmonids for males (Fig. 12). This may be a true difference between the sexes or be biased by data from a few specific nests, as we were able to identify the provider in only 43% of chick provisionings with identified fish.

Estimates of annual consumption of salmonid juveniles for the east Goose Island Caspian tern colony are being calculated using a bioenergetics modeling approach.

Salmon Predation Rates: PIT Tag Studies

Methods:

In September 2005, we recovered PIT tags from the east and west Goose Island colonies. After scanning the surface of the colony area using electronic PIT tag readers, we raked the surface to break up the crust and physically removed PIT tags from the surface using large rolling magnets and small magnets attached to rakes. In addition, we excavated nest cups of pairs we observed throughout the 2005 breeding season.

To examine electronic interference among tags, we individually scanned each nest cup using the PIT tag reader and then excavated and sieved nest contents to remove tags deposited in the nest during the breeding season.

In order to estimate the detection efficiency of PIT tag deposition on the breeding colony, 400 test tags were distributed on the East Goose colony in 2005. Tags were spread over of the colony on four different occasions (100 tags each time) during the breeding season. Prior to the birds' arrival on the colony (March 24), during incubation (May 17), during fledging (July 5), and following the nesting season after the birds had left the colony (July 23).

Results and Discussion:

PIT Tag Data

The total number of intact PIT tags detected by both electronic scanning and tag removal of the east and west Goose Island breeding colonies in 2005 was 10,382. Of these tags, 161 were test tags distributed on the east Goose Island Caspian Tern breeding colony during the 2005 breeding season. Additional tags recovered from east Goose Island included 84 acoustic tags, 1 radio tag, and 9 spaghetti tags. The acoustic and radio tags were from studies of timing of juvenile salmonid outmigration in the Columbia and Snake rivers. The spaghetti tags originated from rainbow trout released in Lake Roosevelt, WA, over 70 km to the northeast of Potholes Reservoir; eight of the nine were from 2005, and one was from 2003. A majority of the rainbow trout were triploid (7/9) and the others were regular Spokane stock.

Over 8500 PIT tags from migration year 2005 that were recovered from Goose Island and found in the PTAGIS database. This number is a minimum estimate of salmonids depredated by Caspian Terns from the Goose Island colonies in 2005, as it is not corrected for detection efficiency; not all PIT tags deposited on the colony are detected, and not all PIT tags consumed by terns nesting at the colony are deposited on the colony. Of the recovered PIT tags, the vast majority of tags (95%) were from steelhead; 4% of tags were from Chinook salmon, and less than 1% of tags were from coho salmon or sockeye salmon (Fig. 13). Almost all of the tags (99%) were from hatchery fish, 0.7% of tags were from wild fish, and 0.3% of tags were of unknown origin.

Since 2000, thousands of PIT tags have been detected or physically recovered from Solstice and Goose islands in the Potholes Reservoir. The overall number of PIT tags found on these colonies has been increasing (Fig. 14) and has shifted from Solstice Island to Goose Island as the use of these islands by breeding Caspian Terns has shifted.

The vast majority of PIT tags originated from basins in the upper Columbia River (Table 3). However, a small number of PIT tags from Snake River salmonids have been recovered annually since 2000 from colonies in the Potholes Reservoir (Table 4).

PIT tag electronic interference study

PIT tag electronic interference was examined for all nest cups used by Caspian Terns on the east Goose Island colony. Only 1% of all readable tags excavated from nest cups were detected by an electronic scan of the nest cup area, and the percentage of tags detected electronically declined as a function of increasing numbers of tags buried in the nest cup (Fig. 15). For the 168 electronically-scanned and excavated nests, the mean number of PIT tags found in nest cups was 15 (range: 0 - 68).

PIT tag Detection efficiency

Of the 400 test tags spread on the east Goose Island colony, (40.3%) were subsequently recovered on-colony (Table 5). Detection efficiency for all tag types ranged from a low of 18% for the 5 July tag release group to a high of 71% for the 17 May tag release group. It is difficult to determine the relationship between date of tag dispersal and recovery rate. On July 5, PIT tags were not dispersed over the test tag area in the heart of the colony but were thrown from the blind to prevent disturbance of the remaining pairs in the colony. These tags did not make it very far from the blind and may have been lost in the rock rubble under the blind or trampled during de-construction of the blind in late July, which may have affected their detection efficiency value. The island is also prone to human traffic after fledging in July, which may have affected the late July estimate. For this reason, we have not applied any detection efficiency correction to our PIT tag recoveries; however, PIT tag recoveries are clearly underestimates of the number of PIT-tagged salmonids taken by Caspian Terns nesting on Goose Island.

Nest Predation and Kleptoparasitism

Interactions with other breeding colonial waterbird species appeared to influence the nesting success of Caspian Terns on Goose Island in 2005. California Gulls, which nest in close proximity to the Caspian Tern colony on East Goose Island, were significant nest predators, stealing eggs from 59% of all active Caspian Tern nests and accounting for the loss of 48% of all observed eggs laid during the 2005 breeding season. California Gulls were also observed attempting to steal chicks; on several occasions, they succeeded in carrying small chicks away from their nests. It is unknown what proportion of chick mortality was attributable to predation by California gulls or starvation.

Kleptoparasitism of Caspian Terns may also have affected the overall impact that this breeding colony of Caspian Terns has on juvenile salmonid populations, if kleptoparasitized Caspian terns harvested additional salmonids from the Columbia River to compensate for losses. In 2005, gulls stole an estimated 3% of all bill loads brought to the colony on East Goose; however, as salmonids made up 50% of all thefts by gulls (Fig. 16), about 10% of all salmonid bill loads were lost to gulls. While terns also kleptoparasitized each other, Centrarchids made up 65% of their thefts (Fig. 17); thus, only 2% of all salmonid bill loads were stolen by other terns. Moreover, larger fish appeared to be stolen more frequently (Fig. 18). The average length of a fish stolen by a gull was 2.06 bill lengths (SD = 0.42) whereas the average length of all bill loads was 1.55 bill lengths (SD = 0.44).

REFERENCES

Antolos, M., D.D. Roby, and K. Collis. 2004. Breeding ecology of Caspian terns at colonies on the Columbia Plateau. Northwest Science 78:303-312.

Antolos, M., D.D. Roby, D.E. Lyons, K. Collis, A.F. Evans, M. Hawbecker, and B.A. Ryan. 2005. Caspian tern predation on juvenile salmonids in the Mid-Columbia River. Transactions of the American Fisheries Society 134:466-480.

Collis, K., D. D. Roby, D. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Collis, K., D. D. Roby, D. E. Lyons, R. M. Suryan, M. Antolos, S. K. Anderson, A. M. Myers, and M. Hawbecker. 2002. Caspian tern research on the lower Columbia River. Final 2001 Summary (http://www.columbiabirdresearch.org). October, 2002.

Collis, K., D. D. Roby, D. E. Lyons, R. M. Suryan, M. Antolos, S. K. Anderson, and A. M. Myers. 2003a. Caspian Tern Research on the Lower Columbia River. Final 2002 Season Summary (http://www.columbiabirdresearch.org). November, 2003.

Collis, K., D. D. Roby, C. Couch, G. Dorsey, K. Fischer, D. E. Lyons, A. M. Myers, S. K. Nelson, and R. M. Suryan. 2003b. Caspian Tern Research on the Lower Columbia River. Draft 2003 Summary (http://www.columbiabirdresearch.org). December, 2003.

IMST (Independent Multidisciplinary Science Team). 1998. Pinniped and Seabird Predation: Implications for Recovery of Threatened Stocks of Salmonids in Oregon Under the Oregon Plan for Salmon and Watersheds. Technical Report 1998-2 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resources Office. Salem, Oregon.

NMFS. 2000. Predation on Salmonids Relative to the Federal Columbia River Power System. White Paper. Northwest Fisheries Science Center (NMFS/NOAA), Seattle, WA.

NMFS. 2005. Caspian tern predation on juvenile salmonid out migrants in the Columbia River estuary. Appendix C in *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary Final EIS - January 2005* (by Good, T. P., K. Barnas, D. M. Marsh, M. M. McClure, B. A. Ryan, B. P. Sandford and E. Casillas (Northwest Fisheries Science Center, NMFS/NOAA), Seattle, WA, 31 pages.

Roby, D. D., D. P. Craig, K. Collis, and S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, OR.

Roby, D. D., D. E. Lyons, D. P. Craig, K. Collis, and G. H. Visser. 2003. Quantifying the effects of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81:250-265.

Ryan, B. A., J. A. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:417-421.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary, 1998–2000. Transactions of the American Fisheries Society 132:275–288.

USFWS. 2005. Caspian Tern management to reduce predation of juvenile salmonids in the Columbia River estuary, Final Environmental Impact Statement, Portland, Oregon

Tables

Table 1. Field chronology for Potholes Caspian Tern colonies in 2005.

Date	Notes
3/24 & 3/25	Colony preparation; PIT tags (100) released on Goose and Solstice Island colonies for detection efficiency studies; no terns present on colony
4/12	Colony observations began on Goose and Solstice Island colonies
4/19	First egg laid on Goose Island
4/22	Colony wide disturbance from humans; all terns abandoned current nests and eggs; majority of terns moved to West Goose Island
4/30	Placed Caspian Tern decoys on East Goose Island colony to encourage birds back and flagging to discourage birds from West Goose Island
5/1	Colony started re-establishing on East Goose Island
5/1	First eggs laid at re-established colony on Goose
5/2	Ended colony observations on Solstice Island; no nesting observed this season.
5/17	PIT tags (100) released on colony for detection efficiency studies (100 tags)
5/26	First chicks observed on East Goose Island on Goose Island
5/26	Aerial photo taken of western Goose Island @ 12 -12:30 PM
7/5	Last date of colony observations on Goose Island
7/5	PIT tags (100) released on colony for detection efficiency studies (100 tags)
7/23	PIT tags (100) released on colony for detection efficiency studies (100 tags)
9/14 & 9/15	PIT tag scanning and collection on Goose Island

Table 2. Diet composition (% identifiable prey items) of Caspian terns nesting on the east Goose Island colony in 2005.

Prey Type			
Family	**Species**	**Count**	**%**
SALMONIDAE	**All Salmonids**	**641**	**17.0**
	Unidentified Salmonid	595	15.8
	Steelhead	44	1.2
	Rainbow Trout	2	0.05
CENTRARCHIDAE	**All Centrarchids**	**2558**	**68.0**
	Bluegill/ Pumpkinseed	1730	46.0
	Largemouth Bass	633	16.8
	Smallmouth Bass	96	2.6
	Crappie	79	2.1
	Unidentified Centrarchid	10	0.3
	Unidentified Bass	10	0.3
PERCHIDAE	**All Percids**	**541**	**14.4**
	Yellow Perch	538	14.3
	Walleye	3	0.08
ICTALURIDAE	**Bullhead**	**15**	**0.4**
CATOSTOMIDAE	**Sucker**	**1**	**0.03**
PETROMYZONTIDAE	**Lamprey**	**6**	**0.17**
Total no. of prey		**3762**	

Table 3. Number of PIT tags (H – hatchery; W – wild) from Columbia River and Snake River basins recovered from all Potholes Reservoir colonies in 2005.

Species	ESU	Stock	Recovered	
Steelhead	**Snake River**		**H**	**W**
		Imnaha River	1	1
		Grande Ronde River	-	1
		Clearwater River	-	-
		Salmon River	-	-
		Lower Snake	10*	2
	Upper Columbia River			
		Chief Joseph (unknown)	1290	-
		Okanogan River	812	
		Methow River	2469	1
		Entiat River	1511	48
		Wenatchee River	1880	-
		Priest Rapids (unknown)	6	-
Chinook	**Snake River fall-run**			
		Mainstem Snake R.	-	-
	Snake River spring/summer run			
		Salmon River	-	-
		Grande Ronde/Imnaha	-	-
		Lower Snake River	-	-
		Clearwater River	-	-
	Upper Columbia River spring-run			
		Methow River	8**	1
		Entiat River	5	2
		Wenatchee River	39	-
		Priest Rapids (unknown)	148	-
	Upper Columbia River summer-run			
		Chief Joseph (unknown)	12	-
		Entiat River	112	-
		Priest Rapids (unknown)	48	-

* includes one unknown-origin fish

** includes two unknown-origin fish

Table 4. Number of PIT tags from Columbia River and Snake River basins recovered from all Potholes Reservoir colonies from 1999-2005.

Columbia River Basin (excl. Snake River)		**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
	Chinook	-	187	1475	1236	1192	1989	385
	Coho	-	145	161	71	30	142	61
	Steelhead	1	1557	234	78	2270	5316	8018
	Sockeye	-	2	7	3		2	3
	Totals	1	1891	1877	1388	3492	7449	8467
Snake River basin								
	Chinook	-	6	6	7	11	9	3
	Coho	-		1				
	Steelhead	-	11	14	13	8	35	23
	Sockeye	-	1		1	1		
	Totals		18	21	21	20	44	26

Table 5. Detection efficiency of test PIT tags intentionally released (R) on the east Goose Island tern colony during four discrete time periods in 2005.

Vial #	Date	R	DE
CD11893	25 March	100	31%
CD11894	17 May	100	71%
CD11895	5 July*	100	18%
CD11896	23 July	100	41%
TOTAL		400	40.3%

* Tags were dispersed from the observation blind and not in the test tag area; thus, they may not have landed in the area swept by the post-season recovery activities.

Figures

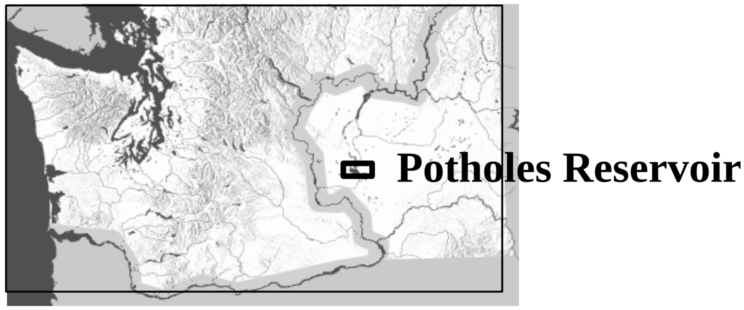

Figure 1. Study areas on Potholes Reservoir in central Washington.

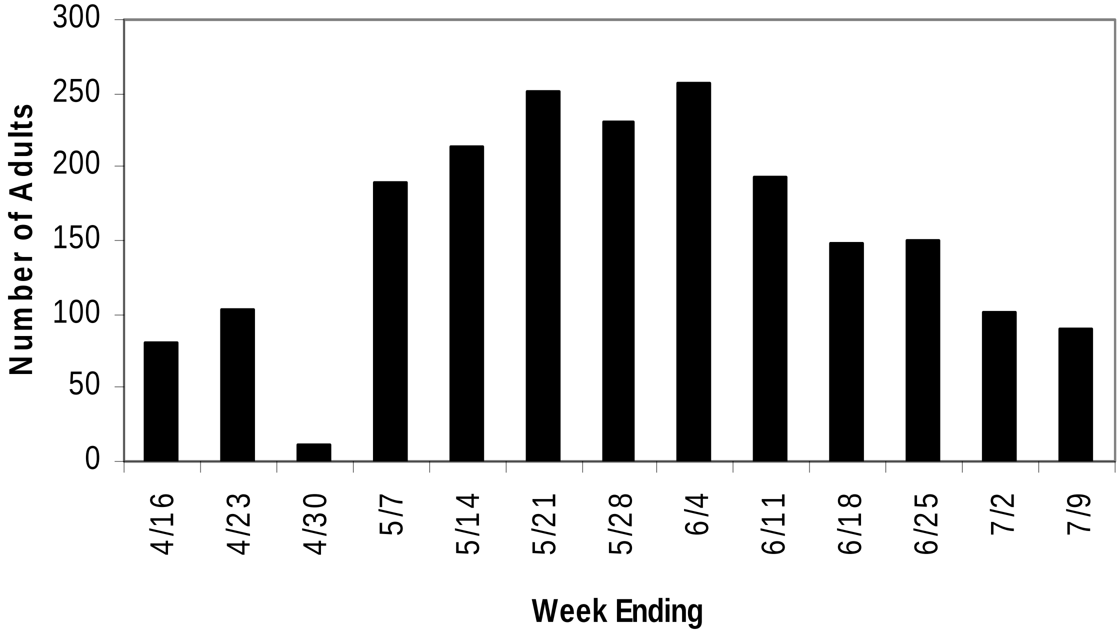

Figure 2. Visual estimate of the number of adult Caspian terns on the east Goose Island colony in 2005. Columns represent the maximum number of adults observed during each week. Estimate includes terns on breeding colony only. A major disturbance on 4/21 led to reduced counts; social attraction techniques restored the colony numbers after 4/30.

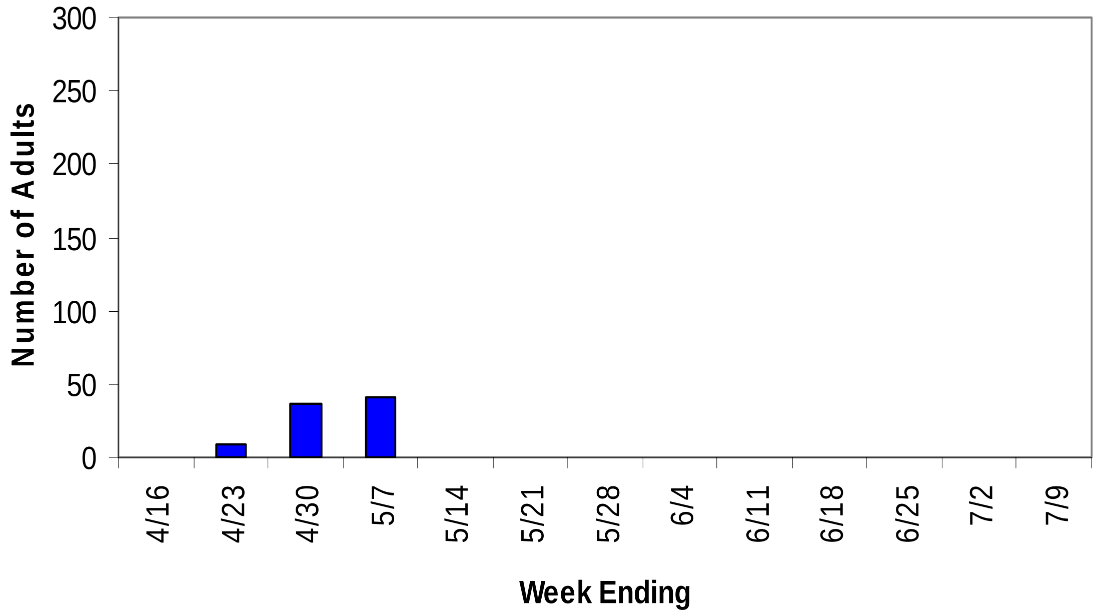

Figure 3. Visual estimate of the number of adult Caspian terns on the Solstice Island colony in 2005. Columns represent the maximum number of adults observed during each week. A major disturbance on Goose Island on 4/21 led to increased counts; after social attraction techniques were employed on Goose Island, Solstice Island was completely abandoned.

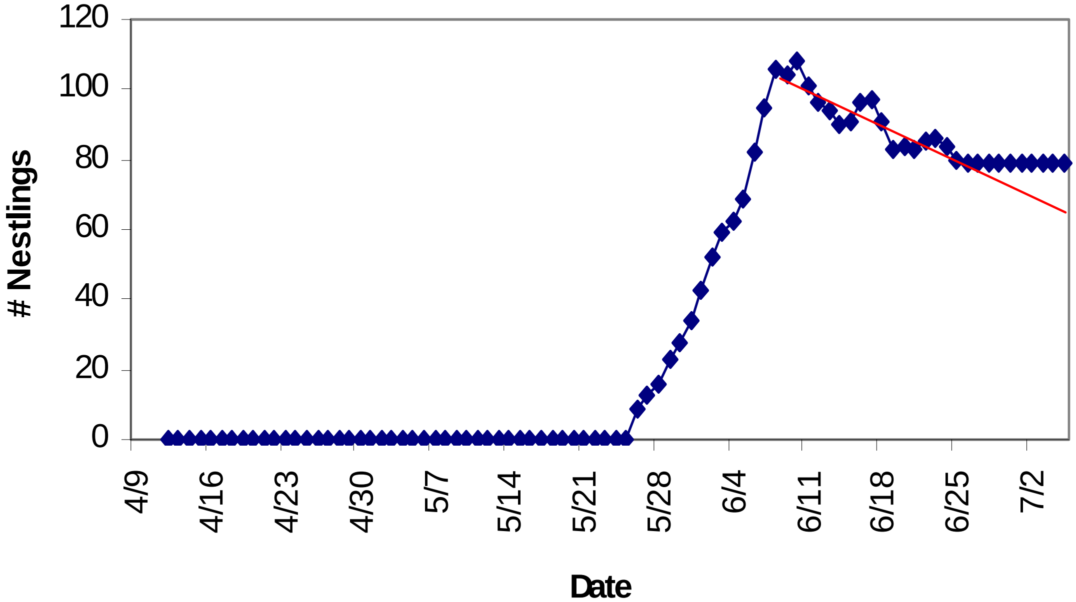

Figure 4. Numbers of Caspian Tern chicks on the east Goose Island colony estimated using individual nest records. The red line is the projected number of nestlings a live on a given day knowing that the total number of fledglings on 7/4/2005 is only 53. (Many chicks were wandering away from nests by 6/25/2005 which is why the blue line is flat beyond this date).

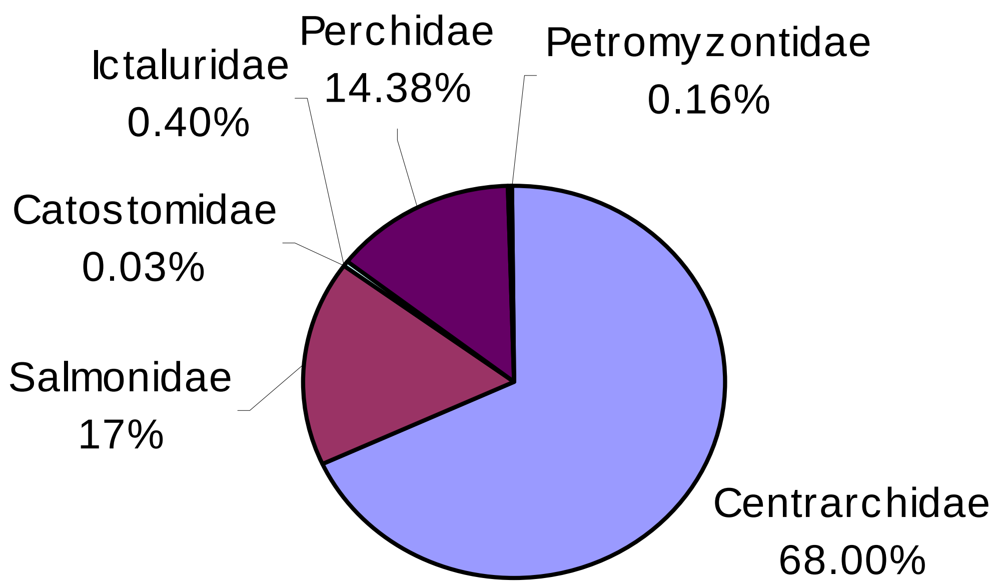

Figure 5. Observed bill-load composition of Caspian terns breeding on the east Goose Island colony in 2005.

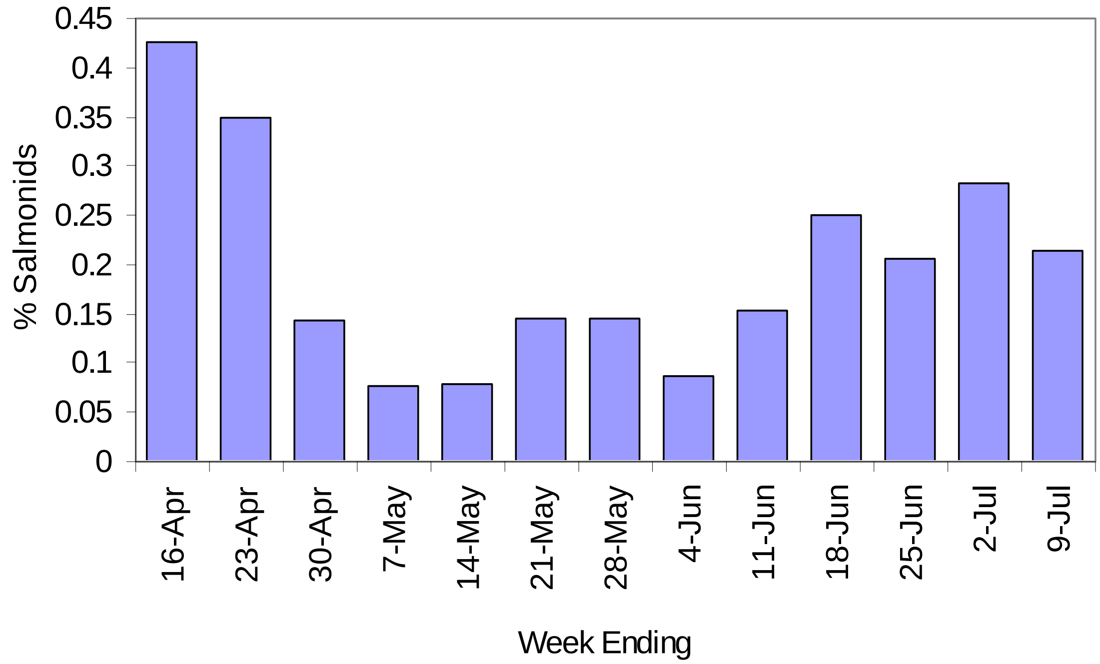

Figure 6. Percentage of juvenile salmonids observed in the diet of Caspian terns on the east Goose Island colony in 2005.

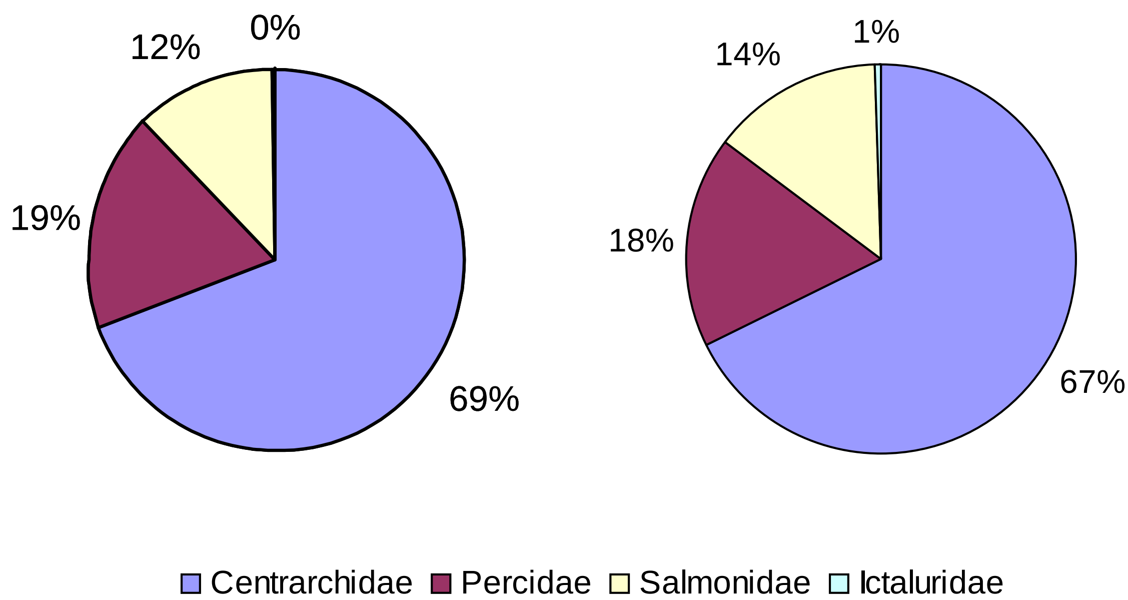

Figure 7. Prey types observed to be consumed by female and male Caspian Terns on the east Goose Island colony in 2005.

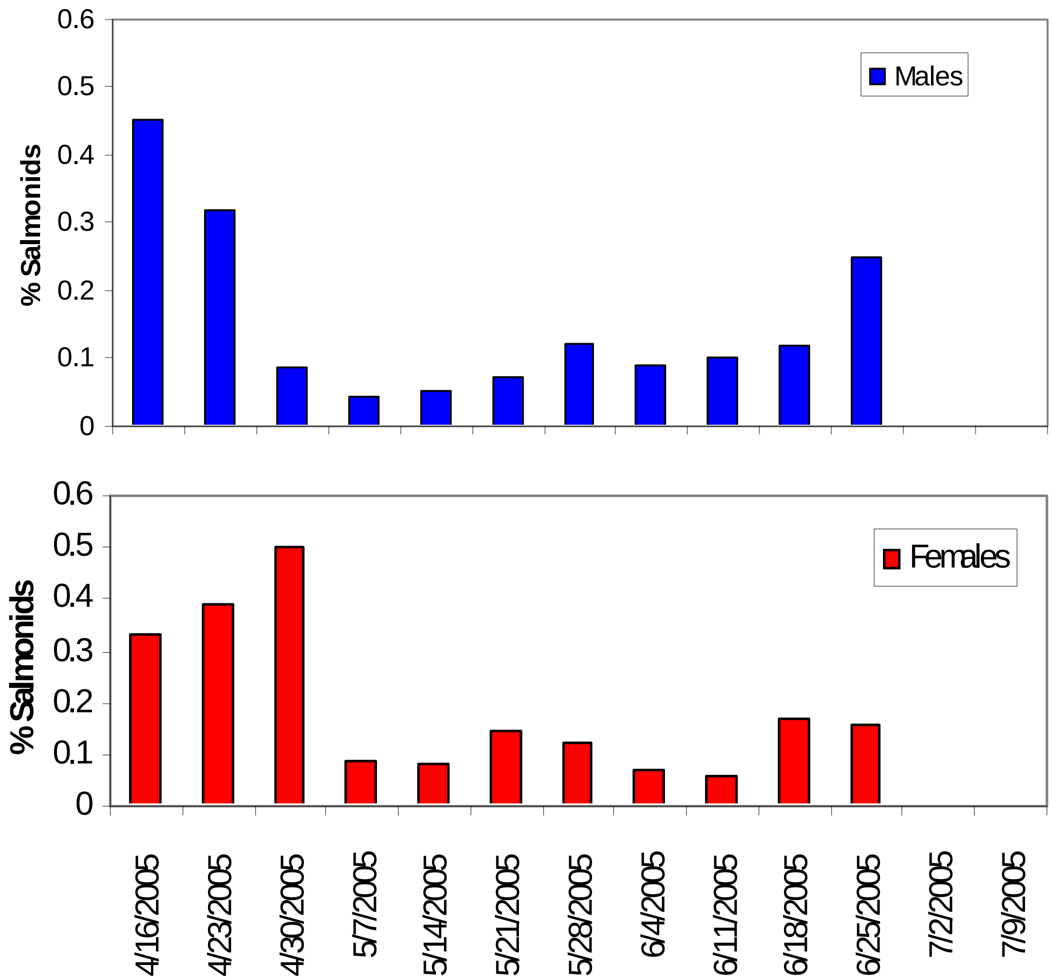

Figure 8. Weekly percentage of salmonids in diet of Caspian Terns on the east Goose Island colony in 2005.

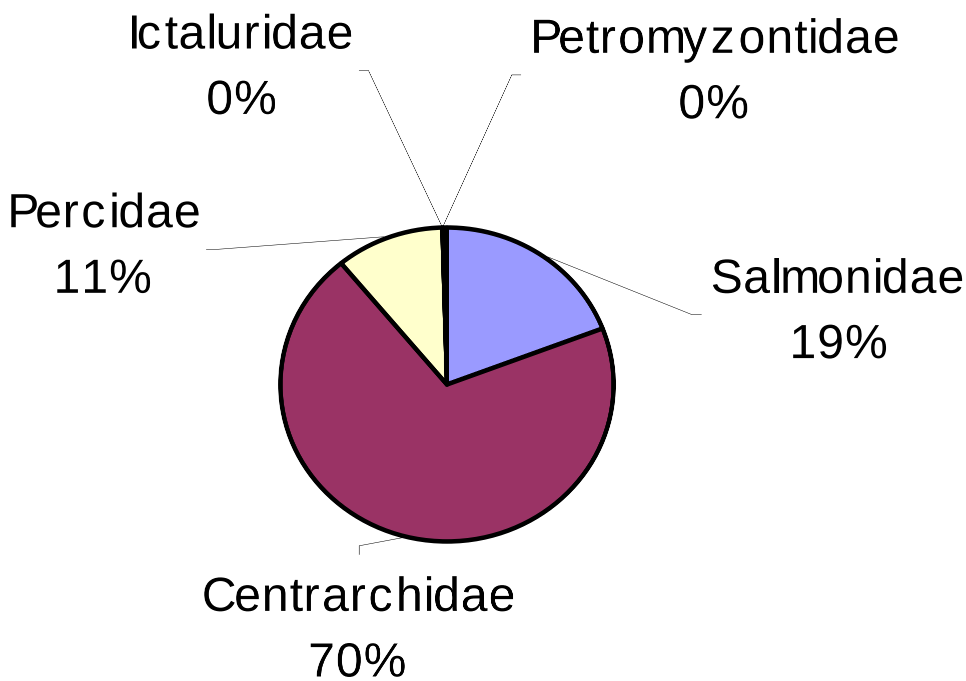

Figure 9. Diet composition of Caspian tern chicks on the east Goose Island colony in 2005.

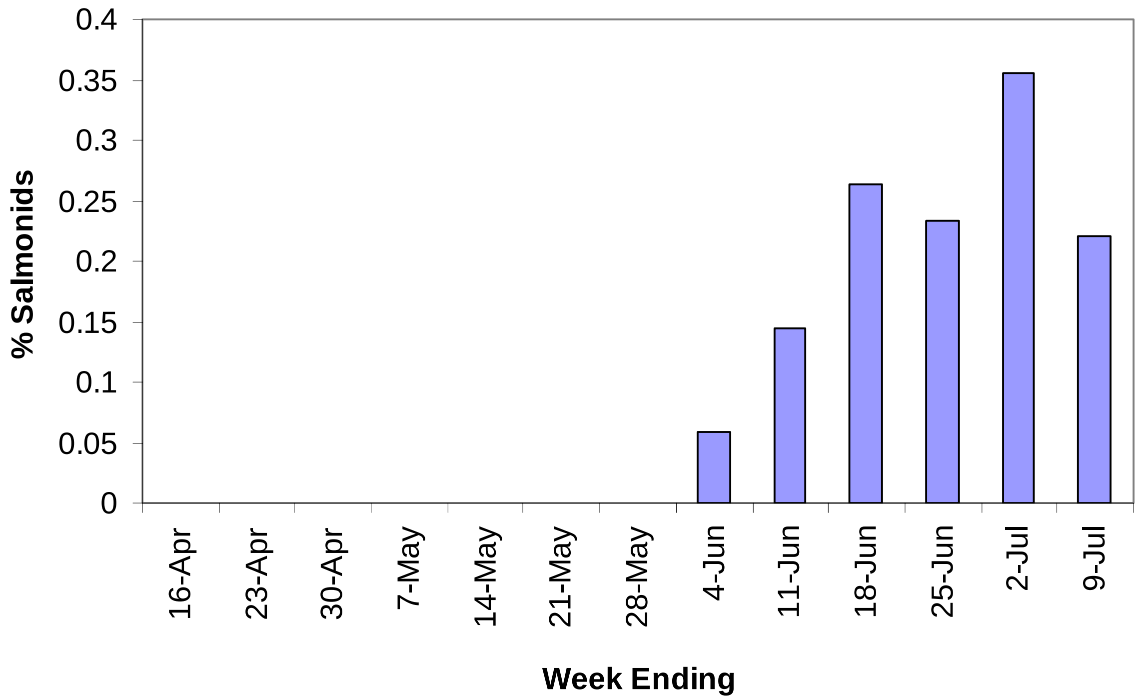

Figure 10. Weekly percentage of salmonids in diet of Caspian Tern chicks on the east Goose Island colony in 2005.

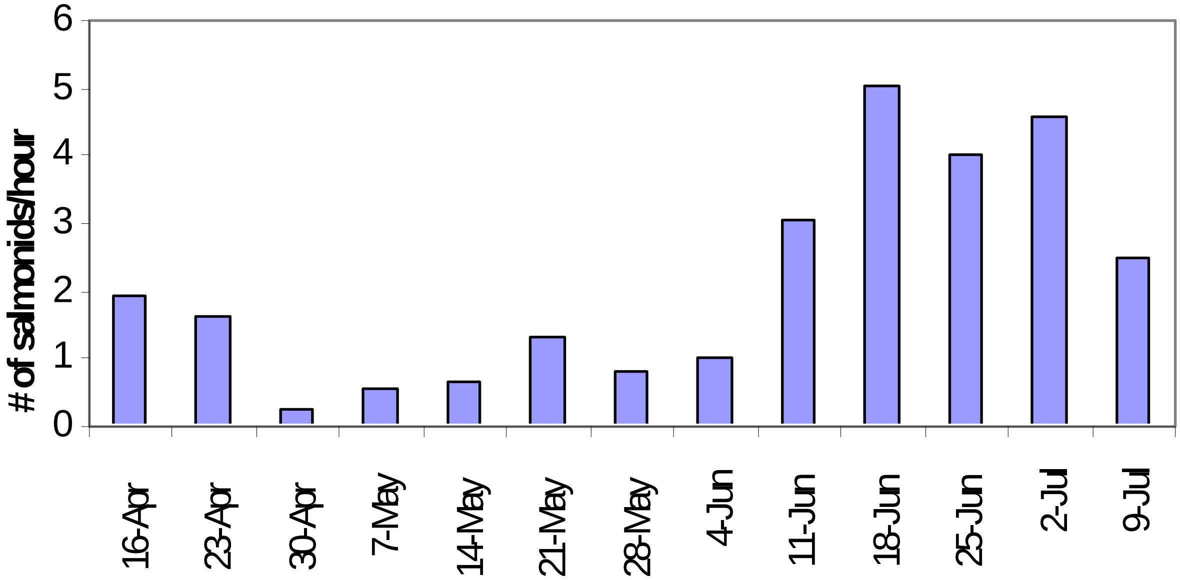

Figure 11. Weekly meal delivery rate (fish/hour) of all salmonid bill loads on the east Goose Island colony in 2005.

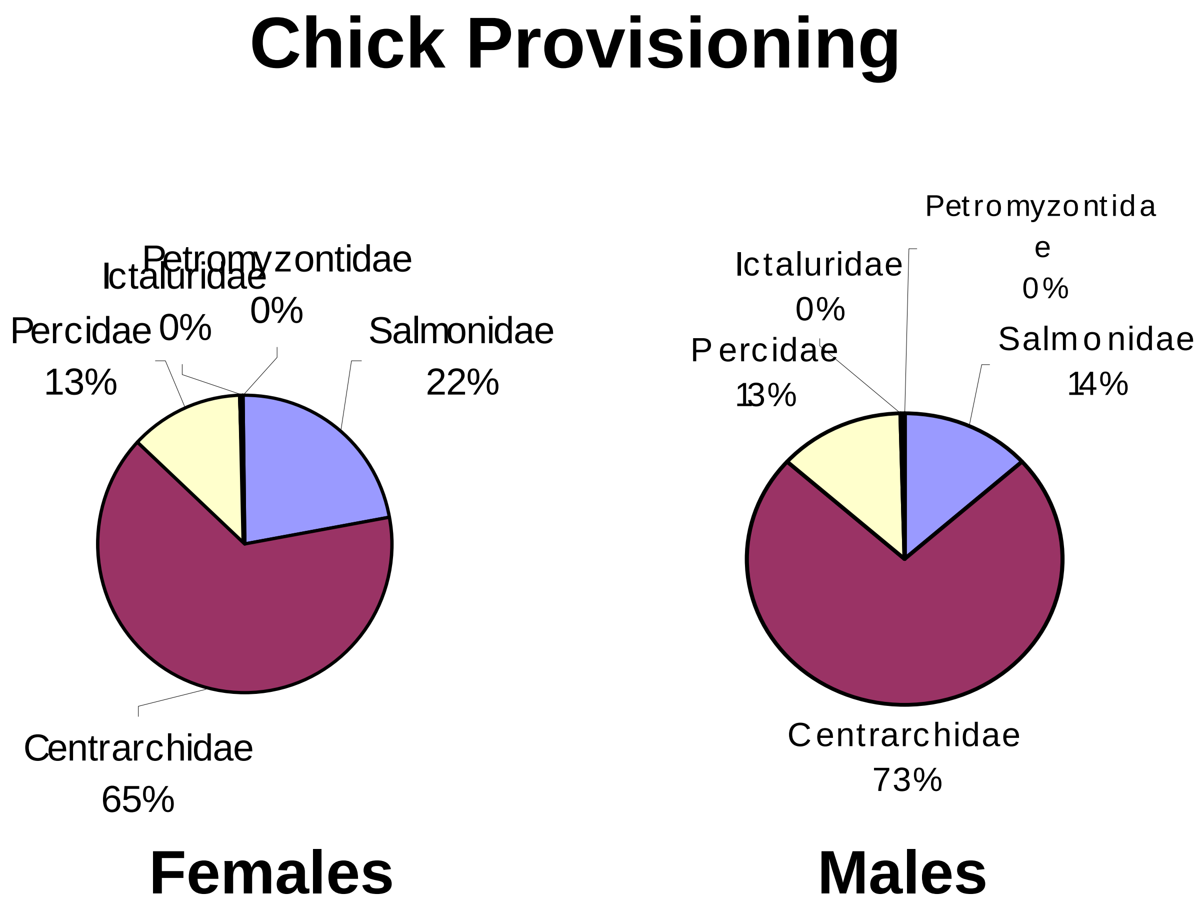

Figure 12. Comparison of chick provisioning by female and male Caspian Terns on the east Goose Island colony in 2005.

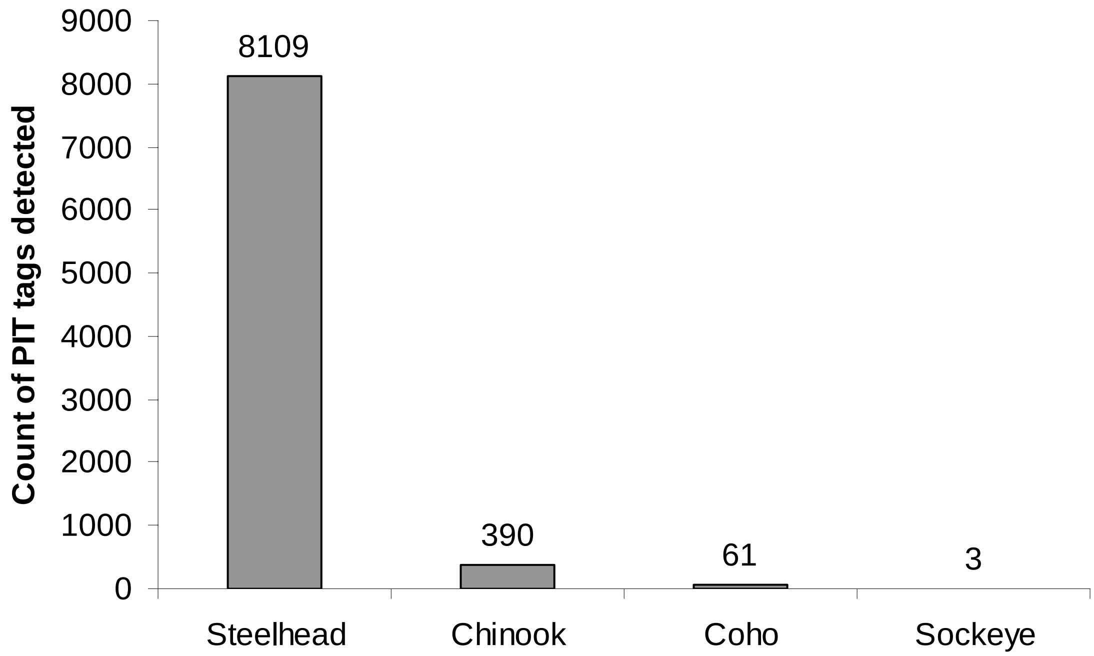

Figure 13. PIT tags detected on or recovered from the east Goose Island colony in 2005.

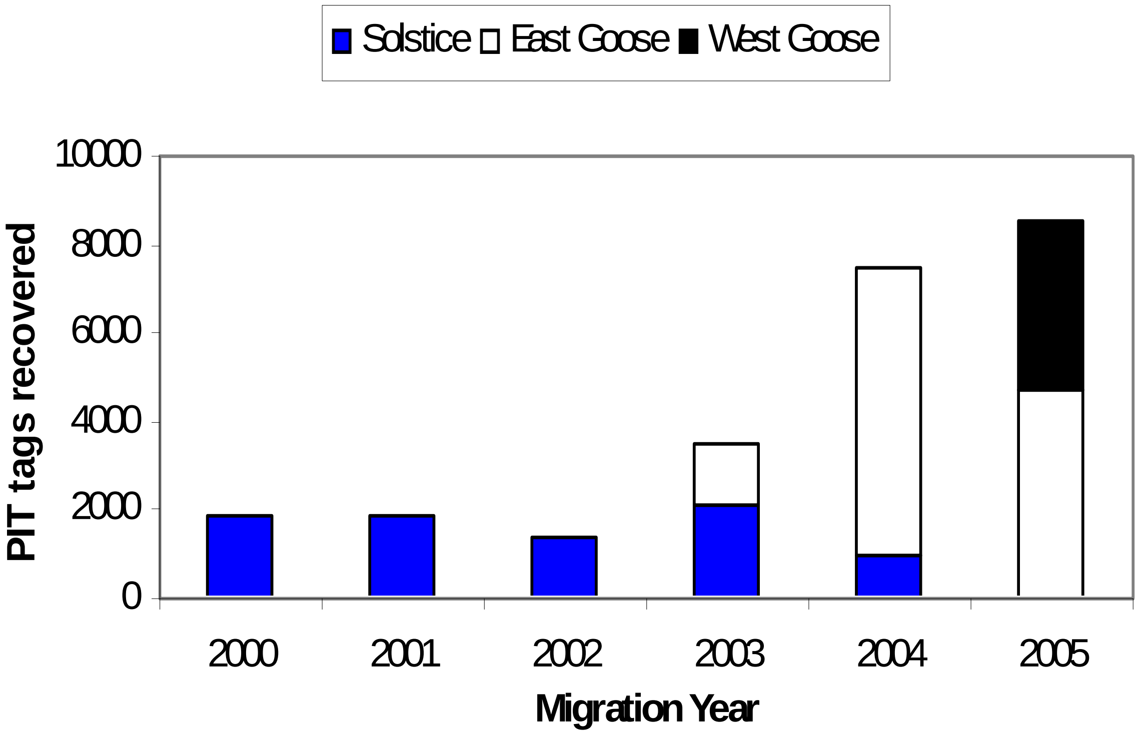

Figure 14. PIT tags detected on/recovered from colonies in the Potholes Reservoir since 2000.

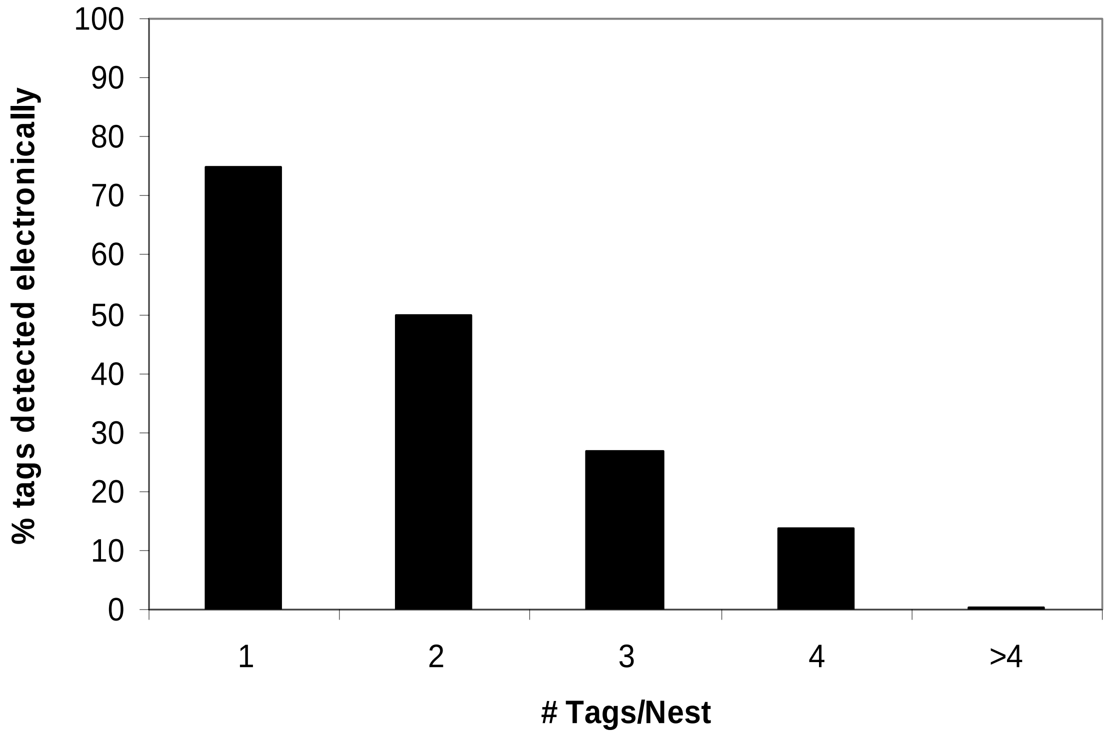

Figure 15. Percent detection of PIT tags in Caspian tern nest cups on the east Goose Island colony in 2005 (# tags detected electronically / total number of tags recovered from each nest cup).

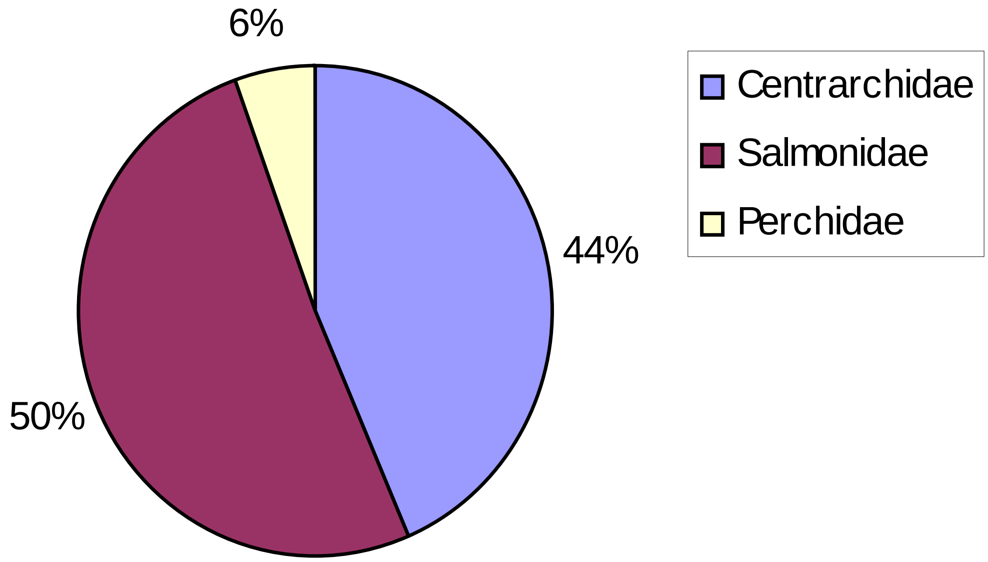

Figure 16. Composition of identified Caspian tern bill loads that were kleptoparasitized by gulls on the east Goose Island colony in 2005.

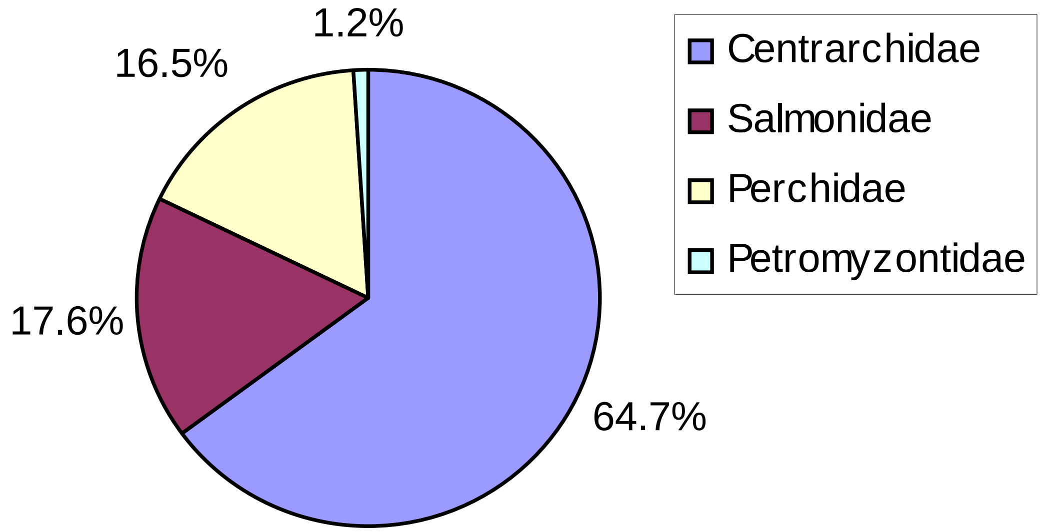

Figure 17. Composition of identified Caspian tern bill loads that were kleptoparasitized by other Caspian terns on the east Goose Island colony, 2005.

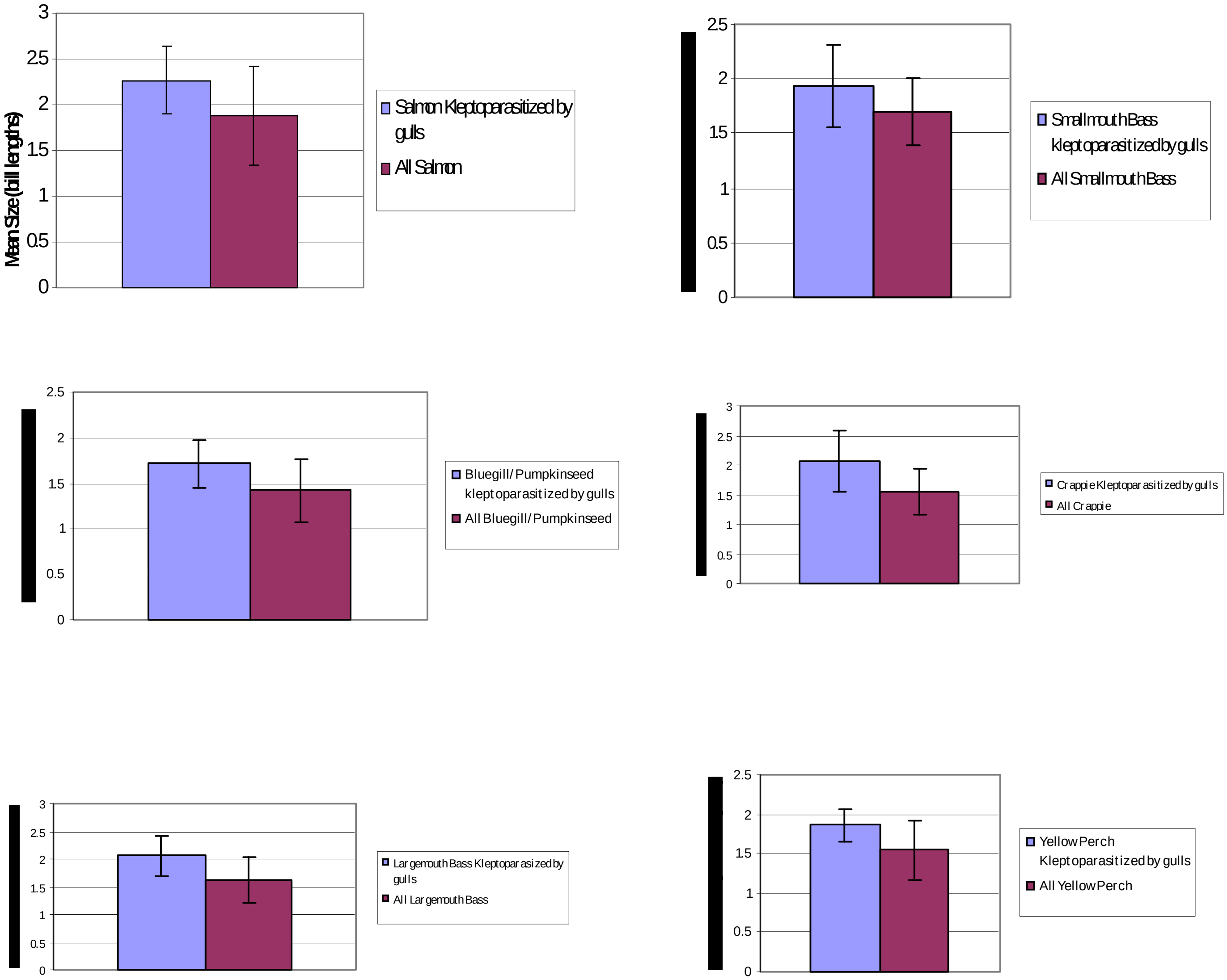

Figure 18. Size of fish kleptoparasitized by gulls as compared to all Caspian Tern bill loads on the east Goose Island colony in 2005 (error bars = 1 SD).