Piscivorous Waterbird Research on the Columbia River

FINAL 2004 Season Summary

Start-up Date: February 1, 1997

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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
and Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 97331-3803
Internet: daniel.roby@orst.edu
Telephone: 541-737-1955

Chris Couch, Garrett Dorsey, Karen Fischer, Donald E. Lyons
Anne Mary Myers, S. Kim Nelson, and Jessica Y. Adkins
USGS - Oregon Cooperative Fish and Wildlife Research Unit
and 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 Califonia 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 lower in the estuary on East Sand Island (river km 8), presumably due to the greater availability of marine forage fishes. These results indicated that avian predation on juvenile salmonids in the lower Columbia River is more prevalent in the estuary than near the large up-river gull colonies. 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 nearer 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 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, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America (Cuthbert and Wires 1999). Using bioenergetics modeling, it was estimated that in 1998 this tern colony consumed about 12.4 million juvenile salmonids (95% c.i. = 9.1–15.7 million), or 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 continued in 2004. In 2004 the estimated size of the Caspian tern colony on East Sand Island was approximately 9,500 nesting pairs. This represents about a 14% increase in the size of the colony compared to the 2003 breeding season. Nesting success at the East Sand Island colony remained high, with an average productivity of 0.92 young raised per breeding pair in 2004. During the 2004 breeding season, the diet of East Sand Island terns averaged 17% salmonids, the lowest proportion of salmonids in the diet so far recorded for this tern colony. Consumption of juvenile salmonids by the East Sand Island tern colony in 2004 was approximately 3.5 million smolts (95% c.i. = 2.9–4.0 million), ca. 9 million fewer smolts consumed compared to 1998, when all terns nested on Rice Island. The area of quality nesting habitat prepared for Caspian terns on East Sand Island (6.5 acres) and the area of habitat used by nesting terns (4.7 acres) were similar to the previous two years. Marine forage fishes were abundant in the Columbia River estuary and nesting success in 2004 was similar to 2002 and 2003, revealing no apparent incentive for Caspian terns to shift to alternative colony sites.

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) is now comparable to or greater than that of the East Sand Island tern colony. This is due largely to the greater size of the cormorant colony on East Sand Island and the greater food requirements of cormorants relative to terns. The double-crested cormorant colony on East Sand Island experienced high nesting success in 2004 (2.05 young/breeding pair), more than twice the nesting success experienced by the East Sand Island Caspian tern colony in 2004. This 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 only other known Caspian tern breeding colony on the lower Columbia River during 2004 was on Crescent Island, just below the confluence of the Snake and Columbia rivers. The tern colony on Crescent Island consisted of about 530 breeding pairs in 2004, similar in size to the previous year. Average nesting success of Caspian terns on Crescent Island in 2004 (0.62 young raised per breeding pair) was somewhat greater than in 2003 (0.55 young per breeding pair). The diet of Caspian terns nesting on Crescent Island in 2004 consisted of ca. 70% juvenile salmonids, similar to diets of Crescent Island terns during the 2000-2003 breeding seasons. An estimated 470,000 (95% c.i. = 370,000–570,000) juvenile salmonids were consumed by Caspian terns nesting on Crescent Island in 2004. Despite the much smaller numbers of salmonid smolts consumed annually by the Crescent Island tern colony compared to the tern and cormorant colonies on East Sand Island, predation rates on particular salmonid stocks were surprisingly high, particularly in low flow years. Preliminary results from 2004 suggest the predation rate by Crescent Island terns on Snake River steelhead smolts was 23%, based on the number of PIT-tagged smolts interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony and corrected for PIT tag collision and detection efficiencies on-colony. In-river steelhead smolts from the Snake River were more vulnerable to tern predation than in-river steelhead smolts from the Upper Columbia (4% of PIT-tagged smolts interrogated at Rock Island Dam were subsequently recovered on the Crescent Island tern colony, corrected for tag collision and detection efficiency). The high predation rate on in-river migrants from the Snake River was, however, offset by the transportation of most juvenile salmonids around the McNary Pool. Conversely, juvenile salmonids from the upper and mid-Columbia River (upstream of McNary Dam) were not transported past Crescent Island, resulting in a much larger proportion of those runs being susceptible to predation by Crescent Island terns. Predation rates on salmonids by Crescent Island terns are unlikely to increase appreciably over those observed in 2004 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.

In 2004, the largest colony of double-crested cormorants on the Mid-Columbia River consisted of ca. 300 pairs on Foundation Island, near Crescent Island, and the diet of Foundation Island cormorants during the chick-rearing period consisted of < 8% salmonids. The American white pelican colony on nearby Badger Island is also small (< 500 pairs) and, based on smolt PIT tag detections on the pelican colony by NOAA Fisheries, is not a source of significant smolt mortality.

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. Additionally, when compared to predation impacts 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 outmigration. Finally, juvenile salmonids from every listed stock from 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 on East Sand Island has the greatest potential to benefit Columbia River salmonid populations across the basin, when compared to potential management of other bird populations. One possible exception is the Caspian tern colony on Crescent Island, where tern management may benefit some stocks in some years (e.g., Upper Columbia River steelhead ESU, particularly in low flow years).

Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is imminent; the Final Environmental Impact Statement 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). Management options to reduce or cap smolt losses to the expanding double-crested cormorant colony have yet to be considered and will require additional research and NEPA analysis. Relocation of a portion of the cormorants nesting on East Sand Island to alternative sites outside the estuary may be an option. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) to relocate nesting cormorants showed some promise; cormorants were induced to nest at two sites on East Sand Island where they had not previously nested. 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.

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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 2002–2004 (see Map 1). In 2004, habitat improvement on the Caspian tern colony site on East Sand Island was accomplished by the U.S. Army Corps of Engineers during 1-5 April. Similar to the previous two 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 pioneer plants. Tern decoys (58) and an audio playback system were deployed near the newly-situated north blind to attract nesting terns to that part of the colony site. On 6 April, a camp was set up on East Sand Island and was continuously occupied by two colony monitors throughout the tern nesting 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 2004.

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 2004 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 2004.

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 2004 (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 at 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 2004, 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 2001–2003, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2004. We estimate that 9,502 breeding pairs (95% c.i. = 8,905–10,099 breeding pairs) attempted to nest at East Sand Island in 2004 (see Figure 1 for weekly counts from the ground of terns on the East Sand Island colony in 2004). This estimate is 14% greater than our estimate of colony size at East Sand Island in 2003 (8,325 breeding pairs, 95% c.i. = 7,837–8,812 breeding pairs). This increase in colony size at East Sand Island in 2004, as compared to the previous year, was likely due to recruitment into the breeding population by first year breeders fledged at East Sand Island 3 or 4 years ago.

We estimate that 8,741 fledglings (95% c.i. = 7,986–9,495 fledglings) were produced at the East Sand Island colony in 2004. This corresponds to nesting success of 0.92 young raised per breeding pair (95% c.i. = 0.82–1.02 fledglings/breeding pair), which was somewhat lower than the estimate of nesting success for the East Sand Island tern colony in 2003 (1.08 fledglings/breeding pair, 95% c.i. = 0.96–1.19 fledglings/breeding pair). Productivity at East Sand Island continues to be higher than was recorded at Rice Island both prior to and after management, and similar to other well-studied Caspian tern colonies along the Pacific Coast (Cuthbert and Wires 1999; see below).

On 13 April, Caspian terns (13) were observed loafing in upland areas on Pillar Rock Sands (a dredged material disposal island in the upper estuary; see Map 1). On 16 April, as many as 297 terns were seen on the upland area of Pillar Rocks Sands during low tide. This is significant because if the terns were just loafing near a foraging site they would likely use the beach during low tide. Other indications of their intention to nest on Pillar Rock Sands were courtship displays, exchange of courtship meals, copulations, and the digging of nest scrapes. Resource managers were informed of the situation and the USACE conducted continuous monitoring and hazing of terns in upland areas on Pillar Rock Sands from 17–21 April. Passive measures to dissuade terns from nesting on Pillar Rock Sands were also deployed (200 stakes fixed with brightly colored flagging and 6 eagle silhouettes). No terns were observed in upland sites on Pillar Rocks Sands following the continuous monitoring and hazing of terns by a USACE contractor, which was discontinued on 21 April.

A group of about 25 Caspian terns was observed on recent dredged material on Miller Sands Spit on 21 April (see Map 1). On subsequent trips to Miller Sands Spit on 23 April and 25 April, 17 and 0 terns were observed in upland areas, respectively. No terns were observed on Miller Sands Spit on subsequent visits, so continuous monitoring and hazing of terns in upland sites on Miller Sands Spit was not necessary to prevent terns from nesting there.

No other aggregations of terns were observed at other dredged material disposal areas in the upper estuary (e.g., Rice Island, Puget Island) in 2004.

1.2.2. Mid-Columbia River

Methods: The number of Caspian tern breeding pairs nesting at Crescent Island (see Map 2) was estimated by averaging six independent ground counts of incubating terns near the end of the incubation period. Nesting success was estimated from ground counts of all fledglings on the colony just prior to fledging.

Periodic boat-surveys of the historic tern colony sites at Three Mile Canyon Island and Miller Rocks were also conducted in 2004.

Caspian tern colonies in Potholes Reservoir (Solstice and Goose islands; Map 2) were occasionally visited to determine status of the colonies. Counts of the number of adult and young terns were conducted at each colony site during each visit.

Results and Discussion: A total of 530 breeding pairs attempted to nest at the Crescent Island tern colony in 2004 (see Figure 2 for weekly counts of terns on the Crescent Island colony in 2004), about 4% more pairs than in 2003. We estimated that 329 young were fledged from that colony in 2004, or 0.62 young raised per breeding pair, higher nesting success than in 2003.

Caspian terns did not attempt to nest at either Three Mile Canyon Island or Miller Rocks in 2004 (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.

Terns nesting on Solstice Island in Potholes Reservoir failed prior to fledging any young in 2004. Flooding of the colony and potentially nest predation by herons were the apparent causes of breeding failure (C. Moranto, University of Washington, pers. comm.). At Goose Island, ca. 200 pairs of terns nested in 2004. It was not possible to precisely estimate productivity due to colony asynchrony; however, based on observations made on 1 July, at least 50 young were fledged from Goose Island in 2004.

1.2.3. Coastal Washington

Methods: Aerial surveys along the southern Washington Coast, including 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 2004 breeding season, no nesting attempts by terns were detected in either area in 2004. 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 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 for the two-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. P. Bently of NOAA Fisheries 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, 17% were juvenile salmonids (n = 5,854 bill loads). As in previous years, marine forage fishes (i.e., Pacific herring [*Clupea pallasi*], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae] were prevalent (75% 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. 37% during the first and second weeks of May (Figure 4), approximately the same time as in the previous year. We estimated that Caspian terns nesting on East Sand Island consumed 3.5 million juvenile salmonids in 2004 (95% c.i. = 2.9–4.0 million), a ca. 17% reduction in smolt consumption compared to 2003 (best estimate = 4.2 million, 95% c.i. = 3.5–4.8 million). Of all the juvenile salmonids consumed, we estimate that 42% were coho salmon (best estimate = 1.5 million, 95% c.i. = 1.2–1.7 million), 24% were yearling chinook salmon (best estimate = 0.8 million, 95% c.i. = 0.7–1.0 million), 18% were sub-yearling chinook salmon (best estimate = 0.6 million, 95% c.i. = 0.5–0.8 million), and 15% were steelhead (best estimate = 0.5 million, 95% c.i. = 0.4–0.6 million).

1.3.2. Mid-Columbia River

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 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 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 two-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. [in press] for a detailed description of model construction and input variables). For the purposes of the bioenergetic modeling, the species composition of salmonids consumed (steelhead vs. other salmonids) in 2004 was assumed to be similar to that observed in 2001 (Antolos et al. in press.). 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 (70% of identifiable bill loads), followed by centrarchids (bass and sunfish, 20%) and cyprinids (carp and minnows, 8%; n = 2,129 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 2004. The salmonid portion of the diet peaked at about 80% of prey items in mid-April, early May, and again in mid-July (Figure 6). These changes in diet composition probably reflected changes in availability of hatchery-reared juvenile salmonids near the colony in mid-April and early May, and the out-migration of sub-yearling chinook salmon in mid-July. We estimated that Caspian terns nesting on Crescent Island consumed 470,000 juvenile salmonids in 2004 (95% c.i. = 370,000–570,000), a ca. 7% increase in smolt consumption compared to 2003 (best estimate = 440,000, 95% c.i. = 340,000–540,000; Figure 7). Per capita smolt consumption in 2004 (887 smolts nesting tern^{-1} breeding season^{-1}) was similar to the previous year (864 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 their tags are subsequently deposited on breeding 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 salmonid populations listed under the Endangered Species Act (ESA) (Collis et al. 2001; Ryan et al. 2003; Antolos et al., in press), and these data can be used to assess the relative vulnerability of various salmonid species, stocks, and rearing types to avian predation.

Previous predation rate estimates based on PIT tag recoveries are considered minimums because not all tags consumed by birds are detected and/or deposited on the breeding colony. In 2004, we worked collaboratively with NOAA Fisheries (the agency responsible for on-colony PIT tag recoveries) to generate more accurate and defensible estimates of predation rates 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 reduce the PIT tag detection efficiency at that site; (2) systematically spreading PIT tags with known PIT tag codes on the East Sand Island and Crescent Island tern colonies in order to directly measure PIT tag detection efficiencies; and (3) conducting experiments to measure on-colony deposition rates of ingested PIT tags. These data are preliminary and, once confirmed by additional data collection, will be used to correct the previously reported PIT tag recovery rates to account for the detection efficiency and deposition rate of these tags on bird colonies, thereby generating more accurate estimates of predation rates based on PIT tags.

1.4.1. PIT Tag Collision

Methods: Smolt 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 detections (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 during 25–27 March 2004 (prior to the birds' arrival at the colony) and again during 17–19 August 2004 (after all the birds had left the colony and after NOAA Fisheries scanned the colony for PIT tags). 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 laid out 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 determine tag functionality and all tag codes were noted. To determine PIT tag collision rates, the number of unique codes from tags removed by hand was then compared to the number of unique tag codes detected by NOAA Fisheries using electronics.

Results and Discussion: In total, we physically removed 31,903 PIT tags that were intact or nearly intact from the Crescent Island tern colony in 2004 (Table 2). This number represents a minimum value because many of the tags removed by hand from Crescent Island, especially those removed in March, were too fragmented/damaged to count (i.e., not intact). Of the 31,903 tags removed by hand, 24,931 (78.1%) were still functional or readable (Table 2). Of the functional tags, 8,609 (34.5%) were tags not previously detected by NOAA Fisheries (Table 2). Not surprisingly, hand removal efforts were much more productive in August (19 days after the end of the 2004 nesting season) relative to March (242 days after the end of the 2003 nesting season); 76.5% of the 24,931 functional tags were recovered in August. The proportion of recovered tags not previously detected by NOAA Fisheries increased from just 4.0% in March to 36.8% in August. In addition to recovering PIT tags, other fish tags were also recovered from the Crescent Island tern colony. In March, we recovered 35 radio tags and 7 floy tags and in August we recovered 210 radio tags and 2 floy tags.

Using electronic receivers, NOAA Fisheries detected 17,100 and 21,518 PIT tags following the tern nesting seasons in 2003 and 2004, respectively. Including all tags either detected by scanners or removed by hand, a total of 17,688 and 29,438 unique tags were detected on the Crescent Island tern colony following the 2003 and 2004 nesting seasons, respectively. A comparison[1] between electronic detection and hand removal indicated that both methods missed a large number of tags, with electronic detectors missing at least 7,921 tags and hand removal efforts missing at least 10,361 tags. Overall missed detections were calculated to be 54% for the hand removal method and 37% for the electronic method. Electronic missed detections were likely the result of tag signals colliding, a phenomenon that was much more prevalent in August due to the greater density of functional tags on the surface of the tern colony. Tags missed by hand removal were likely tags that had been damaged on the colony prior to removal, or tags that were simply missed by researchers, and/or from electronic scanning in areas not

[1] A direct comparison between the two methods was not available because NOAA scanned an area slightly larger than that of the hand removal area and because an unknown number of tags were damaged during the electronic scanning process.

covered by hand removal efforts. Non-functional tags were likely damaged by foot/vehicle traffic on the colony during NOAA Fisheries' electronic detection efforts, during hand removal efforts, or by other factors (e.g., storms or researchers conducting experiments on the colony during the nesting season). Lastly, not all of the tags removed in a given year were from that years' smolt migration. For example, of 29,438 tags removed in August, 21,418 (72.8%) were from 2004 migration year smolts and the remainder were from smolts released in previous migration years or tags used in experiments described elsewhere in this report (see below).

The hand removal of PIT tags from the Crescent Island tern colony greatly increased the number of PIT tag codes recovered from the colony by decreasing PIT tag collision. Overall, hand removal of tags increased the number of unique PIT tag codes recovered from the colony by 30.2%.

1.4.2. Detection Efficiency

Methods: Not all PIT tags that are egested by Caspian terns on their nesting colony are subsequently detected by NOAA Fisheries after the nesting season. In years past, this detection efficiency was estimated by distributing by hand a known number of PIT tags on-colony prior to the tern 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 procedure, NOAA Fisheries estimated detection rates 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 are assumed to be underestimates, however, because tags placed on the colony before the nesting season are potentially subject to higher rates of loss and damage compared to PIT tags deposited on the colony later in the season. Hence, the systematic sowing of PIT tags on multiple occasions throughout the tern nesting season – as opposed to a single release prior to the nesting season – should result in a more accurate and defensible estimate of PIT tag detection efficiency.

In 2004, we intentionally spread 961 PIT tags on four discrete plots on the Crescent Island tern colony during four different time periods (i.e., prior to the birds' arrival on the colony [26 March], during incubation [10 May], during fledging [3 July], and following the nesting season and after the birds had left the colony [29 July]). Each plot measured 4 x 10 m and plots were located roughly in the center of the colony nesting area. To account for the different types of PIT tags used in the Columbia River Basin, we spread equal numbers of ST tags (otherwise known as "super tags"; n = 481) and BE tags (standard tags; n = 480). Detection efficiency estimates were then analyzed relative to the release date and the release plot, thereby describing both temporal and spatial variation.

At East Sand Island, we conducted a similar PIT tag detection efficiency evaluation. In 2004, we intentionally spread 1,018 PIT tags on the East Sand Island tern colony during three discrete time periods (i.e., early adult arrival [4 April], during incubation [19 May], and during fledging [7 July]). Unlike Crescent Island, tags were not spread on discrete plots, but instead dispersed throughout the colony nesting area. Approximately equal numbers of super tags (n = 519) and standard tags (n = 499) were spread on-colony.

Results and Discussion: Of the 961 test tags spread on Crescent Island, 771 (80.2%) were subsequently recovered on-colony (Table 3). There was not a significant difference in detection rate between the higher-read-range ST tags (81.5%) and the lower-read-range BE tags (79.0%). Detection efficiency for all tag types ranged from a low of 58.3% for the pre-season tag release group to a high of 99.0% for the post-season tag release group.

There was a positive association between test tag release date and detection efficiency ($R^2 = 0.81$, $P < 0.001$), with those tags released later in the nesting season more likely to be recovered than tags released earlier in the nesting season. Detection efficiency increased an average of 0.32% per day throughout the 125-day nesting season (95% c.i. = 0.22–0.39%). These results suggest that tags from fish captured early in the season are less likely to be recovered on-colony as compared to tags from later migrating smolts. Therefore, previously reported predation rates may underestimate impacts to early migrant smolts relative to late migrant smolts. These results suggest that predation rates derived from PIT tag data should be corrected for temporal differences in detection efficiency on Crescent Island.

Detection efficiency for the pre-season release group was 58.3% in 2004, higher than comparable data in 2002 (15%) and 2003 (45%). We believe the higher detection efficiency for tags in the 2004 pre-season release group relative to 2003 and 2002 was a result of our hand removal of tags prior to the 2004 nesting season, which reduced tag collision. Basing the calculation of overall detection efficiency on multiple releases of test tags throughout the nesting season further increased the estimated detection efficiency over estimates from previous years.

Of the 1,018 test tags spread on East Sand Island, 956 (93.9%) were subsequently recovered on-colony. Detection efficiency ranged from 97.0% for the early adult arrival release group to 86.3% for the incubation period release group. Similar to Crescent Island, there was no significant difference in recovery rate between ST tags (93.1%) and BE tags (94.8%). Unlike Crescent Island, however, there was no evidence that detection efficiency increased as a function of time ($R^2 = 0.14$, $P = 0.77$). An overall detection efficiency rate of 94% on East Sand Island in 2004 suggests that tag collision was minimal and that hand removal, if implemented, would have yielded few additional tag recoveries over those detected using electronics.

<u>1.4.3. Deposition Rates</u>

Methods: Not all PIT tags consumed by terns are deposited on-colony. It is likely that some proportion of the consumed PIT tags is egested by terns during flight or at off-colony loafing areas. Therefore, predation rate estimates based on on-colony PIT tag recoveries are minimums, but to an unknown extent. We conducted two experiments to measure on-colony deposition rates of PIT tags ingested by terns nesting on Crescent Island. First, we tested the feasibility of allowing terns to forage on PIT-tagged fish confined to a net pen and then scanned for those tag codes at the colony following the nesting season. Similarly, we captured nesting terns on colony and force-fed those birds with fish containing PIT tags and scanned for those tag codes following the breeding season. Results from these experiments, once replicated will be used to adjust estimates of predation rates based on PIT tag recoveries to account for tags consumed but not deposited on-colony.

The net pen, a circular pen 6 meters in diameter, was anchored in Burbank Slough, a backwater slough off the Columbia River located 11 kilometers northeast of Crescent Island; see Map 3). On 23 April, a total of 1,069 juvenile rainbow trout (*O. mykiss*) of two different size classes (small: 11.7 cm, SD = 0.94, n = 563; large: 19.5 cm, SD = 1.60, n = 506) were PIT-tagged and placed in the 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 pen and the surrounding slough 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 success (i.e., number of fish captured, size class of fish captured) from 23 April to 3 June. The net pen was covered with nylon mesh when observers were not present to prevent terns from foraging. The number of fish removed from the net pen was then recorded throughout the 42-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 rate (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 (DE) for the PIT tags from fish captured at the net pen was calculated by dividing the number of tags recovered (R) on the Crescent Island tern colony by the total number of net pen fish captured (C) by adult terns.

Deposition rates were also estimated by force-feeding PIT-tagged fish to adult terns that were nesting on Crescent Island and East Sand Island. Breeding adult terns at both colonies were captured near the peak of incubation (10 May and 18–19 May at Crescent Island and East Sand Island, respectively) by placing noose mats around active nests. Following capture, adult terns were force-fed juvenile rainbow trout containing PIT tags by opening the tern’s bill and gentle massaging the fish down the esophagus. Force-fed trout were semi-frozen when force-fed, and each fish contained 1–3 PIT tags. Adult terns used in the experiment were also weighed, measured, and individually marked with colored leg bands. Following force-feeding, each bird was retained for approximately 5 minutes (to ensure the PIT-tagged fish was ingested), marked with Rhodamine dye on the breast (for easy on-colony identification), and released. Following release, the presence/absence of each marked bird and the bird’s post-release behavior (i.e., nest attendance) was observed from a blind until nightfall or until all of the force-fed birds had returned to the colony. A deposition rate of force-fed fish was then calculated by dividing the number of force-fed tags recovered on the Crescent Island and East Sand Island tern colonies by the total number of tags force-fed and retained until release by adult terns at each colony.

Results and Discussion: Terns began foraging on fish held in the net pen 3 days after stocking the pen with PIT-tagged trout. During the 42-day study period, a total of 94 PIT-tagged trout were removed from the net pen by Caspian terns during 207 attempts (plunge dives into the net pen). On average, successful foraging bouts lasted for 2 min, 46 sec (ranging from 18 sec to over 11 min), with a success rate of 0.45 fish per attempt. Of the 94 fish removed, 50 were immediately consumed and 44 were observed in the tern's bill as it flew back toward the Crescent Island colony. In total, 35 large trout and 59 small trout were removed by Caspian terns. No significant difference in foraging preference between small and large trout was observed throughout the nesting period ($P = 0.08$, Chi-square test). The frequency of trout captures increased dramatically during the latter half of the study period (13 May–3 June), with 86.2% of the captured fish removed during the last 21 days of the study. Interestingly, this time period coincided with the emergence of chicks on Crescent Island, with the first chick observed on-colony on 10 May. Of the 94 PIT-tagged trout captured (C) from the net pen by Caspian terns, 45 were recovered (R) on the Crescent Island tern colony. The estimated deposition rate (DR) for the net pen fish, after accounting for PIT tag retention (*ca.* 96.9%) and on-colony detection efficiency (*ca.* 76.0%; based on interpolated regression values) was 64.8%. Based on these results, we estimate that 35.2% of the ingested PIT tags from net pen trout were egested off-colony.

Twenty-eight adult terns from Crescent Island were captured and subsequently force-fed PIT-tagged trout. Of the 28 terns, 26 (93%) successfully ingested the fish, and the majority of these (24 or 92%) returned to the colony to resume breeding behaviors 1-6 hours post-release. Two of the 28 terns used in the experiment (7%) already had PIT tags in their digestive track at the time of capture (i.e., from a PIT-tagged salmonid naturally ingested prior to capture). The capture and handling of terns at Crescent Island did result in some tern egg loss. In total, 17 eggs were lost during this research activity, the majority due to predation by California gulls. No adult terns, however, were injured during this experiment and all of the captured terns were repeatedly resighted on the colony throughout the nesting season.

Each of the 24 force-fed terns that were observed post-release on the colony at Crescent Island received a fish containing two PIT tags ($n = 48$ PIT tags). Two of these terns had an additional PIT tag from a naturally consumed fish, making the total number of ingested PIT tags equal to 50. In total, 8 of the 24 successfully force-fed terns (33%) deposited at least one PIT tag on-colony. On-colony detection efficiency (DE) was estimated to be 81.8% during this time period, based on test tags ($n = 240$) released on-colony that same day. There was no evidence that those terns observed on-colony 1 to 3 hrs post-release deposited a larger proportion of tags relative to terns arriving on-colony 4 to 6 hrs post-release ($P = 0.68$, Fisher's Exact test), although sample sizes for this comparison were small. A deposition rate (DR) of 41.7% was estimated for Crescent Island force-fed terns, based on an on-colony DE of 81.8%.

Thirty terns from East Sand Island were captured for force-feeding experiments. Of the 30 terns that were force-fed fish at East Sand Island, 26 terns (87%) successfully ingested the fish and all 26 returned to the colony within 1-6 hrs post-release. Similar to terns from Crescent Island, two of the 30 terns used in the experiment (7%) had PIT tags in their digestive tract at the time of capture. A total of 6 tern eggs were lost as a result of this research activity on East Sand Island. A total of five tern chicks wandered from their nests at East Sand Island when traps were being attended to; it is likely that at least some of these chicks suffered mortality due to exposure or aggression by neighboring adult terns. 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.

Each of the 26 force-fed terns observed on colony post-release at East Sand Island received a fish containing two or three PIT tags (n = 68 PIT tags). Two of these terns had an additional PIT tag from a naturally consumed fish, for at total of 70 ingested PIT tags. In total, 21 of the 26 successfully force-fed terns deposited at least one PIT tag on-colony. On-colony detection efficiency was estimated to be 86.3% (DE) based on test tags (n = 199) released on colony that same day. Similar to Crescent Island, there was no evidence that a tern's post-release return time to the colony was associated with a higher deposition rate ($P = 0.43$, Fisher's Exact test), although terns from East Sand Island returned at a higher rate (*ca.* 88% return rate within 1 hr post-release) relative to terns from Crescent Island (*ca.* 38% return rate within 1 hr post-release). An overall deposition rate (DR) of 92.3% was estimated for the East Sand Island force-fed terns based on a DE of 86.3%.

The large discrepancy between PIT tag deposition rates on the East Sand Island and Crescent Island tern colonies could be the result of several factors: (1) the capture and handling process may have been more disruptive on Crescent Island relative to East Sand Island, (2) detection efficiency on Crescent Island may have been lower than suggested by recovery of test tags, and/or (3) adult colony attendance may have differed between the two tern colonies, with Crescent Island terns spending a larger proportion of time off-colony. There was evidence that the capture and handling of terns on the Crescent Island colony was more disruptive relative to the East Sand Island colony, as Crescent Island terns returned to the colony at a lower rate and egg predation was higher on Crescent Island relative to East Sand Island. Secondly, the hard and compacted substrate at the Crescent Island colony results in lower DE rates relative to East Sand Island; however, there is no evidence to suggest DE was lower than the value derived from the test tags. Finally, the hypothesis that colony attendance differs between the East Sand Island and Crescent Island tern colonies requires more research. It is likely, however, that food is less available in the mid-Columbia River compared to the estuary, and Crescent Island terns would be expected to spend more time foraging off-colony, thereby depositing a smaller proportion of ingested PIT tags on-colony compared to terns nesting on East Sand Island.

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. These analyses are ongoing and we will briefly present preliminary information for Crescent Island terns here. These data will be analyzed in more depth in NOAA Fisheries' Annual Reports and in peer-reviewed journal publications that we are currently working on with NOAA Fisheries.

For the analysis presented here, we queried the regional PIT tag database[2] (PTAGIS) 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 mid- and upper Columbia River Basin in 2004. We measured predation rates on different salmonid stocks and in particular ESA-listed stocks. In total, NOAA Fisheries has identified 7 endangered or threatened salmonid ESU's upstream of the Crescent Island tern colony: (1) Snake River steelhead (SR sthd), (2) Snake River spring/summer chinook (SR S/S chin), (3) Snake River fall chinook (SR F chin), (4) Snake River sockeye (SR sock), (5) Upper Columbia River steelhead (UCR sthd), (6) Upper Columbia River spring chinook (UCR S chin), and (7) Middle Columbia River steelhead (MCR sthd). Furthermore, for each of these ESU's there are numerous spawning stocks/populations (based on NOAA Fisheries designations; NOAA Fisheries 2004) and we calculated predation rates on each of these separately. ESU-specific predation rates were based on the proportion of PIT-tagged fish released in-river (i.e., not transported from dams upriver of Crescent Island) from each ESU that ended up on the Crescent Island tern colony in 2004. These estimates of ESU-specific predation rates do not account for in-river mortality that took place between the release site and the McNary pool (reservoir in which Crescent Island is located) and as such do not measure predation rates on just those smolts available to terns nesting on Crescent Island.

A more direct or reach-specific measure of tern predation was calculated by limiting the analysis to actively migrating smolts that were last detected and/or released within the general foraging range of Crescent Island terns. This was done by calculating a predation rate for PIT-tagged smolts interrogated/tagged at Lower Monumental Dam[3] (located on the Snake River, 80 Rkm above Crescent Island), Rock Island Dam[3] (located on the Upper Columbia River; 210 Rkm above Crescent Island), and from release groups of PIT-tagged smolts from the Middle Columbia River upstream of McNary dam (located on the Columbia River, 39 Rkm below Crescent Island). Only smolts tagged/interrogated during the tern's 2004 nesting season (26 March–28 July) were included in our analysis. These reach-specific estimates, however, are still minimums because they do not account for in-river mortality of the fish accrued from the released/interrogation site to the vicinity of Crescent Island.

All predation rate estimates presented here were corrected for on-colony PIT tag detection efficiency, based on the results of the PIT tag detection efficiency study (see above). For the ESU- and stock-specific analyses, we used the average on-colony PIT tag detection efficiency rate for the study (80.2%) because it was impossible to know when during the tern's nesting season certain PIT-tagged groups of fish reached the vicinity of Crescent Island. In the case of the reach-specific analysis, we used the

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[2] Data presented here was downloaded from PTAGIS in October, 2004.
[3] Although Lower Monumental and Rock Island dams are generally considered outside the foraging range of Crescent Island terns, they are the closest PIT tag interrogation/tagging sites for smolts on the Snake and Upper Columbia rivers, respectively, that are up-river of Crescent Island.

weighted monthly average derived from the passage timing of smolts at each interrogation/tagging site to calculate on-colony detection efficiency. This approach ensured that detection efficiency on earlier migrating smolts was given a comparable weight to that of late migrating smolts.

Results and Discussion: Nearly 2 million PIT-tagged fish were released into the Columbia River basin in 2004. The majority of these fish were released into the Upper Columbia River (1.1 million), Lower Snake River (0.7 million), and Mid-Columbia River (0.1 million). Most tagged fish were of hatchery origin (83.9%). Of the nearly 2 million PIT-tagged fish released into the Columbia River basin, 1.1% or 21,418 were recovered on the Crescent Island tern colony in August of 2004. The vast majority of these PIT tags were from steelhead smolts (79.9% or 17,108 tags).

Results from the ESU-specific analysis indicate that Snake River steelhead were the most vulnerable ESU to Crescent Island terns in 2004, with an estimated predation rate of 7.6% for all in-river migrating PIT-tagged fish from this ESU (Table 4). Snake River steelhead included in this analysis were from five different spawning populations and predation rates ranged from as low 0.8% to as high as 16.3% (Table 5), indicating high stock-specific variability within this ESU. Hatchery steelhead from the Snake River were particular vulnerable to Crescent Island terns, with predation rates nearly double that of their wild counterparts (Table 5). The next most vulnerable ESU's to Crescent Island terns were Upper Columbia River steelhead, followed closely by Middle Columbia River steelhead, with estimated predation rates of 2.1% and 1.7%, respectively, for each ESU (Table 5). Estimated predation rates on all other listed/protected ESU's by Crescent Island terns in 2004 were negligible, ranging from 0.0% for Snake River sockeye salmon to 0.8% for Snake River fall chinook salmon (Table 4).

Reach-specific predation rates by terns nesting on Crescent Island were surprisingly high for steelhead traveling through the McNary Reservoir. In 2004, predation rates of 22.5%, 3.9%, and 4.1% were estimated for steelhead from the Snake, Upper Columbia, and Middle Columbia rivers, respectively (Table 6). Tern predation was also high on coho salmon from the Snake River, with 9.3% of the PIT-tagged coho that were detected at Lower Monumental Dam being subsequently detected on the Crescent island tern colony. Interestingly, predation on coho salmon from the Middle Columbia River (primarily fish released into the Yakima River) was negligible in 2004 (ca. 0.4%; Table 6). In general, in-river smolts from the Snake River were much more vulnerable to Crescent Island terns than in-river smolts from the Upper Columbia and Middle Columbia rivers (Table 6). As has been reported previously (Antolos et al. in press), predation rates on in-river smolts from the Snake River are particularly high during low flow years, as was the case in 2004. In 2004, flows in the Snake River (as determined by outflow from Ice Harbor Dam) averaged only 70.5 kcfs (70% of the 10-year average) during the months of April-June. Conversely, flows in the Upper Columbia River (as determined by outflow from Priest Rapids dam) averaged 122.7 kcfs (75% of the 10-year average) during the same time period in 2004. We are currently working with NOAA Fisheries to quantify the relationship between river conditions (e.g., flow, turbidity) and salmonid predation by

Crescent Island terns. Result of this analysis will be presented in a subsequent report or publication.

It is important to note that although some of these estimated predation rates based on PIT tag recoveries seem alarmingly high; these rates apply only to the in-river component of each run. For Snake River smolts, this represents only a fraction of the over-all ESU because the vast majority of smolts are transported around the McNary Pool in barges and trucks each spring. For example, 96.4% and 87.2% of all steelhead and yearling chinook smolts, respectively, arriving at Lower Granite Dam (the upper most dam on the Lower Snake River) were collected for transportation around the McNary Pool in 2004 (Fish Passage Center, unpublished data). Thus, even though predation rate estimates for in-river PIT-tagged steelhead were high in 2004, these fish represent a small fraction of the overall ESU (Table 7). Lastly, it is important to emphasize that predation rate estimates based on PIT tag data are not likely an unbiased proxy for consumption rate estimates.

Finally, Figure 9 illustrates how predation rate estimates can be made more precise by accounting for PIT tag collision, PIT tag detection efficiency, and PIT tag deposition rates. When taken together, predation rate estimates on Snake River steelhead increase from just 10.4% to 34.7%, while predation rate estimates for Upper Columbia River steelhead increase from 2.0% to 6.3% (Figure 9). Further research is needed, however, to determine if estimates of PIT tag deposition rates in 2004 are repeatable. As such, we are reluctant to correct the predation rate estimates for deposition rates until more data are collected; hence, the deposition rate corrections for Snake River and Upper Columbia River steelhead smolts are provided as a preliminary indication of the magnitude of the correction.

1.5. Dispersal and Survival

Methods: Juvenile terns were banded at two tern colonies in the Columbia Basin and one tern colony in California in 2004 (see Roby et al. 2004 for banding results outside the Columbia River basin) in order to continue our efforts to measure survival rates, post-breeding dispersal, and movements among colonies. Each tern was banded with a federal numbered metal leg band and a unique color combination of plastic leg bands that allows for the identification of individual terns at a distance (i.e., at roosts or on colonies). As part of this study, tern chicks that were near fledging were banded at East Sand Island, (n = 453) and Crescent Island (n = 223). Tern chicks were captured on-colony by herding flightless young into holding pens. Once captured, chicks were immediately transferred to holding crates until they were banded and released. Chick banding operations were conducted only during early morning and evening hours when moderate temperatures reduced the risk of heat stress for captive chicks. Terns that were color-banded in previous years (2000–2003) were re-sighted on various breeding colonies by researchers throughout the 2004 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 2004, over 1,900 re-sightings of color-banded Caspian terns had been reported as of 30 September. Of these, 92 banded individuals were resighted at East Sand Island or Crescent Island and were identified such that the banding year, age class (i.e., adult or chick), and location were known. A total of 79 banded individuals were resighted at East Sand Island and all but eight of the re-sighted terns were initially banded as adults in previous years at either the Rice Island/East Sand Island colonies (48) or the ASARCO colony (23; Commencement Bay, WA; see Map 2). The remaining eight birds were banded as chicks at either the East Sand Island (4), ASARCO (1), or Crescent Island (3) colonies.

In addition to these resightings, there were 9 individuals that were banded at either Rice Island, East Sand Island, or ASARCO that were resighted at colonies in San Francisco Bay (3) or along the Washington Coast (6; Dungeness National Wildlife Refuge). Of these, 4 were banded as adults and 5 were banded as chicks.

The analysis of the band re-sighting data is on-going and will allow us to estimate adult survival, juvenile survival, age at first breeding, colony site fidelity, and other factors important in determining the status of the population 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 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 remained on East Sand Island in 2002, 2003, and 2004 (Figure 10). Habitat restoration, social attraction, and gull control at the East Sand Island colony site were successful in attracting terns to breed there and provided suitable nesting habitat for 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). The number of Caspian terns nesting in the estuary has remained relatively stable 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 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

Juvenile salmonids were less prevalent and marine forage fishes (i.e., Pacific herring, anchovies, smelt, surf perch, Pacific sand lance [*Ammodytes hexapterus*]) were more prevalent in the diets of Caspian terns nesting on East Sand Island, compared to terns nesting on Rice Island (Table 1, Figure 12). 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.

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%, and 72% in 2000, 2001, 2002, 2003, and 2004, respectively (Figure 13). Per capita smolt consumption has also declined since the study began in 1997 (Figure 14); in 2004 per capita smolt consumption (184 smolts/nesting tern/breeding season) declined 76% from the highest rate measured during this study (1999: 777 smolts/nesting tern/breeding season). 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 making marine forage fish more available near East Sand Island. This large reduction in the estimated number of juvenile salmonids consumed by terns in 2000–2004 compared to 1998 was primarily due to a reduction in the number of sub-yearling chinook salmon consumed, along with smaller reductions in consumption of steelhead and coho salmon (Figure 15).

The diet composition of Caspian terns nesting on Rice and East Sand islands suggests that relocating the tern colony to East Sand Island significantly enhanced survival of juvenile salmonids in the estuary. As predicted, juvenile salmonids were less prevalent and marine forage fishes more prevalent in the diets of Caspian terns nesting on East Sand Island compared to terns nesting on Rice Island (Table 1 and Figure 12). The differences in the proportion of salmonids in the diets of Caspian terns nesting on Rice and East Sand islands are also consistent with significant inter-colony differences in the diets of other piscivorous waterbirds (i.e., double-crested cormorants [*Phalacrocorax auritus*], glaucous-winged/western gulls [*L. glaucescens* X *L. occidentalis*]) nesting on the two islands. Birds nesting on Rice Island were consistently more reliant on juvenile salmonids and consumed a less diverse fish diet than birds nesting on East Sand Island. 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.

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 1999–2004 (1.04 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 sub-adult 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.

Gull control on the East Sand Island tern colony may have been partly responsible for differences in nesting success between the Rice Island and East Sand Island colonies in 1999 and 2000; however, in 2001–2004, when there was no gull control on the East Sand Island tern colony, tern nesting success was still significantly higher than was ever recorded at Rice Island (Figure 16). 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.

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 2004 high resolution aerial photos of the colony were taken late in the incubation period. Counts of the total number of individuals 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 conducted a count of stick nests in the photographs to estimate the number of breeding pairs in 2004. Counts from aerial photos also provided an assessment of habitat use and distribution of nesting cormorants on East Sand Island in 2004.

Boat-based surveys of eight navigational markers near Miller Sands Spit (river mile 24; see Map 2) were conducted 2–4 times monthly from mid-April through the beginning of August in 2004. Because nesting chronology varies among the different channel markers, numbers of nesting pairs at each marker were 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 will sometimes jump from the nest and into the water when disturbed), we did not climb the navigational markers to check nests to estimate productivity.

Monthly boat-based surveys of the Astoria-Megler Bridge (see Map 1) were conducted from May through July in 2004. 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, attended by an adult, was considered active, along with any nests containing visible chicks.

In 2004, periodic boat-, land-, and air-based surveys were also conducted of Rice Island and Miller Sands Spit looking for early signs of nesting by double-crested cormorants.

Results and Discussion: In 1989 fewer than 100 pairs of double-crested cormorants nested on East Sand Island, but continued growth over the past 15 years has made this the largest colony of its kind on the Pacific Coast (Anderson et al. 2004) and perhaps anywhere in North America (L. Wires, University of Minnesota, pers. comm.). We estimate that 12,480 breeding pairs attempted to nest at East Sand Island in 2004. This estimate is 17% greater than our estimate of colony size at East Sand Island in 2003 (10,646 breeding pairs) and nearly three times higher than our first estimate of the double-crested cormorant colony size at East Sand Island in 1997 (Figure 18). More data are needed to assess the extent to which factors limiting colony size and reproductive success at the East Sand Island colony are also influencing population trends of the double-crested cormorant throughout the Pacific Coast of North America.

Increases in colony size at the East Sand Island cormorant colony seems to be associated with an increase in colony area (Figure 19) as opposed to an increase in nesting density (Figure 20). In 2004, double-crested cormorants nesting on East Sand Island used 4.2 acres, compared to 3 acres the year before (Figure 19), while nesting density declined during that same time period (Figure 20). Cormorants nested exclusively amongst the boulder riprap and driftwood on the southwest shore of the island until 1999, after which they began nesting in satellite colonies in the adjacent low-lying habitat (see Map 4 for comparison of the nesting distribution in 2003 and 2004). In 2004, nearly half of the breeding population nested in 14 separate satellite colonies away from the rocky riprap on the south shore (Map 4). In addition to the inland expansion of the colony, we have seen continued expansion eastward along the riprap on the southwest shore (Map 4). Based on the habitat preferences of nesting cormorants, there currently exists ample unused habitat on East Sand Island that could support continued expansion of the colony for the foreseeable future.

In 2004, 194 pairs of double-crested cormorants nested on seven channel markers located in the upper estuary. The previous year, 183 cormorant pairs nested on eight different channel markers in the same area. Peak nest counts on individual markers were recorded during 10 May - 18 June in 2004. The asynchrony in nesting chronology among the different channel marker colonies was likely due to differences in disturbance and predation rates by bald eagles (*Haliaeetus leucocephalus*) on cormorants nesting on each of the channel markers.

In 2004, we observed double-crested cormorants nesting on the Astoria-Megler Bridge for the first time. Nests were located immediately south of the southernmost portion of the pelagic cormorant (*Phalacrocorax pelagicus*) colony (see below). During a boat-based census on 16 June, 6 nests were attended by double-crested cormorants.

Double-crested cormorants did not nest at Rice Island or Miller Sands Spit in 2004.

2.1.2. Mid-Columbia River

Methods: To estimate colony size for cormorants nesting on Foundation Island in 2004 (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 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 2004.

In September 2004, we visited two other colony sites where cormorants nested during earlier that year: on the Columbia River near the mouth of the Okanogan River (referred to as the “Okanogan colony”) and in Potholes Reservoir in the North Potholes Reserve (referred to as the “North Potholes colony”; see Map 2). At each site we counted nests to get a rough estimate of the number of breeding pairs at each colony.

Results and Discussion: Our best estimate of the number of nesting pairs at the Foundation Island double-crested cormorant colony in 2004 was 300 pairs, approximately equal to or larger than in 2003 (200-300 pairs). As was the case in previous years, all cormorant nests were in trees at the south end of the island.

Based on our counts of cormorant nests at the Okanogan and North Potholes colonies, we estimate that there were 20–30 and 300–500 nesting pairs at each site in 2004, respectively. Cormorant nesting at each of these sites in 2004 was further confirmed by the recovery of PIT tags from cormorant nests by NOAA Fisheries.

2.1.3. Coastal Washington

Methods: As in previous years, boat-based and aerial surveys of channel markers and the islands in Grays Harbor, WA (Map 1) were conducted in 2004. Because nesting chronology varies among the different channel markers, numbers of nesting pairs at each marker were 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 will sometimes jump from the nest and into the water when disturbed), we did not climb the navigational markers to check nests to estimate productivity.

Results and Discussion: In total, we estimate that there were 190 breeding pairs of double-crested cormorants in Grays Harbor in 2004. These birds nested on channel markers located in the western and northeast portions of the estuary. The channel markers in the western portion of the estuary were monitored in previous years and we saw a 35% increase in the number of cormorants nesting on these markers in 2004 (104 breeding pairs) compared to 2003 (77 breeding pairs).

We saw no evidence of nesting attempts on Sand Island in Grays Harbor in 2004, a site where double-crested cormorants had 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 2004 (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 2004, 182 individual cormorant nests in seven segregated plots were monitored. Visual observations of nest contents were made weekly from mid-April through July to determine nesting chronology and productivity. Productivity was estimated as the number of nestlings in each monitored nest 36 days post-hatch.

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

Results and Discussion: The first cormorant eggs on East Sand Island were observed on 23 April in 2004, 12 days earlier that in 2003. The first hatchlings were observed on the colony on 21 May in 2004, 12 days earlier than in 2003.

We estimate that 25,584 fledglings (95% c.i. = 23,837–27,331 fledglings) were produced at the East Sand Island colony in 2004. This corresponds to nesting success of 2.05 young raised per breeding pair (95% c.i. = 1.91–2.19 fledglings/breeding pair), which was slightly lower than the estimate of nesting success for the East Sand Island cormorant colony in 2003 (2.25 fledglings/breeding pair, 95% c.i. = 1.93–2.57 fledglings/breeding pair; Figure 21). Productivity at the East Sand Island cormorant colony falls towards the upper end of the typical range (1.2–2.4 young per nest) reported for other North American colonies (Hatch and Weseloh 1999).

Confirmation of eggs in nests in 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 in both 2004 and 2003 by mid- to late May, synchronous with the nesting chronology of cormorants on East Sand Island. Chicks were visible in 4 of the 6 cormorant nests observed on the Astoria-Megler Bridge on 14 July. Nesting on the bridge was initiated sometime between mid-May and mid-June, after peak laying at East Sand Island. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for either the nests on channel markers or on the bridge.

2.2.2. Mid-Columbia River

Methods: In 2004, we conducted weekly monitoring of 29 nests on Foundation Island from the observation blind (see Map 3). Brood size at fledging was estimated as the number of chicks in the monitored nests 36 days post-hatching. Because of our distance from the colony and our vantage below the nests we assumed chicks were approximately ten days old when they were first observed.

Results and Discussion: In 2004, 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 diet samples at Foundation Island heard chicks vocalizing. Brood size at fledging at Foundation Island (1.86 ± 0.11) was significantly less ($P = 0.02$) than at East Sand Island (2.20 ± 0.06) in 2004. Nest monitoring did not begin early enough in the breeding season to produce an accurate estimate of overall productivity (fledglings produced per nesting attempt, including failed nest attempts).

2.2.3. Coastal Washington

Methods: As was done in previous years, boat-based surveys of channel markers were conducted to assess nest chronology and nesting success of cormorants in Grays Harbor, WA (Map 1) in 2004.

Results and Discussion: Nesting cormorants in Grays Harbor were successful in hatching young; chicks were visible on all of the markers by mid-June in 2004. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for the nests on channel markers in Grays Harbor in 2004.

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 was 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 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 laboratory analysis.

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 tissue. The diet composition results from 2004 are preliminary because they are based on identifiable fish tissue only. Fish were identified to genus and species, whenever possible. Intact salmonids in fore-gut samples were identified as chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on soft tissue, otolith, or genetic analysis. Unidentifiable fish samples were artificially digested (work that is ongoing) according to the methods of Peterson et al. (1990, 1991). Once digested, diagnostic bones (i.e., cleithra, dentaries, pharyngeal arches, and opercles) were removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish samples that did not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) were not included in diet composition analysis. Taxonomic composition of double-crested cormorant diets was expressed as % of identifiable biomass. The percent of the identifiable biomass in cormorant diets was calculated for two-week periods 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 were calculated using a bioenergetics modeling approach (after the Caspian tern model used in Roby et al. 2003). We used a Monte Carlo simulation procedure to estimate 95% confidence intervals for estimates of smolt consumption by cormorants.

The estimates of double-crested cormorant diet composition and smolt consumption presented below are preliminary and may change slightly with further analysis.

Results and Discussion: Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 5% of double-crested cormorant diets (by mass) at East Sand Island in 2004 (n = 146 adult fore-gut samples or 28,252 total grams of identifiable fish tissue; Figure 22), a lower percentage compared to the previous year (9%; Table 8). As in previous years, marine forage fishes (i.e., Pacific herring and anchovies) comprised the largest proportions of the diet, comprising 46% and 13% in 2004, respectively (Table 8). The proportion of the diet that was salmonids peaked at ca. 15% during the first and second week in May (Figure 23), approximately the same time as in the previous year. We estimated that double-crested cormorants nesting on East Sand Island consumed 6.4 million juvenile salmonids in 2004 (95% c.i. = 2.5–10.3 million), a 25% increase in smolt consumption compared to 2003 (best estimate = 5.2 million, 95% c.i. = 1.1–9.3 million; Figure 24). Per capita smolt consumption increased slightly in 2004 (513 smolts nesting cormorant^{-1} breeding season^{-1}) compared to the previous year (488 smolts nesting cormorant^{-1} breeding season^{-1}), and is now higher than the per capita smolt consumption by terns nesting on East Sand Island (368 smolts nesting tern^{-1} breeding season^{-1}).

The increase in overall smolt consumption by double-crested cormorants in 2004 compared to the previous year was due to a much higher consumption of sub-yearling chinook in 2004; consumption of all the other species declined from the previous year (Figure 24). These preliminary results suggest that double-crested cormorants nesting on East Sand Island are now consuming a similar or greater number of juvenile salmonids than Caspian terns nesting on the same island.

2.3.2. Mid-Columbia River

Methods: During the 10-week chick-rearing period, we collected diet samples that were spontaneously regurgitated by nesting adults and their young from late April to the end of June. A total of 105 regurgitations were collected from the ground beneath cormorant nesting trees. These samples were analyzed in our laboratory at Oregon State University to determine the diet composition of cormorants nesting on Foundation Island in 2004. We should note that the diet data presented are only for the chick-rearing period; the diet composition for cormorants nesting on Foundation Island prior to chick-rearing is unknown and likely varies from what we report for the chick-rearing period.

Results and Discussion: In 2004, the diet samples collected from late April through June indicated that minnows (Cyprinidae) and bass and sunfish (Centrarchidae) were the most prevalent prey types in the diet of Foundation Island cormorants during chick-rearing. Salmonids were only a minor component of the diet during chick-rearing (5.9%). Salmonids were only detected in regurgitations during late April and early May, when 12.5% and 17.1% of the identifiable prey biomass was salmonids, respectively. These diet composition data suggest that, unlike Caspian terns nesting on Crescent Island, double-crested cormorants nesting on Foundation Island do not rely primarily on juvenile salmonids as a food source.

2.4. Management Feasibility Studies

Methods: In 2004, a pilot study was conducted to determine if social attraction could be used to induce double-crested cormorants to nest in areas where they had not nested previously and, if successful, the technique might be used to manage cormorants 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 in two separate plots in the interior portion of the breeding colony to investigate whether we could induce cormorants to nest in specific areas which had not previously been used for nesting. Both plots were near but not connected to previously established nesting areas (Map 4). The two plots were separated by 68 ft of grass and a shallow gully.

In one of the experimental plots we placed pieces of driftwood to create nesting habitat that looked similar to driftwood collections used by nesting cormorants elsewhere on the island. The 41m^2 driftwood collection was filled in with sticks small enough to be used in nesting structures. A few dozen nest structures from the previous year's breeding colony were moved into the experimental driftwood plot. Twelve cormorant decoys and two speakers broadcasting audio playbacks of the cormorant colony were placed amidst the experimental driftwood plot.

The second experimental plot on East Sand Island was a matrix of 49 truck tires laid out in a 99 m^2 plot. In the center of the plot 16 tires were placed in a 4 x 4 array immediately adjacent to each other (touching) and 33 additional tires were placed around the array roughly 1–4 meters apart (Map 4). The tires ranged in size from 14–17 inch inner radius. The hollow tires were filled with sand and one old nest structure was placed in the center of each tire. Pairs of decoys were placed in 6 of the tires and two speakers broadcasting audio playbacks were placed in amongst the experimental tire plot.

Nesting chronology and productivity data from the experimental plots were collected by direct nest observations from the observation tower. A total of 20 and 23 individual nests were monitored within the experimental tire and experimental driftwood plots, respectively. Visual observations of nest contents were recorded weekly from mid-April through July. Productivity was estimated as the number of nestlings remaining in each monitored nest 36 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 mile 24). Approximately 10 pairs of double-crested cormorants attempted to nest on 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 northwest point of the upland portion of the island, near the area where cormorants had previously attempted to nest. The design of this experimental plot was similar to the experimental driftwood plot on East Sand Island. Large and small pieces of driftwood were placed in an 8 x 10 m plot; the area was filled in with smaller sticks and reeds that could be used as nesting material. A total of 62 decoys were placed throughout the plot, mostly in pairs with nesting material gathered underneath them. 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 weekly from mid-April through mid-June, and weekly thereafter through July.

Results and Discussion: On East Sand Island, cormorants were seen in both experimental plots carrying nesting material and engaging in courtship displays just 5 days after researchers had finished working in the area and within 2 days of initiating audio playbacks. Nest initiation in the two experimental plots was synchronous with other non-experimental, monitored plots; median laying dates in the experimental plots were just 4 days later (2 May) than in the nearby natural plots (29 April). Productivity was also similar between plots in the natural portion of the colony (2.02 ± 0.08; n = 139) and the experimental plots (2.17 ± 0.15, n =43).

Based on relatively similar nesting chronology and productivity, it appears that we were able to create nesting habitat that was similar in quality to the natural habitat available on East Sand Island and that suitable habitat preparation in conjunction with social attraction techniques may be feasible for inducing cormorants to move short distances to nest in areas not previously used for nesting.

Double-crested cormorants did not attempt to nest anywhere on Miller Sands Spit in 2004. 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 upland areas near the experimental plot. The first attempt at inducing double-crested cormorants to nest on an island removed from East Sand Island may have been unsuccessful for several reasons. First, cormorants prospecting for nest sites 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 is evidence to suggest that there may be greater disturbance rates to nesting birds on Miller Sands Spit as compared to East Sand Island. Bald Eagles are commonly seen roosting on Miller Sands Spit and recreational boaters are often seen just offshore or on the island. Social attraction of nesting cormorants from East Sand Island to an alternative nesting island may have a greater probability of success at sites more protected from disturbance. Also, for the first time in several years, double-crested cormorants did not attempt to nest on nearby Rice Island, suggesting that nesting conditions for cormorants may not have been favorable in the upper estuary during 2004.

SECTION 3: OTHER COLONIAL WATERBIRDS

3.1. Distribution

3.1.1. Columbia River Estuary

Gulls: Based on island-based surveys, both glaucous-winged/western gull and ring-billed gull (*L. delawarensis*) breeding colonies were confirmed at several sites in the Columbia River estuary in 2004. Glaucous-winged gulls nested on three islands in 2004: East Sand Island, Rice Island, and Miller Sands Spit (see Map 1), with the East Sand Island gull colony being the largest (ca. several thousand nesting pairs). Ring-billed gulls, which previously nested on Miller Sands Spit (Collis et al. 2002), are now nesting on East Sand Island (ca. hundreds of pairs).

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 endangered species in the estuary (Wright 2004). In 2004, the first California brown pelicans were observed roosting on East Sand Island on 6 April and 65 pelicans were counted during the last island-wide census of the season on 4 November. The number of brown pelicans roosting on East Sand Island peaked at 7,786 on 13 August. We observed breeding behavior by 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 roosting brown pelicans in 2004.

Brandt's and Pelagic Cormorants: Small numbers of Brandt's cormorants (*P. penicillatus*; 58 nesting pairs) and pelagic cormorants (*P. pelagicus*; 144 nesting pairs) were nesting on structures (i.e., pile dikes and the Astoria–Megler Bridge, respectively) in the Columbia River estuary in 2004 (see Map 1). 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. Mid-Columbia River

Gulls: Based on aerial, boat-, and land-based surveys along the mid-Columbia River, gulls, primarily California and ring-billed gulls, were confirmed to be nesting on at least six different islands in impoundments above The Dalles Dam in 2004; Miller Rocks (river km 333), Three Mile Canyon Island (river km 414), Crescent Island (river km 510), and at least two islands near Richland, Washington (i.e., Richland Island [river km 547] and Island 18 [river km 553]; see Map 2). The gull colony on Little Memaloose Island (river km 315) which was active in 1998 (Collis et al. 2002), was not active in 2004 (see Map 2). The gull colonies near Richland, Washington (e.g., Richland Island and Island 18) were the largest colonies along the mid-Columbia River in 2004, totaling over 30,000 nesting birds when last censused in 1997 and 1998 (Collis et al. 2002).

Gulls were also confirmed to be nesting in Potholes Reservoir (ca. thousands) on the same islands occupied by nesting Caspian terns (see Map 2).

American White Pelicans: We conducted weekly boat-based counts of American white pelicans (*P. erythrorhynchos*) on Badger Island in 2004 (see Map 3) to assess seasonal pelican activity on the island. An aerial photograph was taken of the colony on 24 May (i.e., during incubation) 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 were 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 537 adult American white pelicans were counted in the aerial photograph taken on 24 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; 301 were counted in a nesting area mid-way along the northeast bank of the island and 236 were counted in a nesting area near the upriver end of the island along the northeast bank. Our boat-based counts resulted in a maximum count of 204 adults on 10 May, and a maximum count of 301 juveniles on 27 July. Maximum counts of adults during boat surveys were 211 in 2002 and 193 in 2003. Maximum counts of juveniles during boat surveys were 238 in 2002 and 141 in 2003. Our boat-based surveys suggest that, while the regional population of American white pelicans may be increasing (A. Stephenson, Yakima Klickitat Fisheries Project, pers. comm.), the size of the breeding population of pelicans at Badger Island has likely remained relatively stable over the past 3 years. The relatively high maximum count of juveniles suggests that nesting success in 2004 was relatively good.

3.2. Diet Composition

3.2.1. Columbia River Estuary

Gulls: As part of the current study, we no longer collect diet data from gulls nesting in the Columbia River estuary. Our previous research has shown 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 4.2% and 10.9% of the diet (by mass) of glaucous-winged/western gulls nesting on East Sand Island and Rice Island/Miller Sand Spit, respectively. At least some of these fish had been kleptoparasitized from terns nesting at the nearby Caspian tern colony on Rice Island.

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 mostly 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 the small colony size and 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. Mid-Columbia River

Gulls: As part of the current study, we no longer collect diet data from gulls nesting in the mid-Columbia River. Our previous research has shown 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 the total diet mass; this colony no longer exists) and Miller Rocks (3% of the 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 control 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 have previously been 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 upriver colonies are having a negligible impact on survival of juvenile salmonids.

American White Pelicans: The American white pelican colony on Badger Island is small (< 500 pairs) and, based on smolt PIT tag detections on the pelican colony by NOAA Fisheries (a total of 510 tags from the 1998–2003 migration years; Ryan et al in prep), is not a source of significant smolt mortality. Despite this there appears to be a growing non-breeding white pelican population along the mid-Columbia River and they are often observed foraging below mid-Columbia River dams (Tiller et al. 2003), and at sites in the Yakima River basin (A. Stephenson, Yakima Klickitat Fisheries Project, pers. comm..), presumably foraging on out-migrating juvenile salmonids. The impacts of this non-breeding population on juvenile salmonid survival are not understood.

SECTION 4: SYSTEM-WIDE OVERVIEW

4.1. Predator Population Trajectories

Although numbers of Caspian terns nesting in the estuary and upriver 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 time period to ca. 12,500 pairs (Figure 25). 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 increasing, while productivity for terns nesting in the estuary and upriver tends to be stable or slightly declining (Figure 26). 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). Expansion of the tern breeding population along the mid-Columbia River is also unlikely due to the paucity of suitable nesting habitat for terns in that region. Based on these results, it is likely that the cormorant breeding population will continue to expand for the foreseeable future, while numbers of Caspian terns nesting in the estuary and upriver 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 their relatively small predation impacts on juvenile salmonids from the Columbia River basin (see below).

4.2. Relative Impact of Predation

Although juvenile salmonids represented only ca. 5% of the diet of cormorants nesting on East Sand Island in 2004 (compared to 17% and 70% for terns nesting on East Sand Island and Crescent Island, respectively), estimated smolt consumption by the cormorant colony (6.4 million; 95% c.i. = 2.5–10.3 million) may be greater than these two Caspian tern colonies combined (4.0 million; 95% c.i. = 3.3–4.6 million). This is due in part to the larger colony size and greater food requirements of cormorants relative to terns. Management options to reduce or cap smolt losses to the expanding double-crested cormorant colony have yet to be considered and will require additional research and NEPA analysis.

In 2004, Caspian terns nesting at East Sand Island consumed 7-fold more salmonids than did Caspian terns nesting on Crescent Island, while double-crested cormorants nesting on East Sand Island consumed 9-fold more salmonids than terns nesting on Crescent Island. The large disparity in smolt consumption between the upriver tern colony and the estuary tern and cormorant colonies was primarily due to differences in colony size, with the Crescent Island tern colony (ca. 530 breeding pairs) being more than an order of magnitude smaller than both the estuary tern colony (ca. 9,500 breeding pairs) and the estuary cormorant colony (ca. 12, 500 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 surprisingly high, particularly in low flow years. For example, preliminary data from 2004 suggest the predation rate by Crescent Island terns on Snake River steelhead smolts was 17% (based on the number of PIT-tagged fish interrogated at Lower Monumental Dam that were subsequently recovered on the Crescent Island tern colony). This predation rate estimate increases to 23% when corrected for PIT tag detection efficiencies on the colony. In-river steelhead smolts from the Snake River were more vulnerable to tern predation than in-river steelhead smolts from the upper Columbia (ca. 3.0%; based on PIT-tagged smolts detected at Rock Island Dam that were subsequently recovered on the Crescent Island tern colony). The high predation rate on in-river migrants from the Snake River was, however, offset by the transportation of most juvenile salmonids around McNary Pool. Conversely, juvenile salmonids from the upper and mid-Columbia River were not transported past Crescent Island, resulting in a much larger proportion of those runs being susceptible to predation by Crescent Island terns.

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 the terns and cormorants nesting on East Sand Island combining to consume ca. 10 million smolts in 2004 (Figure 27). Additionally, when compared to predation impacts 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 on East Sand Island has the greatest potential to benefit Columbia River salmonid populations across the basin, when compared to potential management of other bird populations. One exception may be the Caspian tern colony on Crescent Island, where tern management may benefit some stocks (e.g., Upper Columbia River steelhead ESU), particularly in low flow years.

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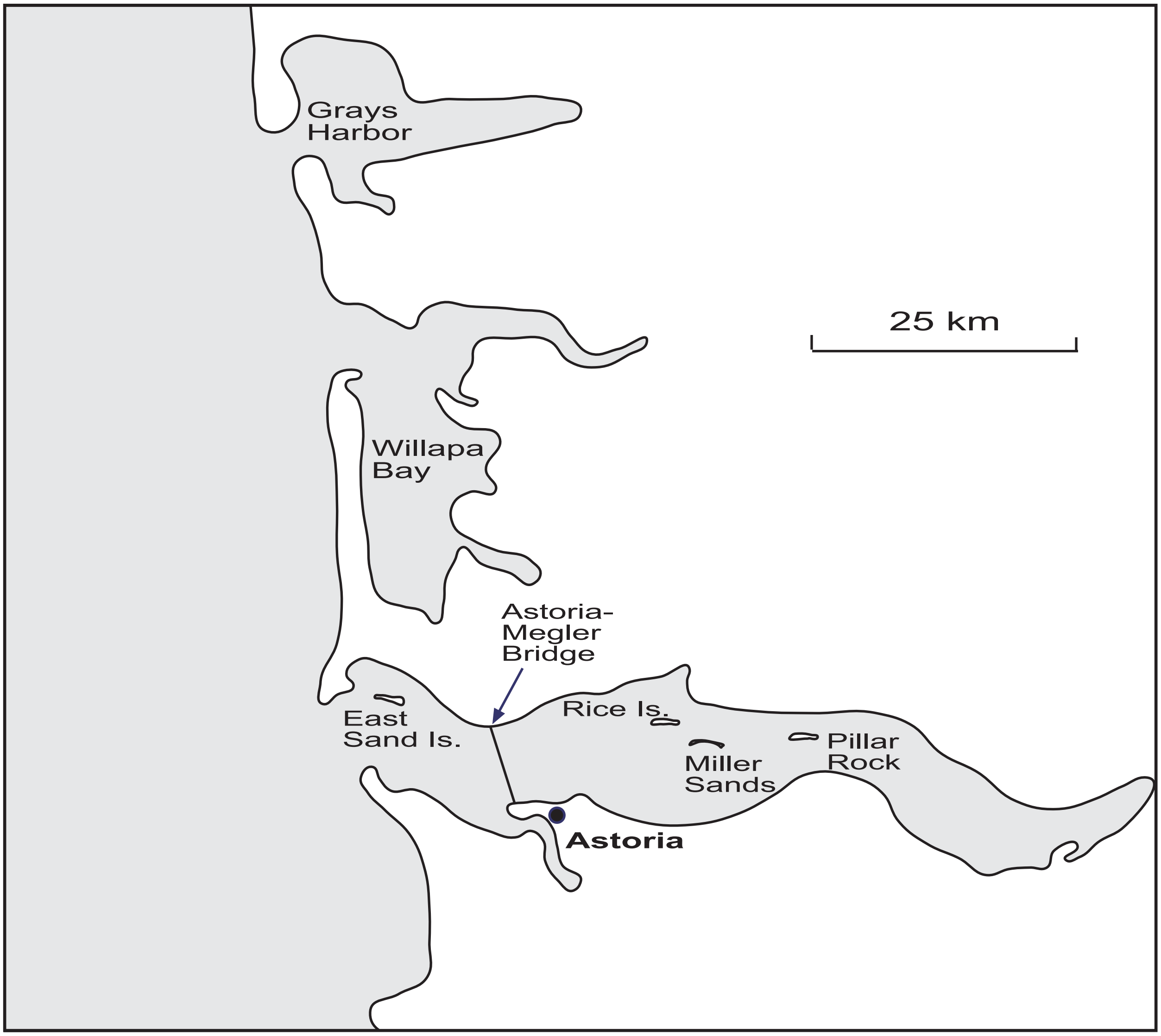
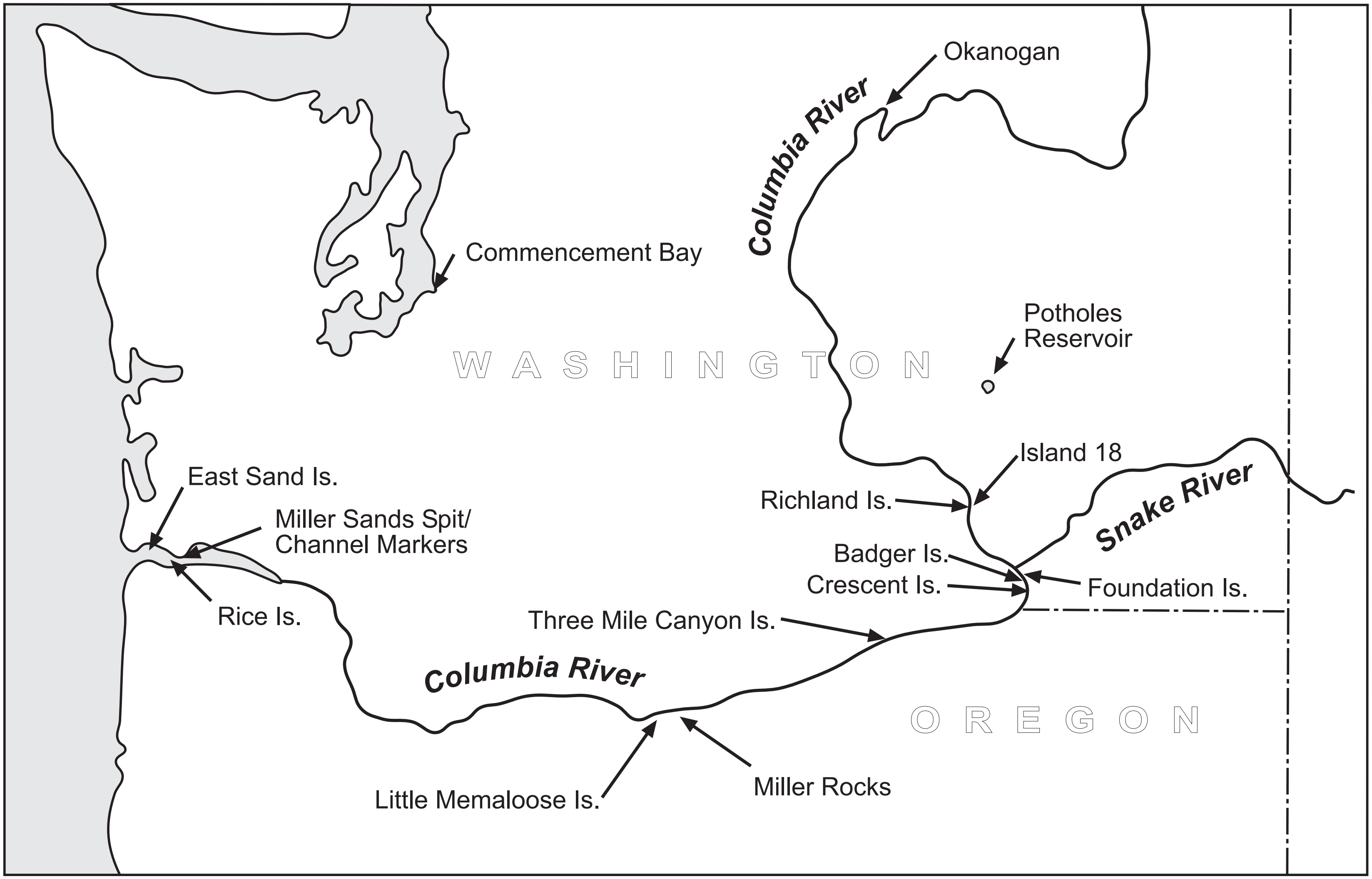
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian terns			
1.1. Preparation and Modification of Nesting Habitat			
1.1.1. Columbia River Estuary		x	
1.2. Colony Size and Productivity			
1.2.1. Columbia River Estuary	x	x	
1.2.2. Mid-Columbia River	x		x
1.2.3. Coastal Washington		x	
1.3. Diet Composition and Salmonid Consumption			
1.3.1. Columbia River Estuary	x		
1.3.2. Mid-Columbia River	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	

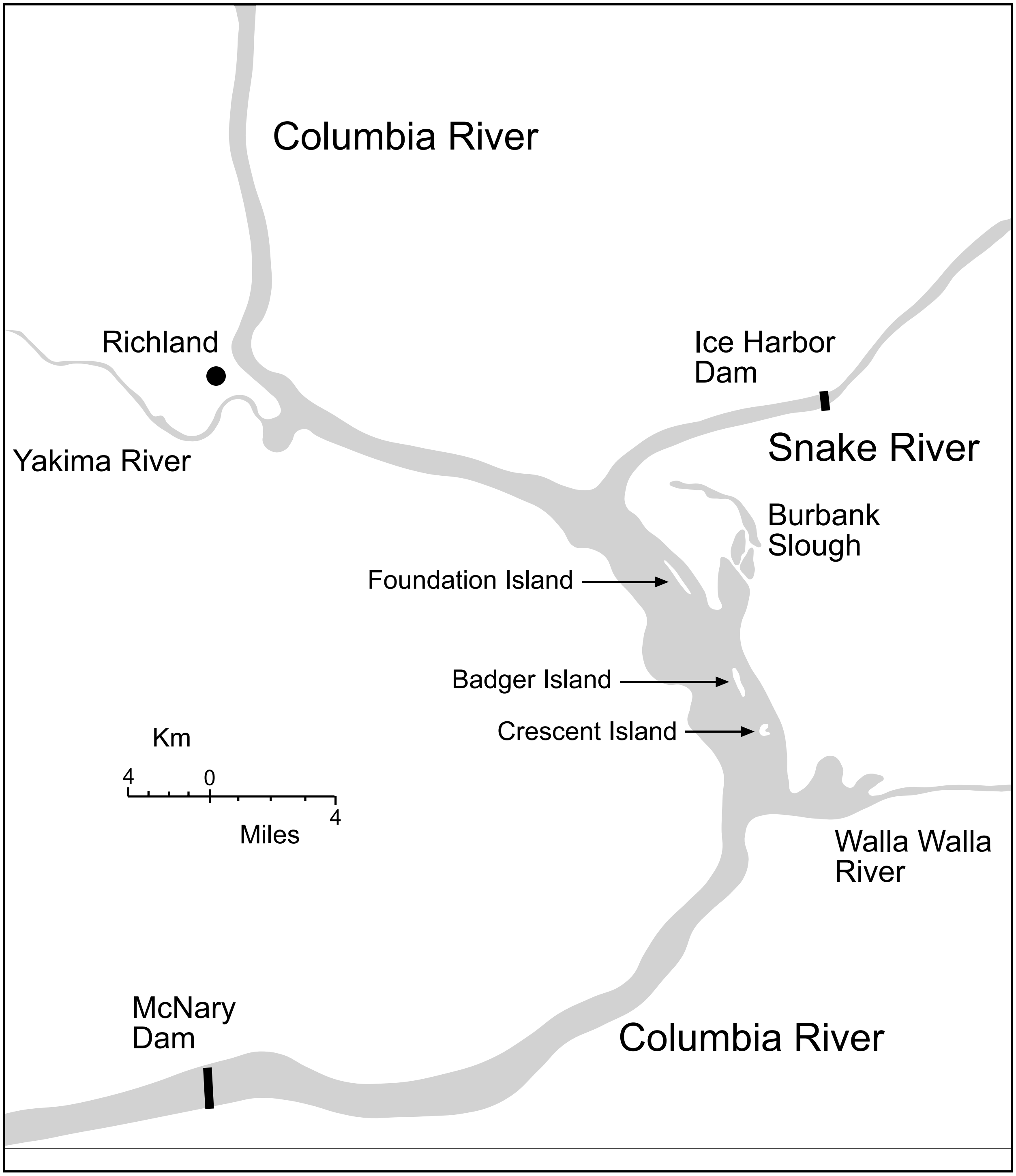
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Double-crested Cormorants			
2.1. Nesting Distribution and Colony Size			
2.1.1. Columbia River Estuary	x	x	
2.1.2. Mid-Columbia River			x
2.1.3. Coastal Washington		x	
2.2. Nesting Chronology and Productivity			
2.2.1. Columbia River Estuary	x	x	
2.2.2. Mid-Columbia River			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. Mid-Columbia River			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. Mid-Columbia River			x
3.2. Diet Composition			
3.2.1. Columbia River Estuary	x	x	
3.2.2. Mid-Columbia River			x



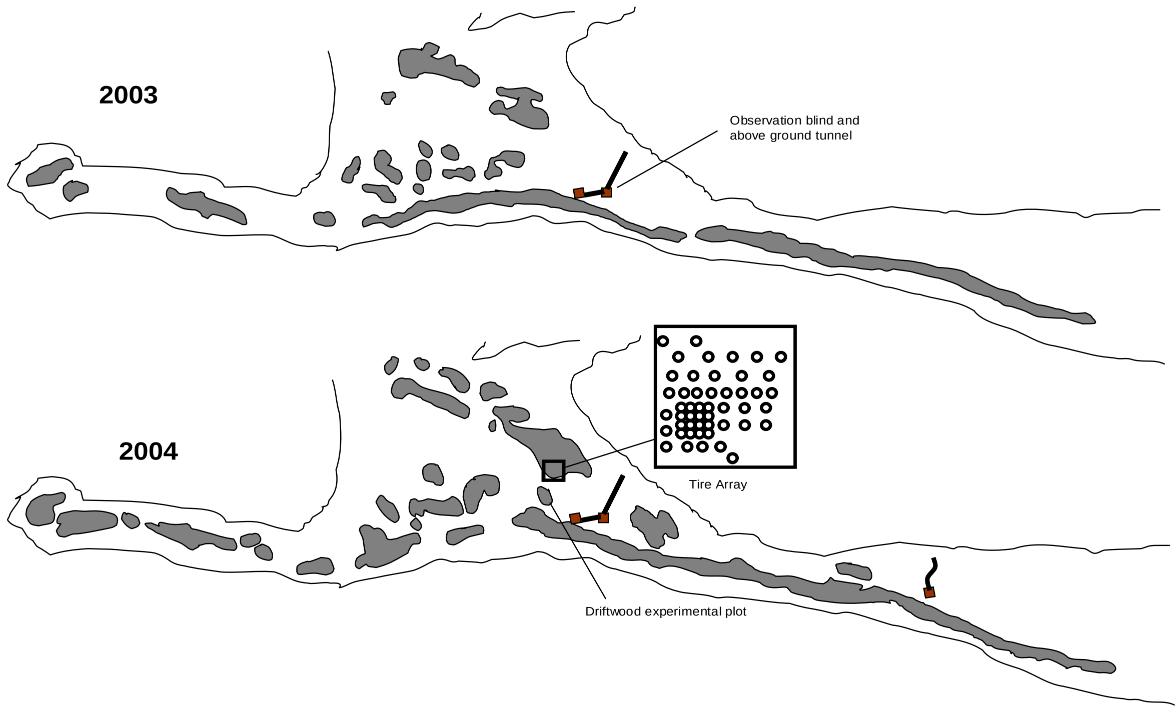
Map 1. Study area in the Columbia River Estuary and along the Washington Coast in 2004.



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



Map 3. Mid-Columbia River study area.



Map 4. The distribution of nesting double-crested cormorants on East Sand Island in 2003 and 2004 and the location of the tire array and experimental nesting colony in 2004 (see text for details). Nesting cormorants occupied the extreme western end of the island (shown here) and did not nest anywhere else on East Sand Island in either year.

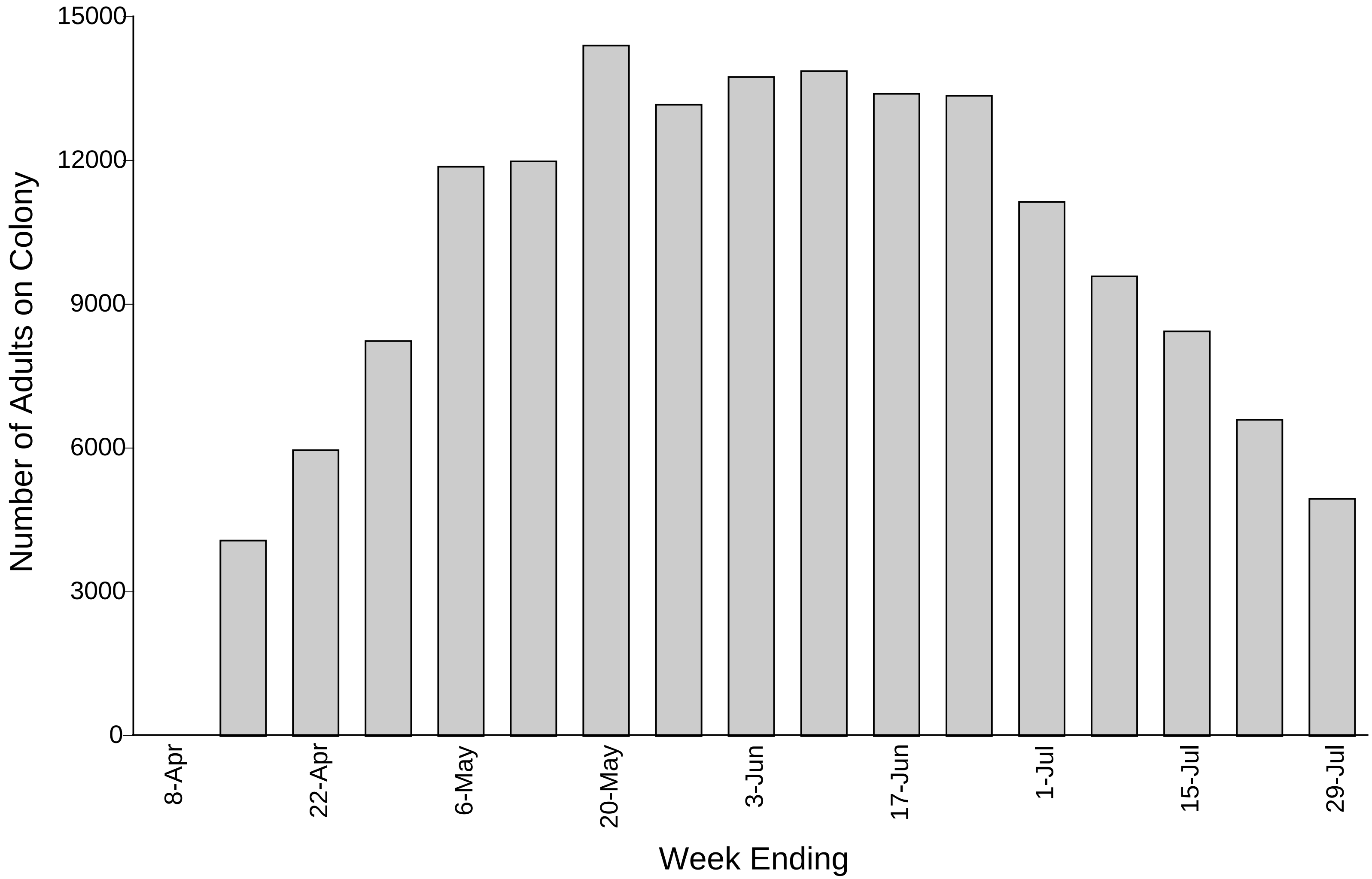


Figure 1. Visual estimates of the number of adult Caspian terns on the East Sand Island colony in 2004.

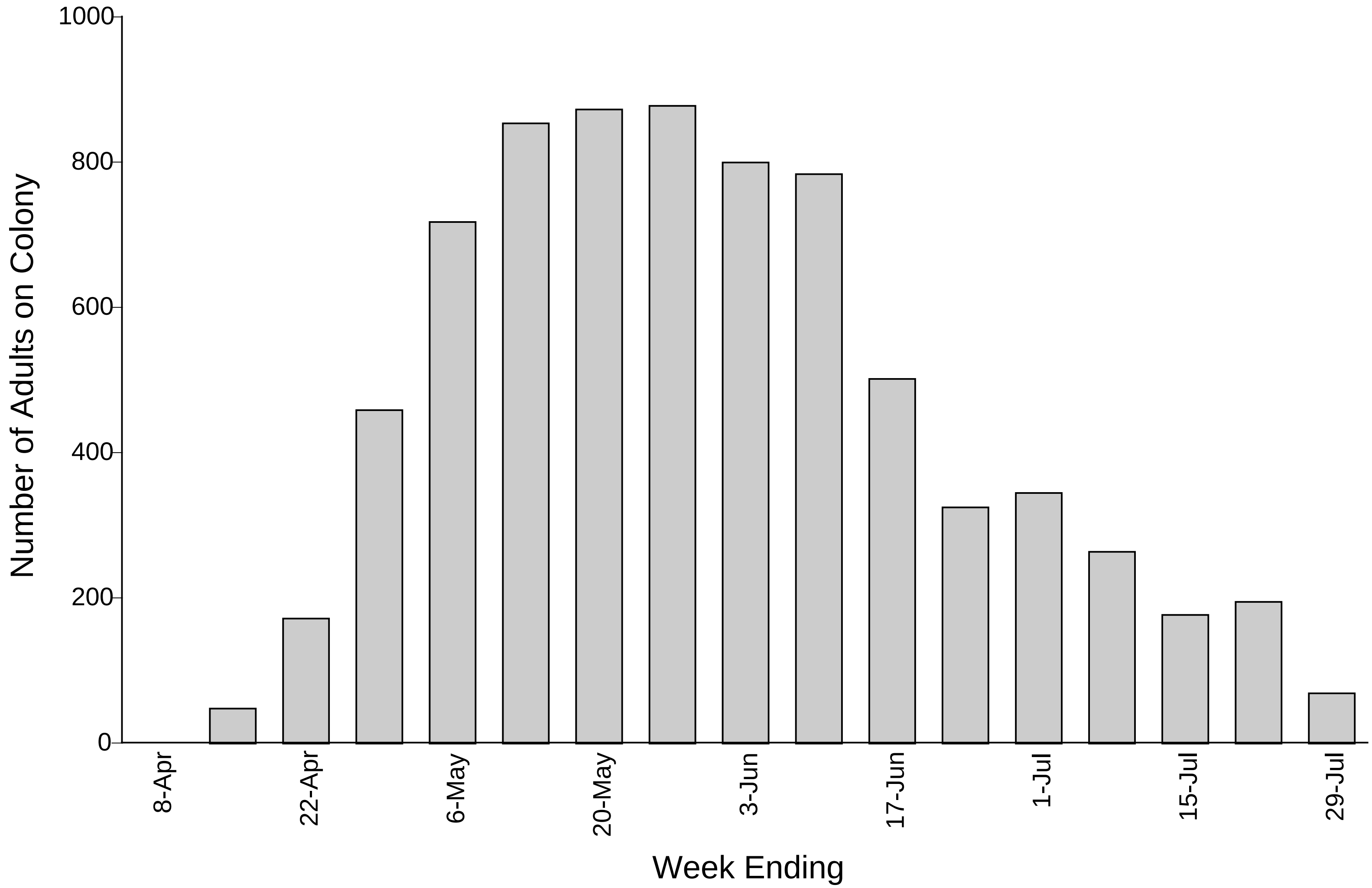
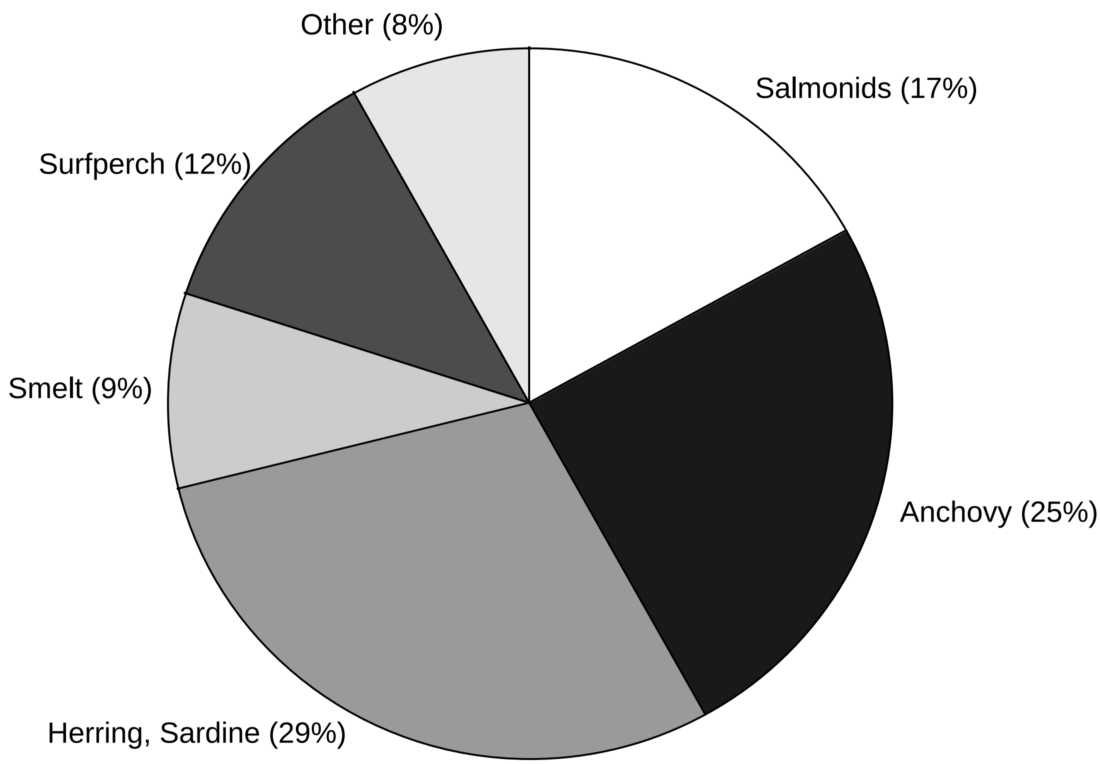


Figure 2. Visual estimates of the number of adult Caspian terns on the Crescent Island colony in 2004.



N = 5,854 bill load fish

Figure 3. Diet composition of Caspian terns nesting on East Sand Island in 2004 (see text for methods of calculation).

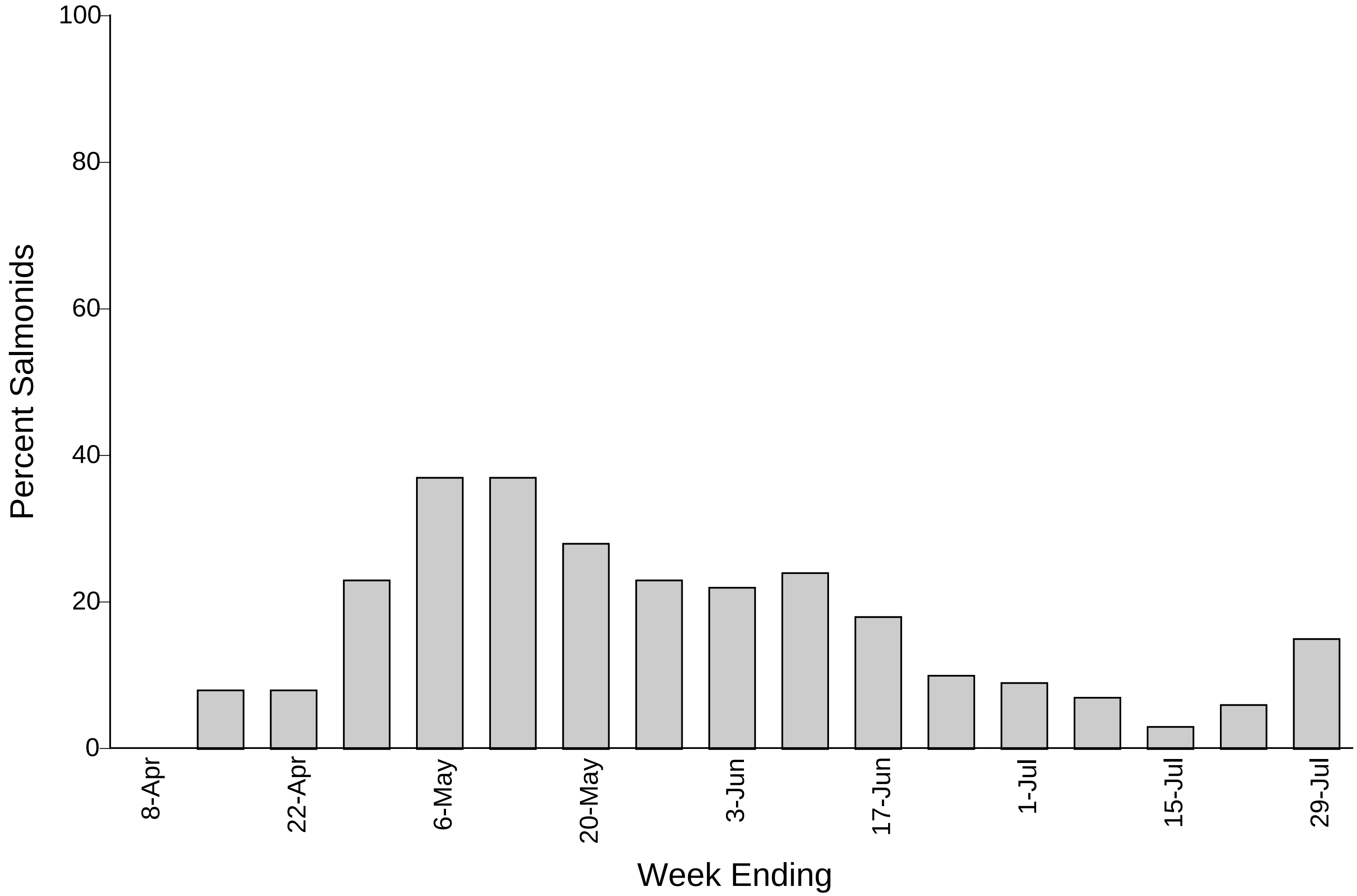


Figure 4. Proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in 2004.

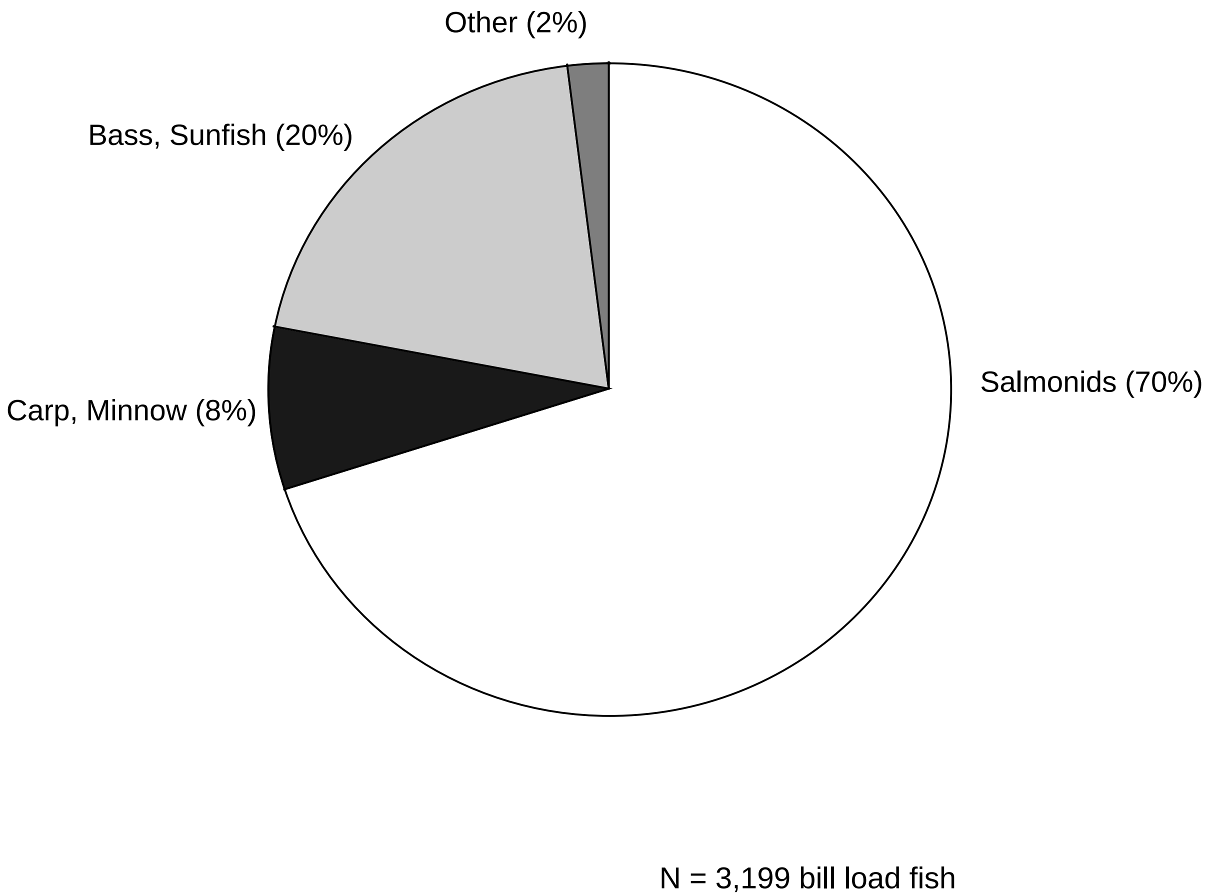


Figure 5. Diet composition of Caspian terns nesting on Crescent Island in 2004 (see text for methods of calculation).

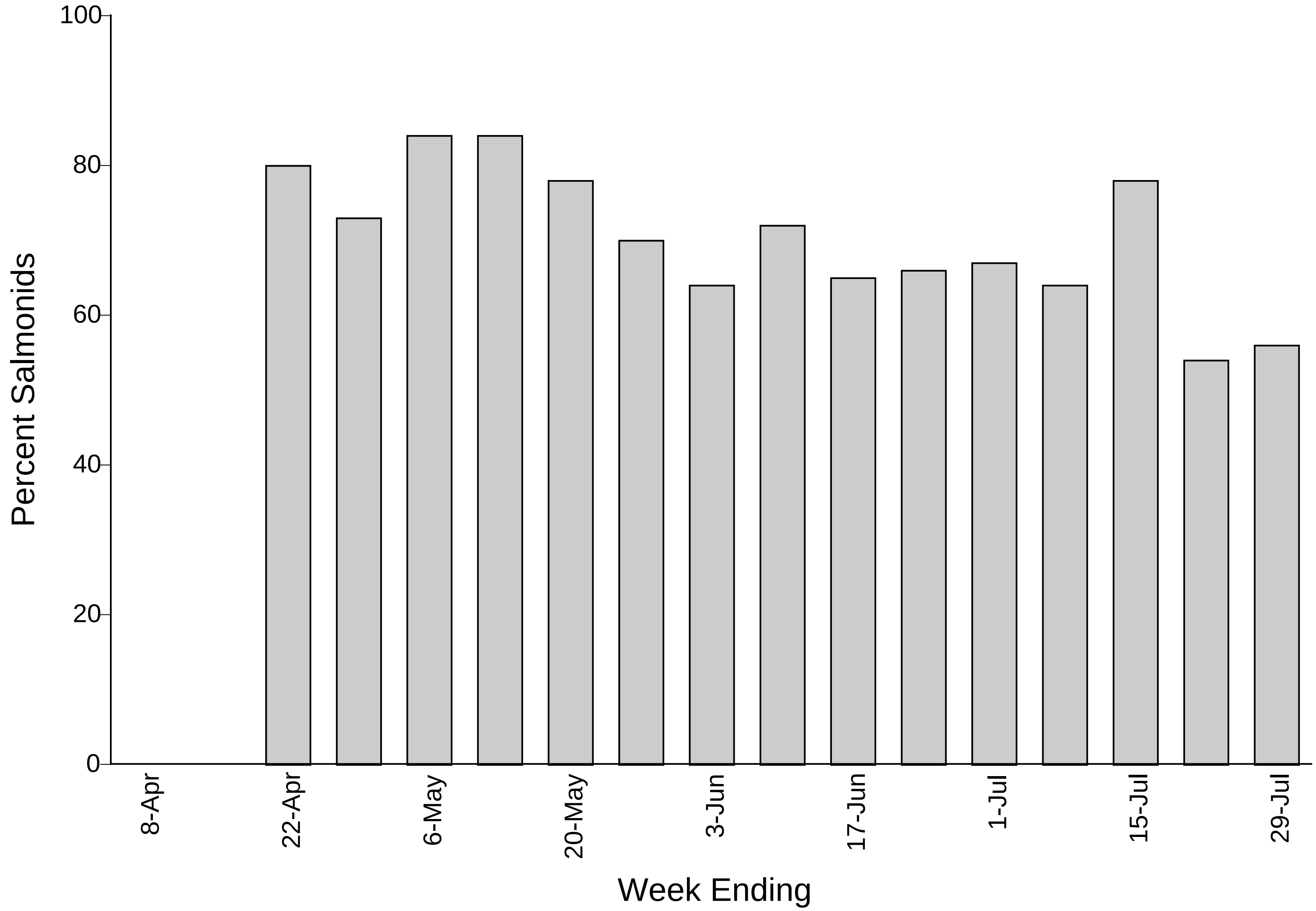


Figure 6. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in 2004.

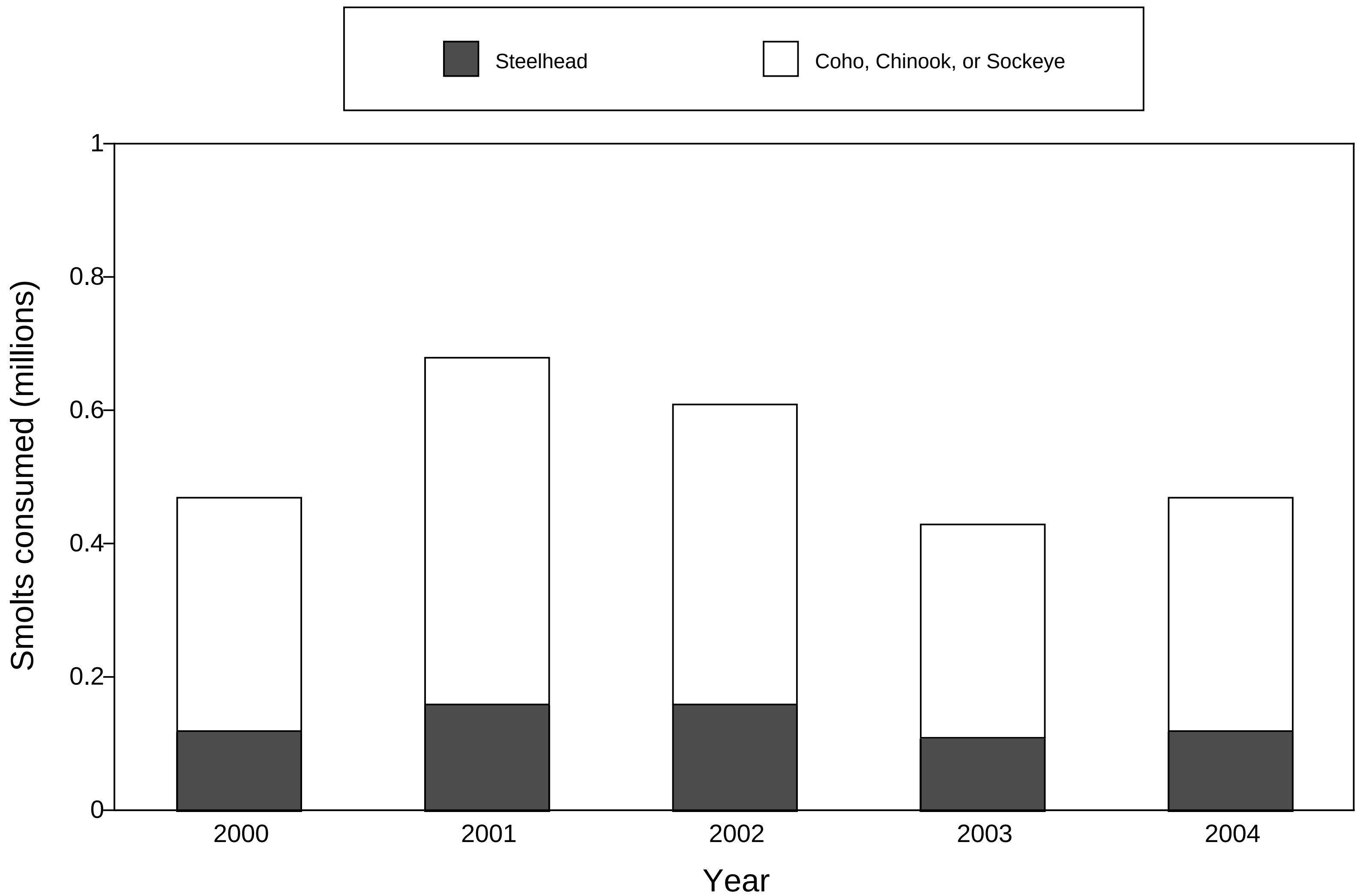


Figure 7. Total estimated consumption of juvenile salmonids by Caspian terns nesting on Crescent Island, 2000-2004.

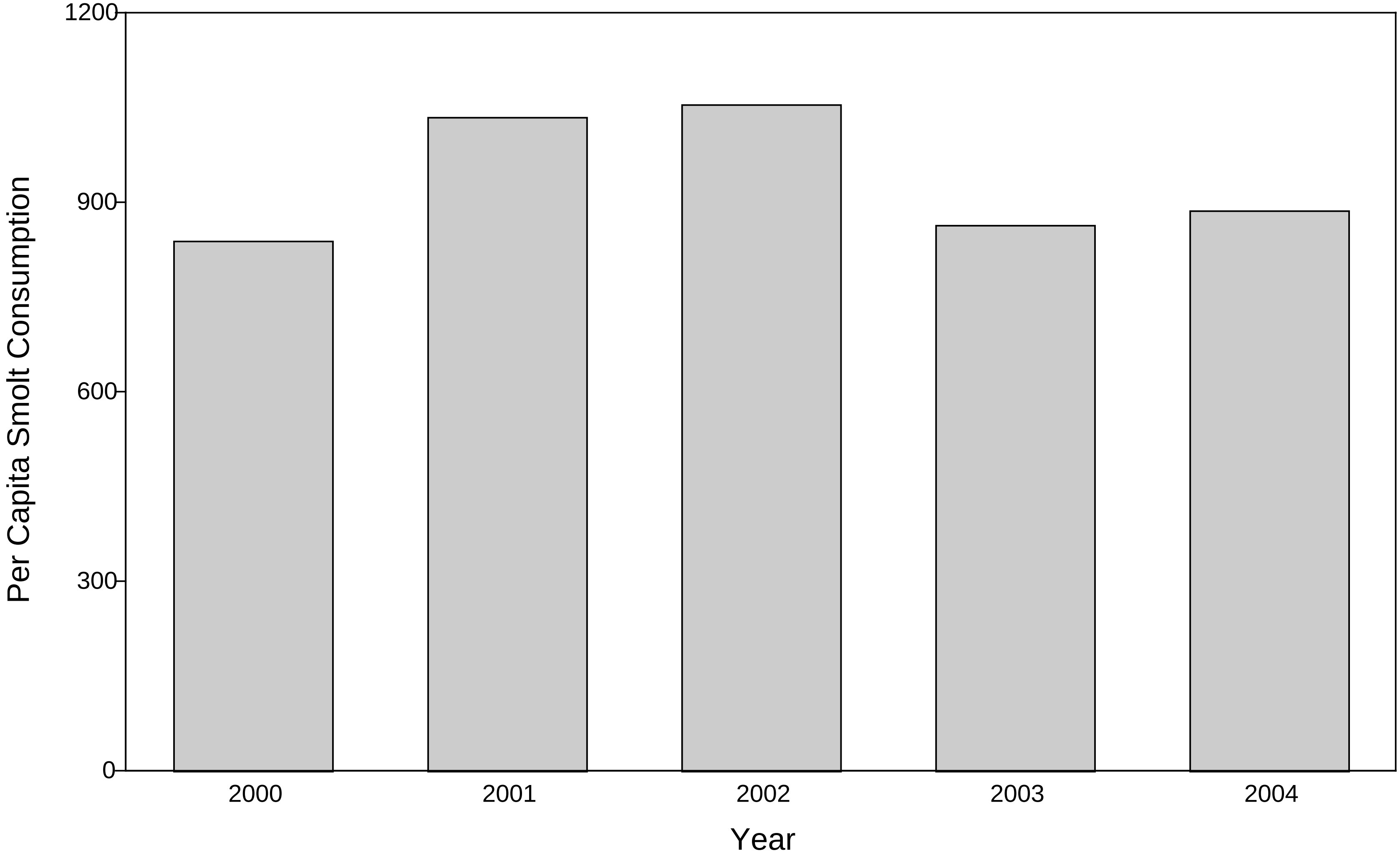


Figure 8. Per capita smolt consumption by Caspian terns nesting on Crescent Island, 2000 - 2004.

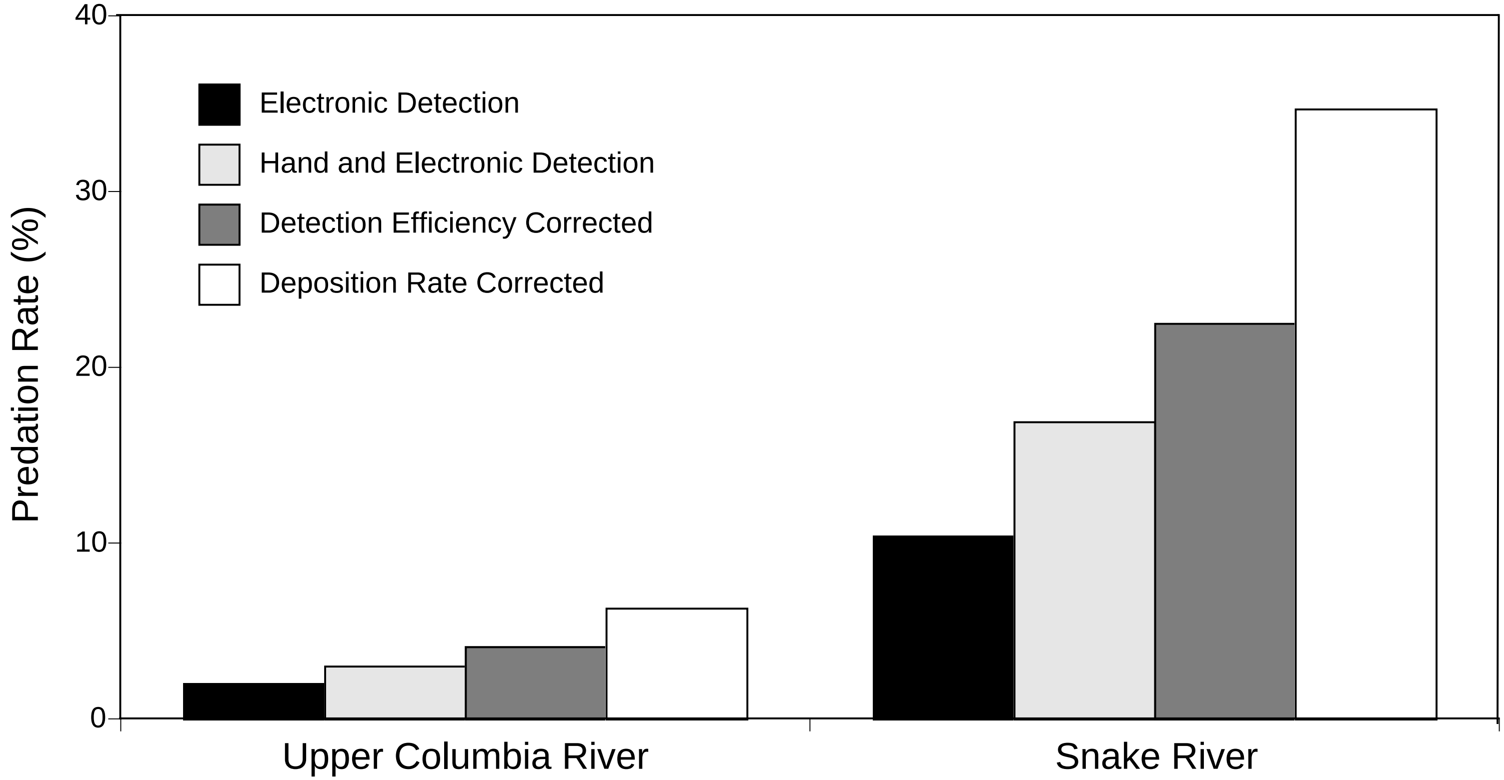


Figure 9. Predation rates on in-river steelhead from the Snake and Upper Columbia rivers by Caspian terns nesting on Crescent Island in 2004. Tags were from smolts interrogated at Lower Monumental Dam (Snake River) and Rock Island Dam (Upper Columbia River). Predation rate estimates were adjusted for bias due to tag collision, detection efficiency, and deposition rate.

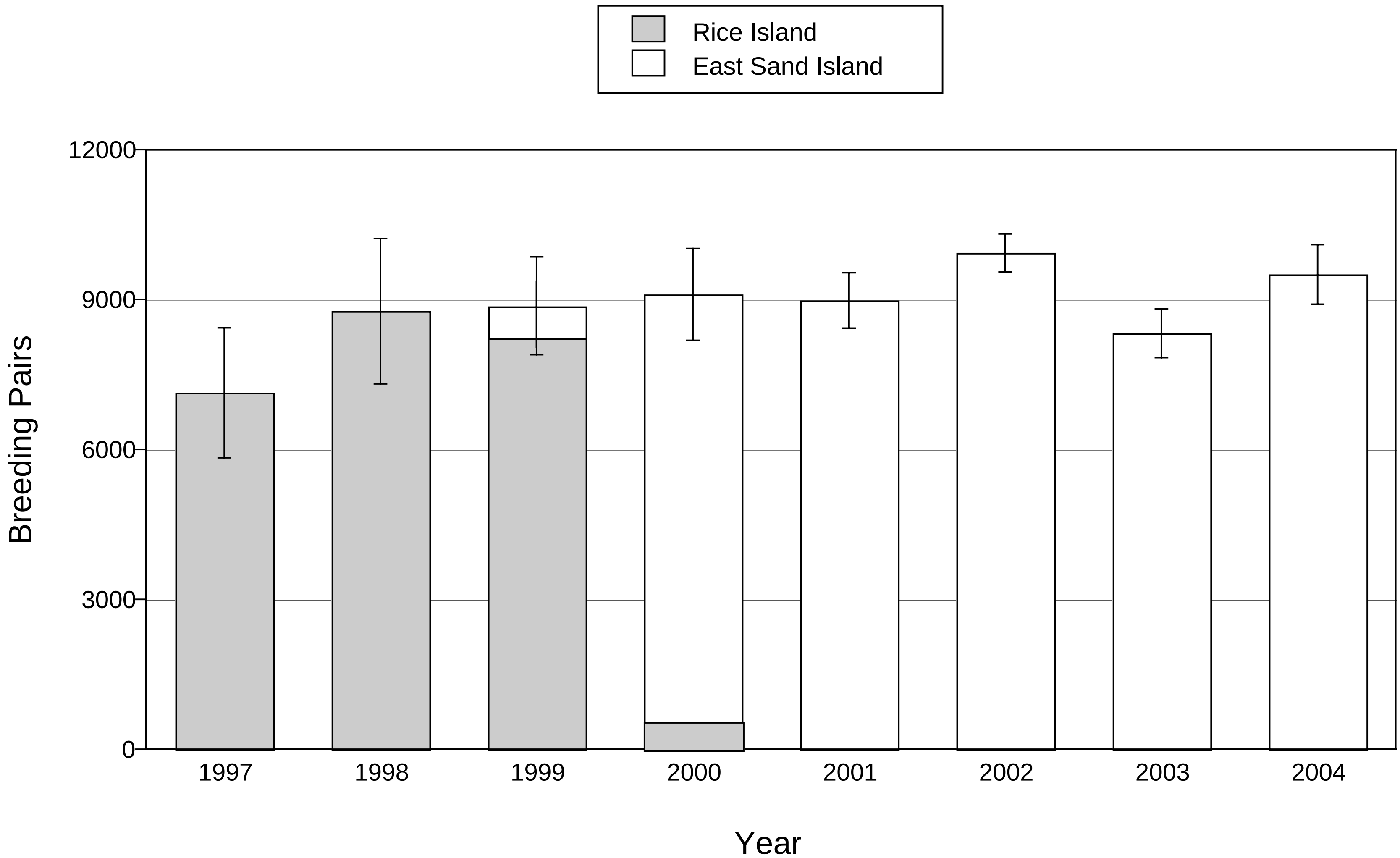


Figure 10. Caspian tern colony size in the Columbia River Estuary, 1997 - 2004.

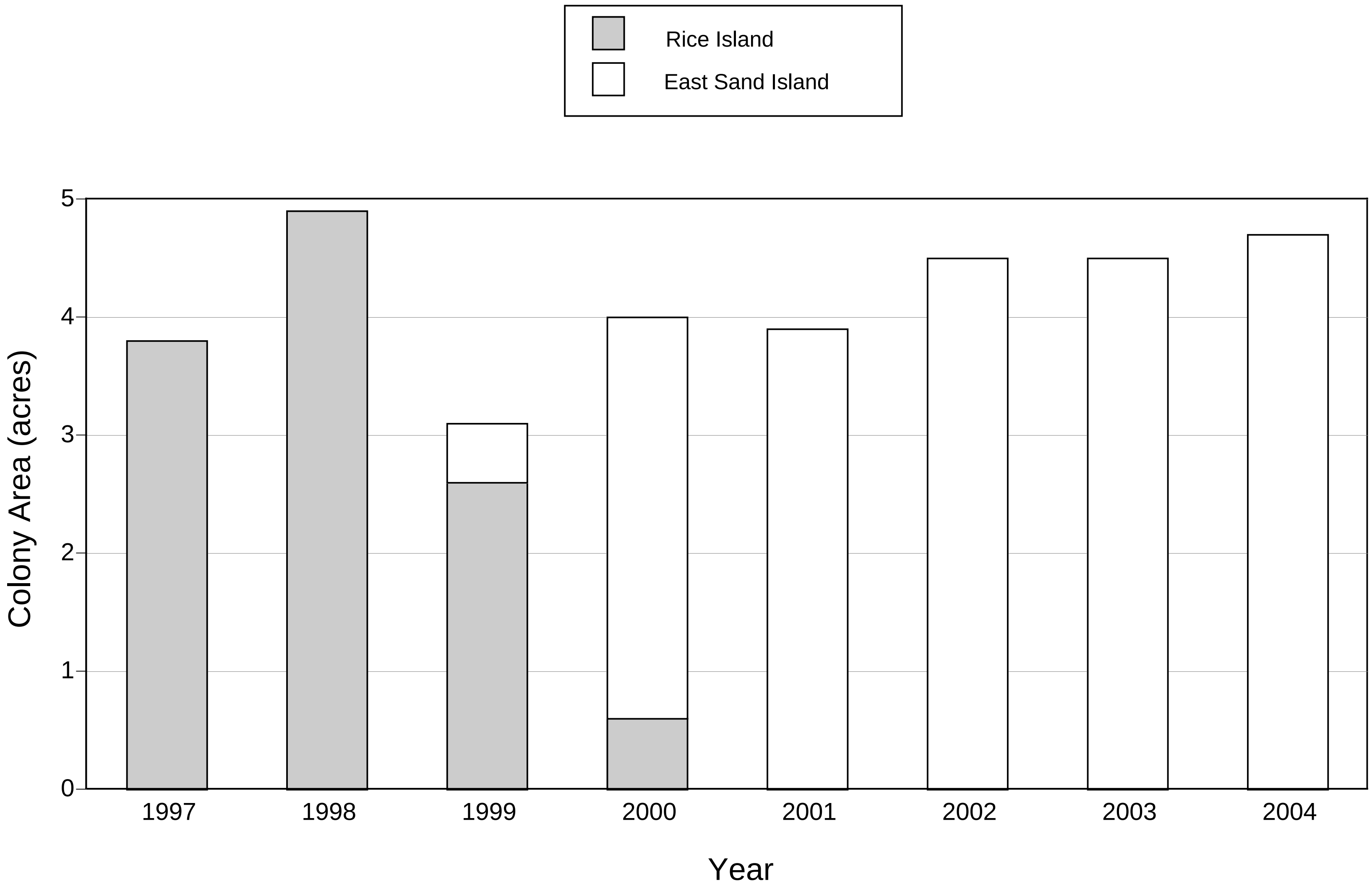


Figure 11. Caspian tern colony area in the Columbia River Estuary, 1997 - 2004.

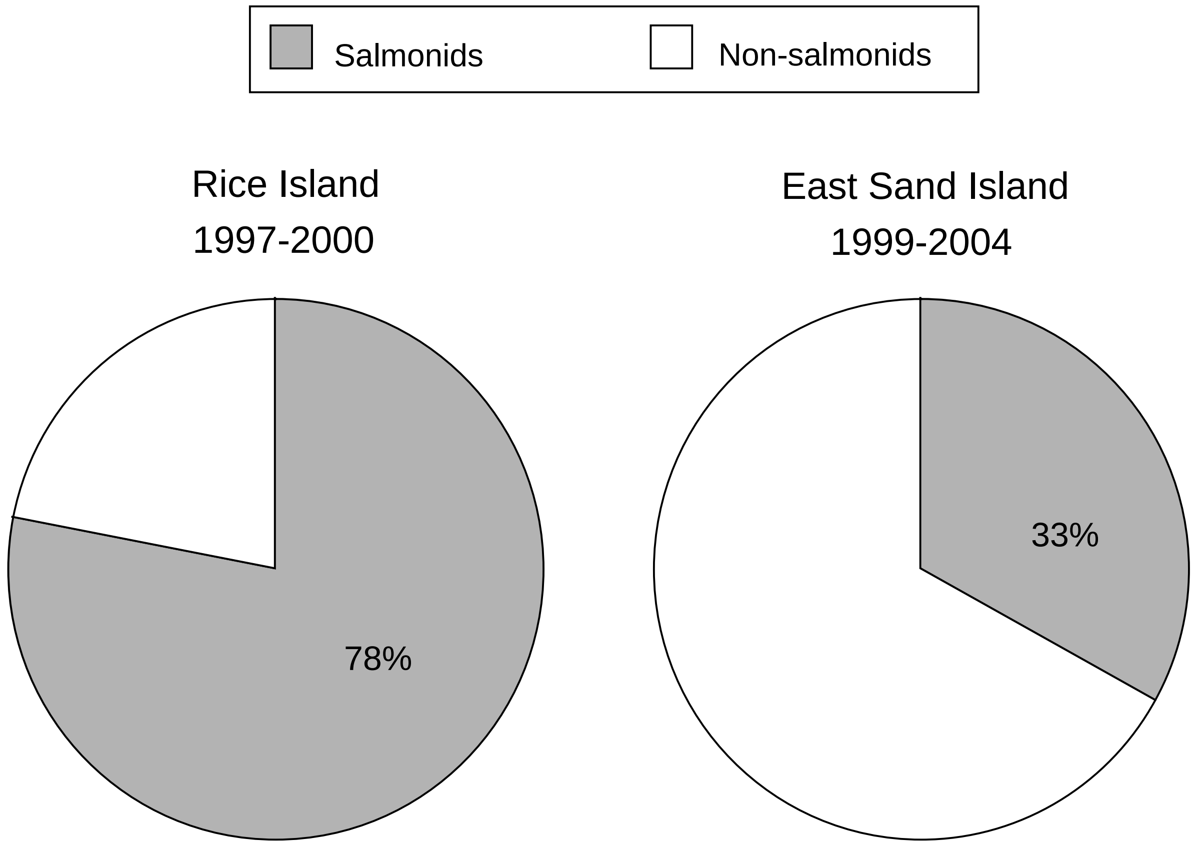


Figure 12. Mean proportion of juvenile salmonids in the diet of Caspian terns nesting on two colonies in the Columbia River Estuary, 1997-2004.

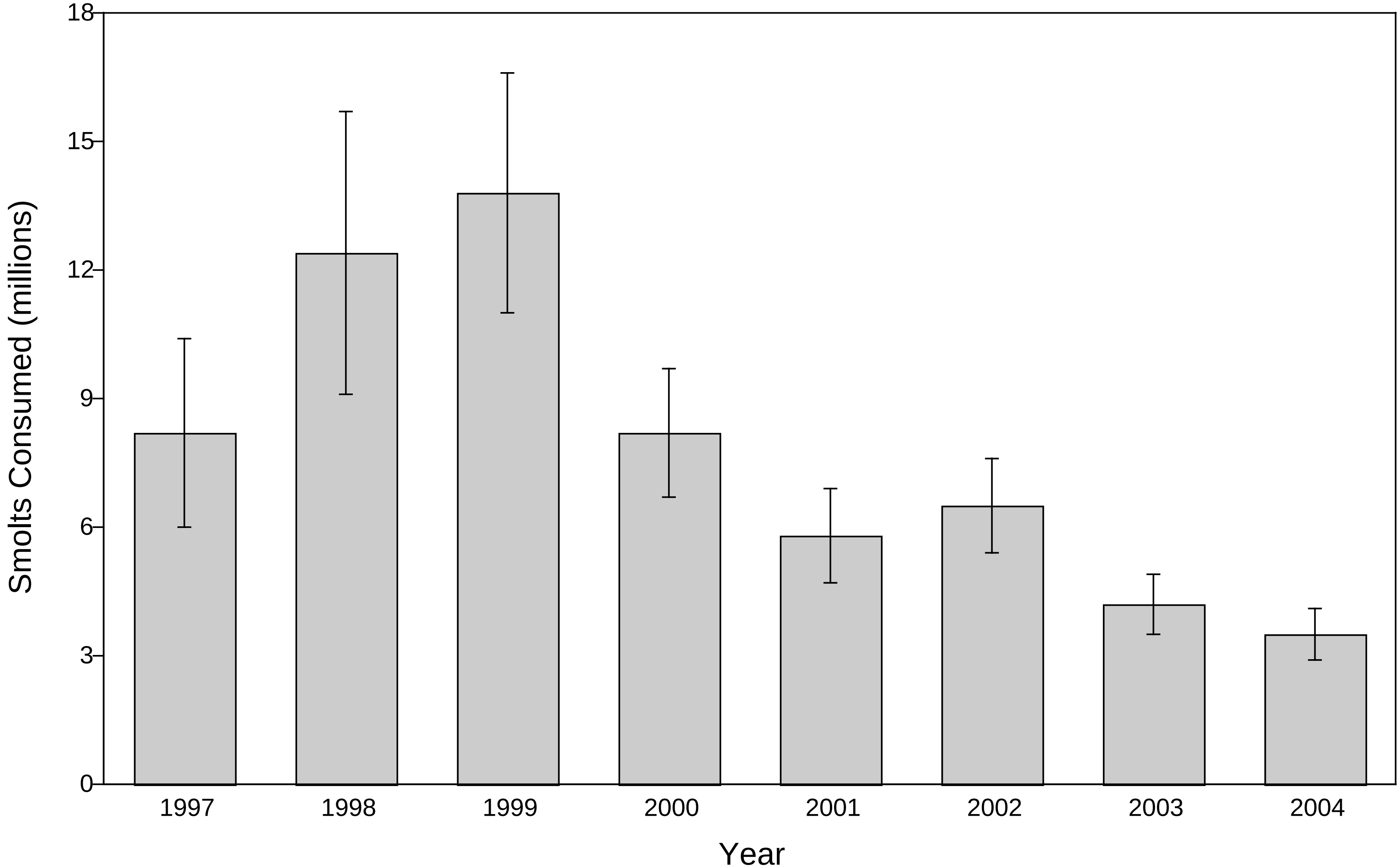


Figure 13. Total estimated consumption of juvenile salmonids by Caspian terns nesting in the Columbia River Estuary, 1997 - 2004.

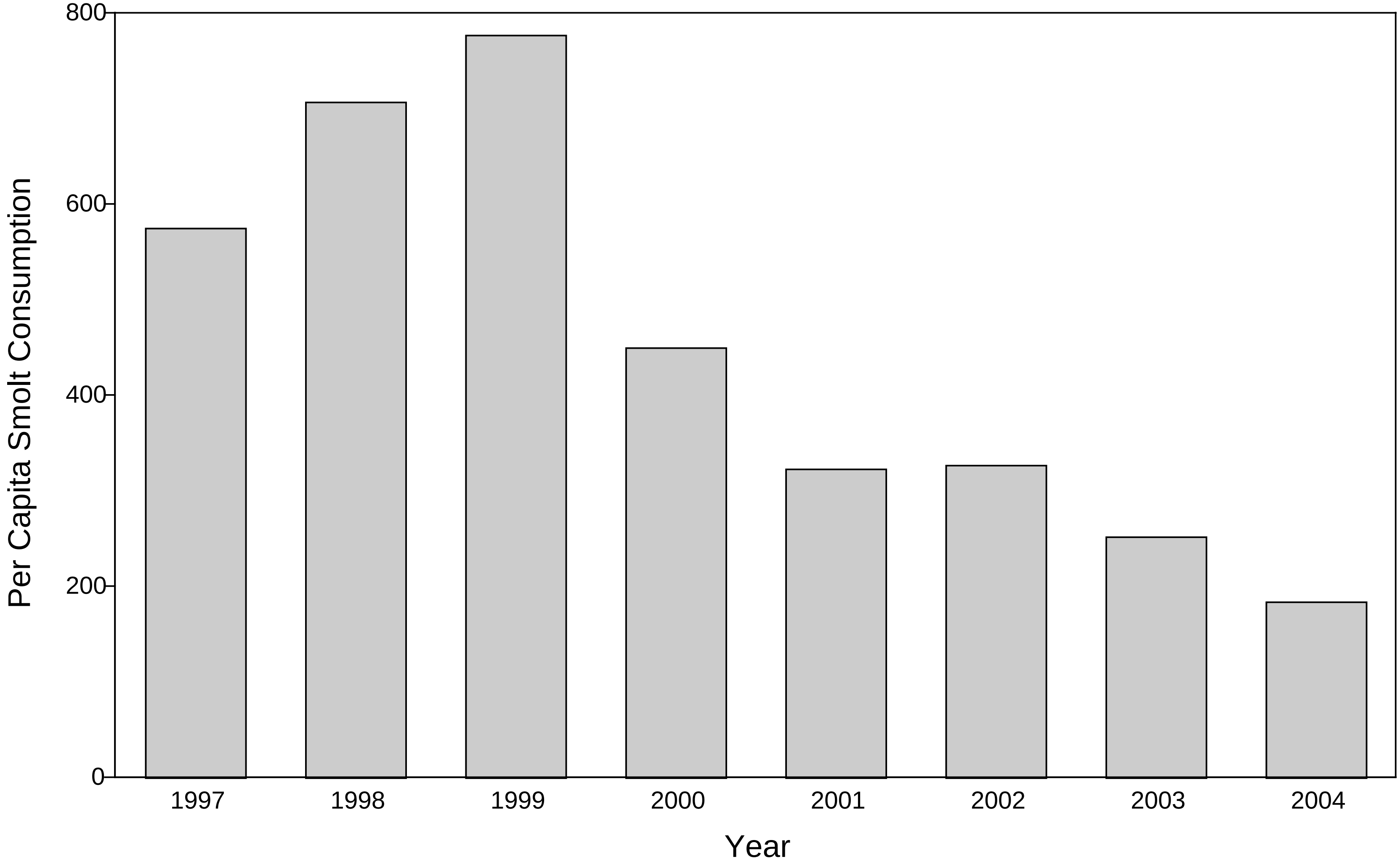


Figure 14. Per capita smolt consumption by Caspian terns nesting in the Columbia River Estuary, 1997 - 2004.

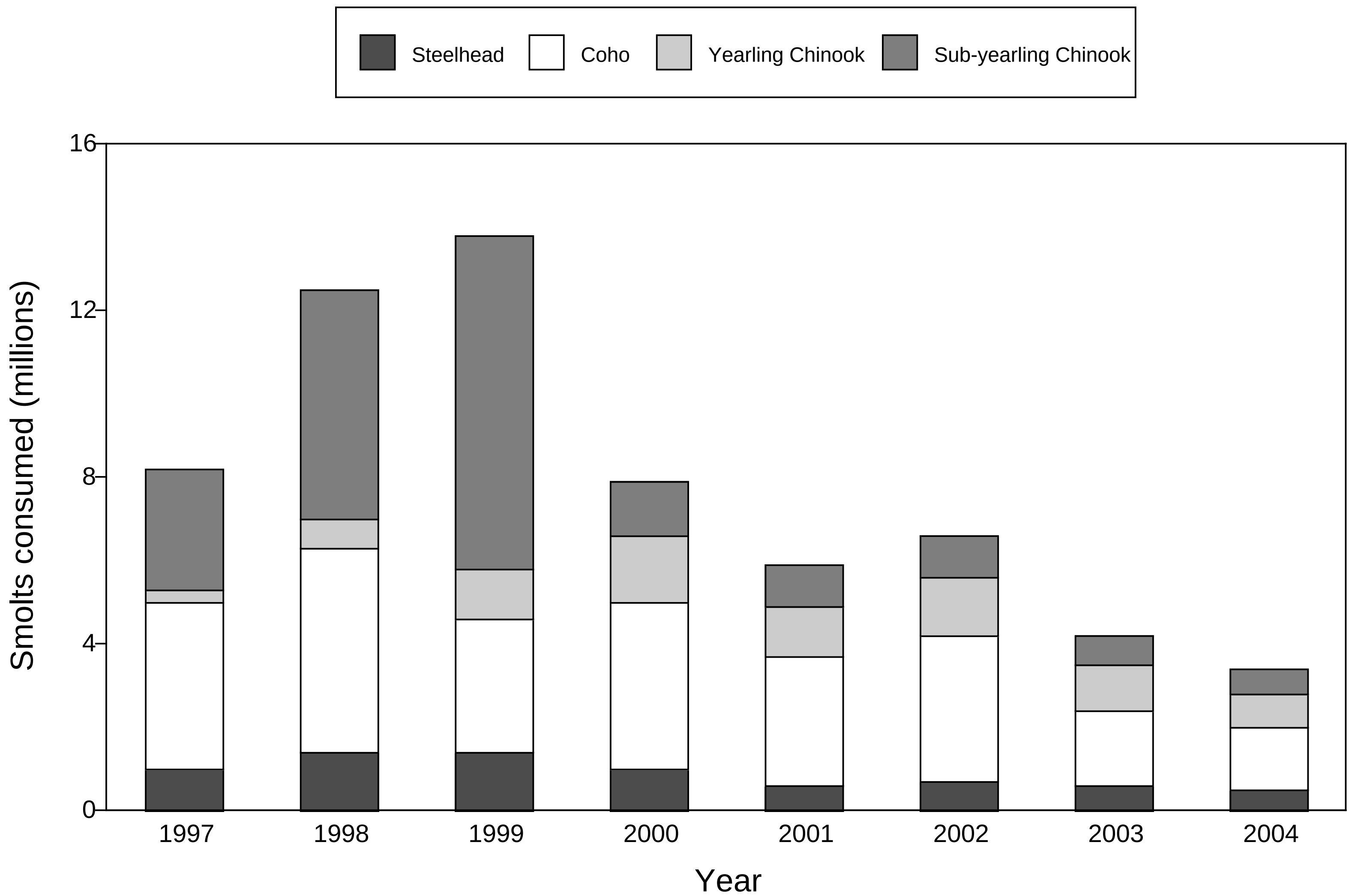


Figure 15. Total estimated consumption of three species of juvenile salmonids by Caspian terns nesting in the Columbia River Estuary, 1997-2004.

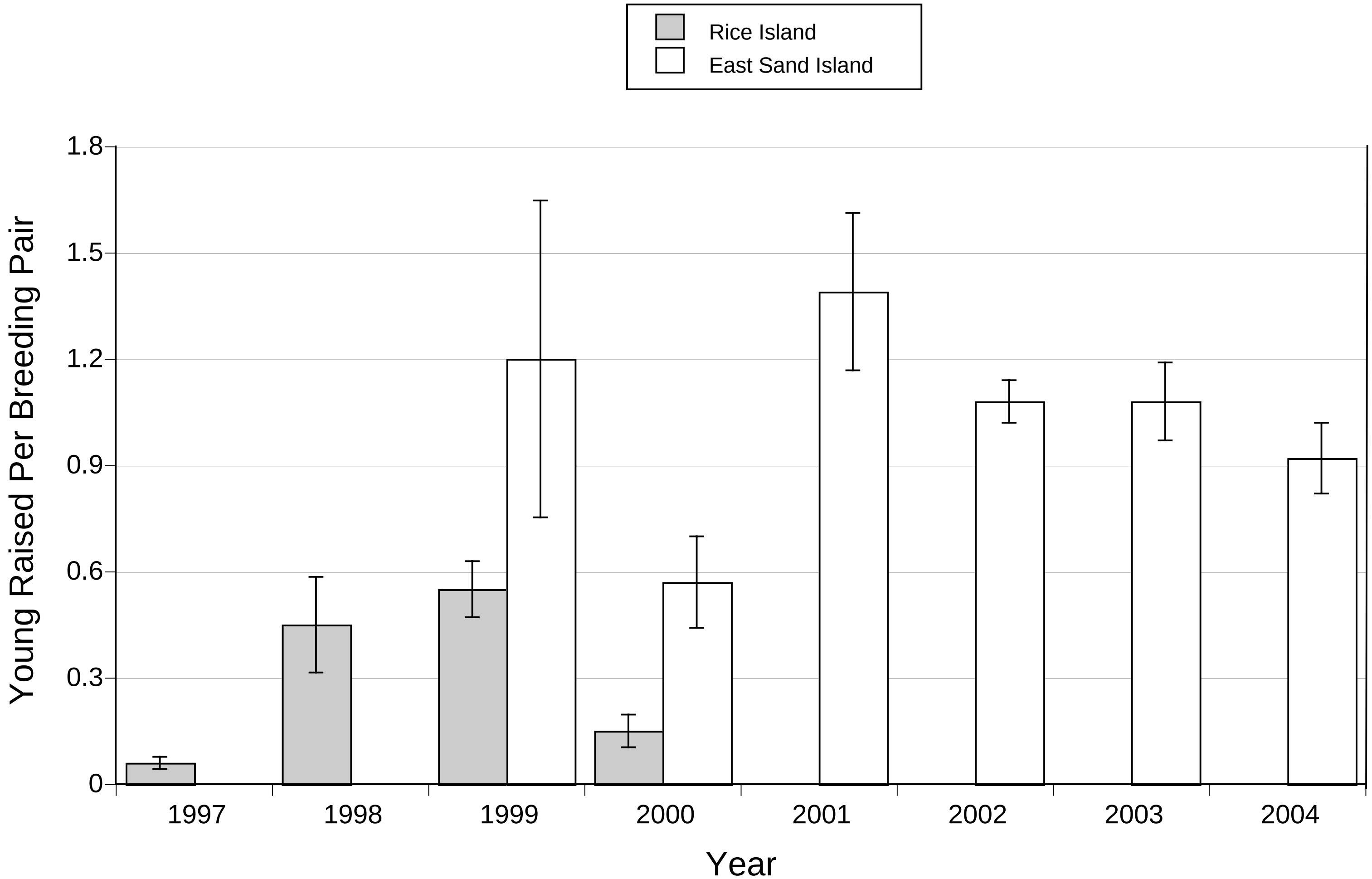


Figure 16. Caspian tern nesting success at two colonies in the Columbia River Estuary, 1997 - 2004.

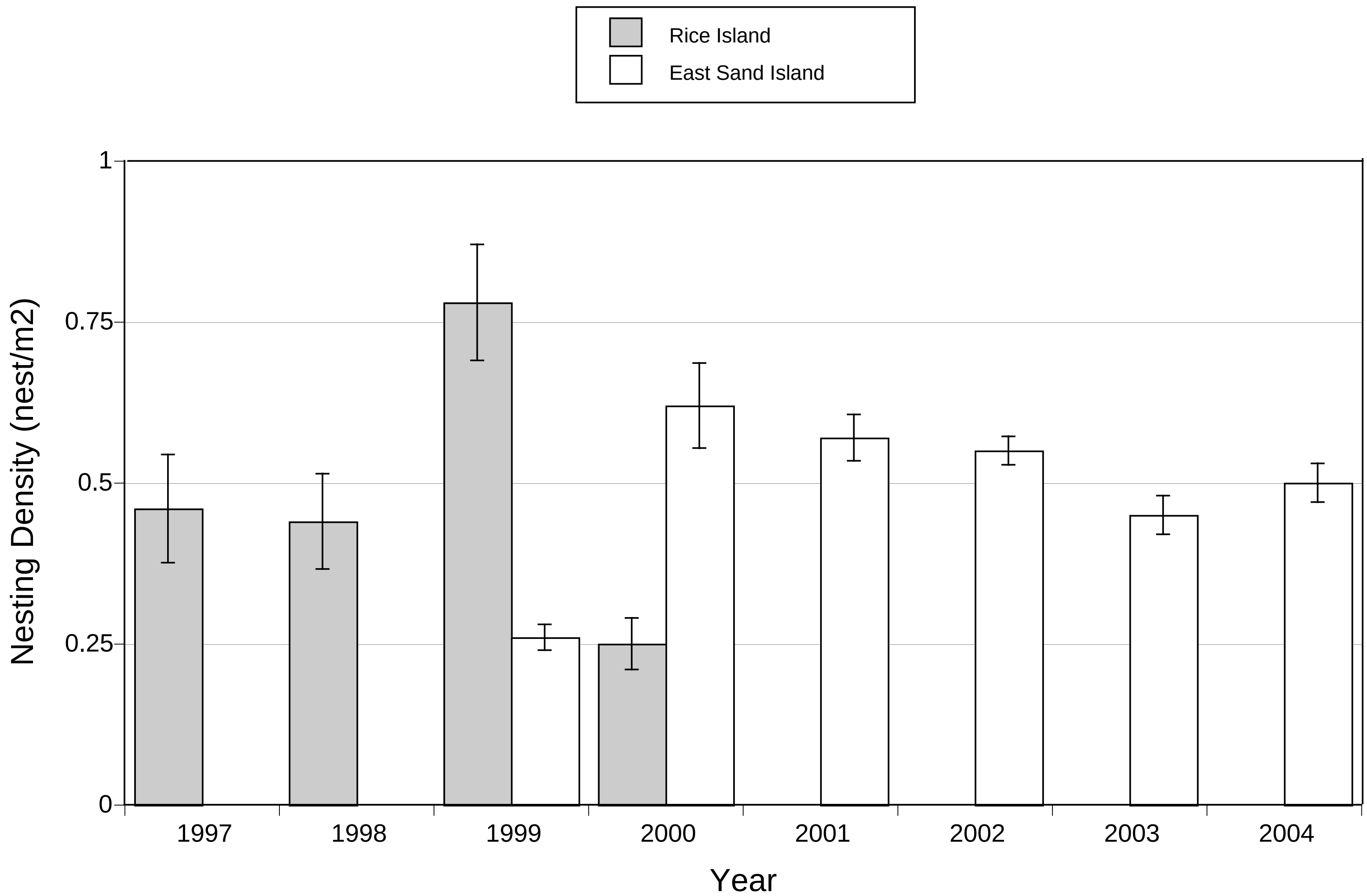


Figure 17. Caspian tern nesting density at two colonies in the Columbia River Estuary, 1997 - 2004.

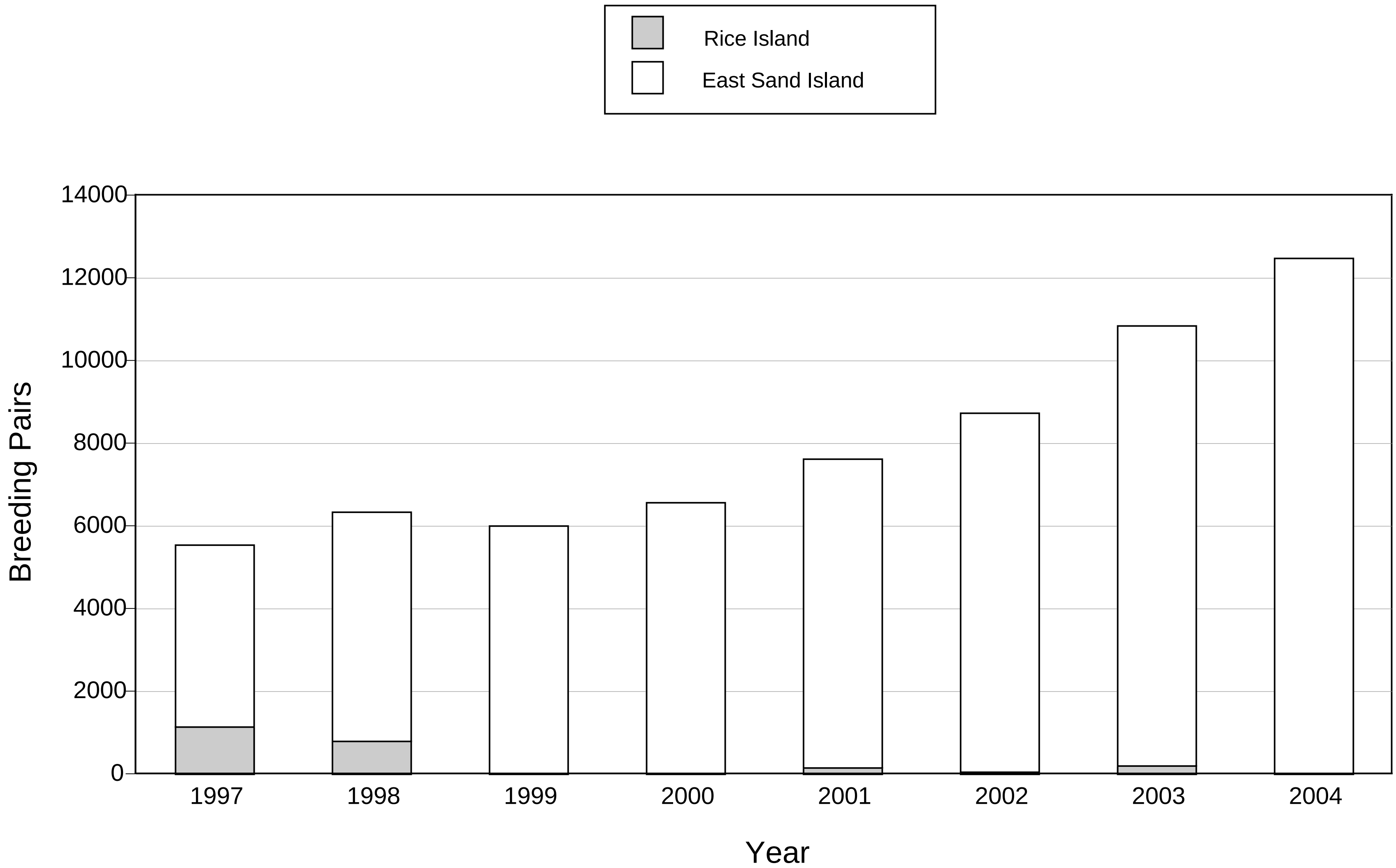


Figure 18. Double-crested cormorant colony size in the Columbia River Estuary, 1997 - 2004.

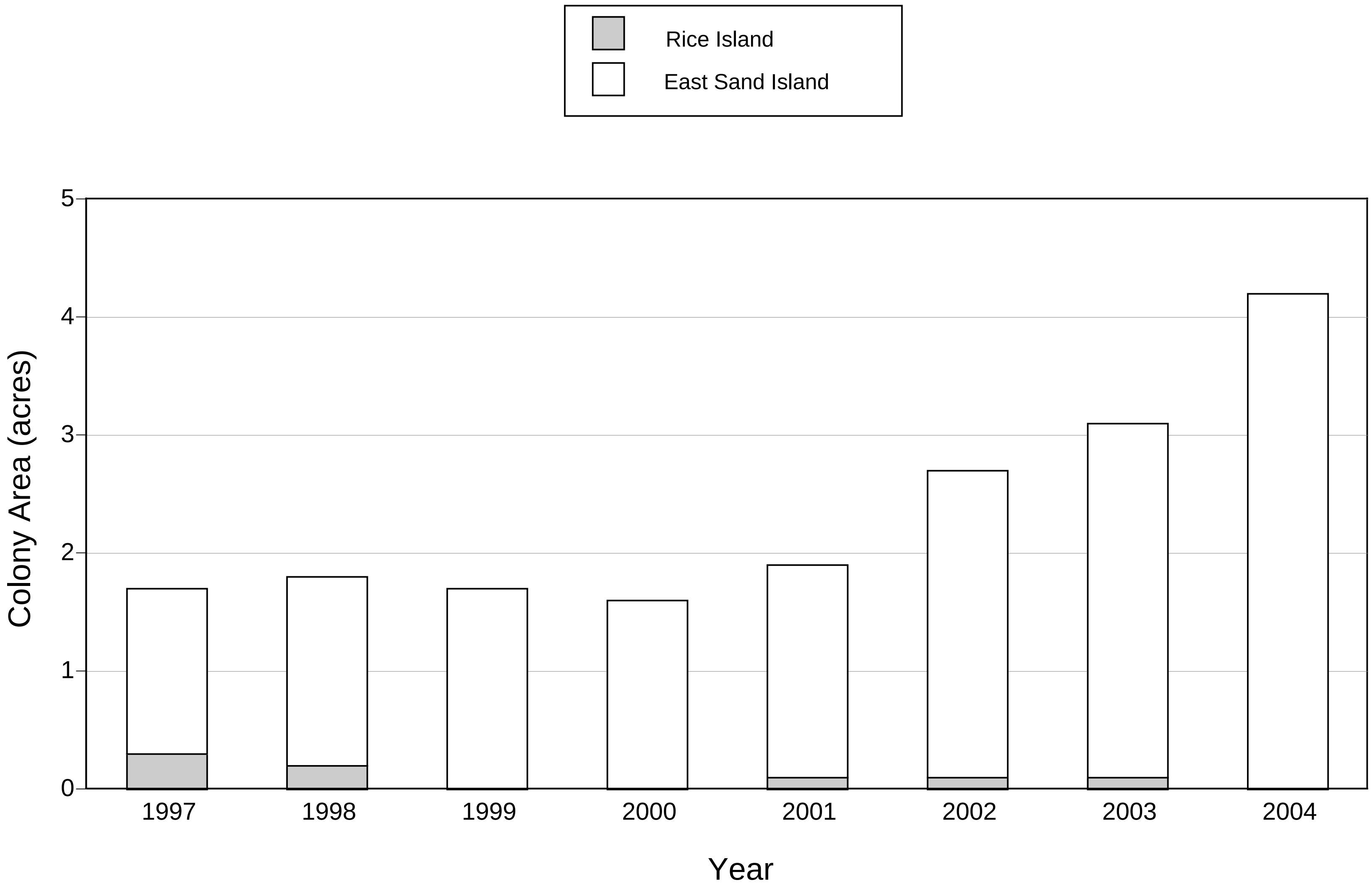


Figure 19. Double-crested cormorant colony area in the Columbia River Estuary, 1997 - 2004.

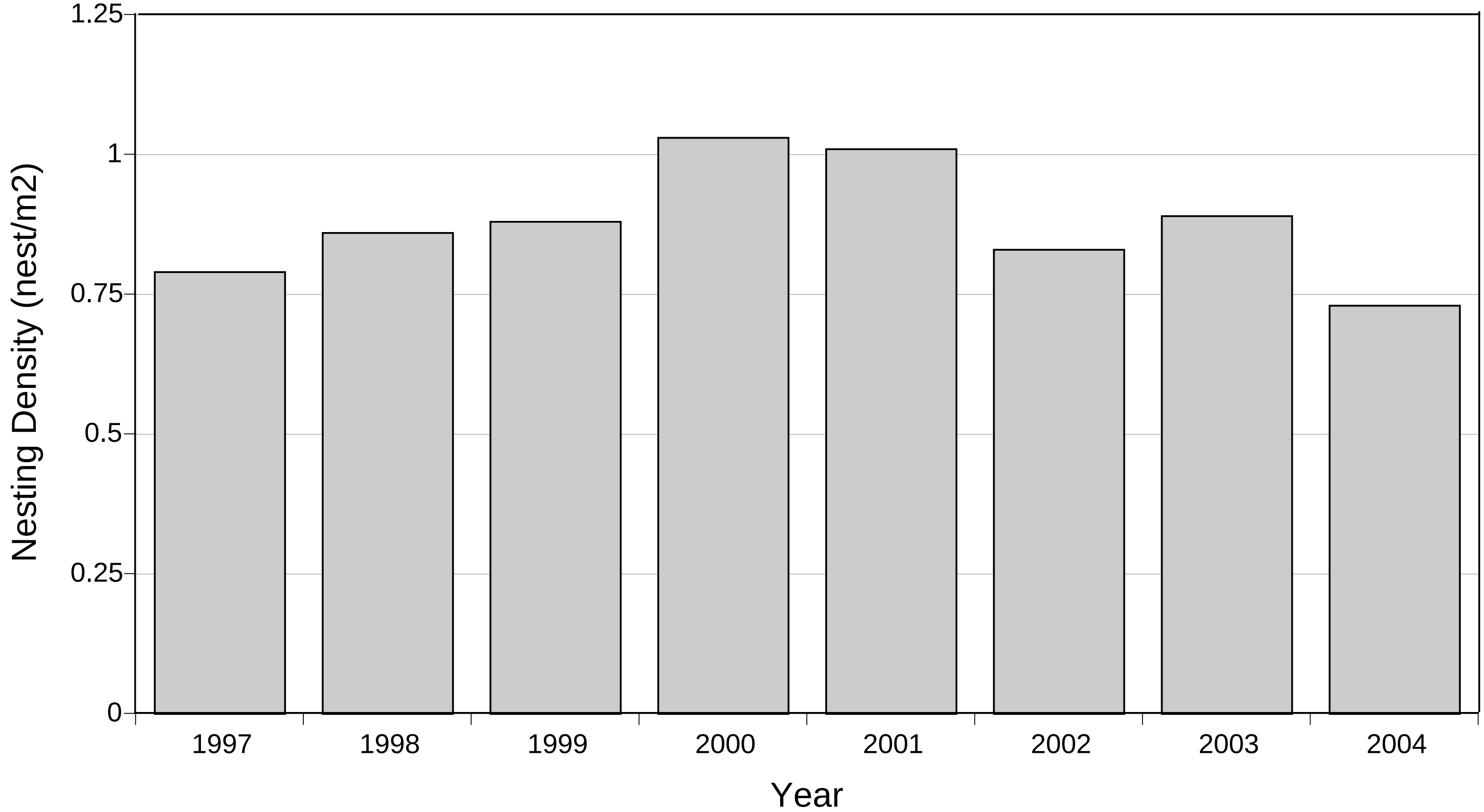


Figure 20. Double-crested cormorant nesting density at East Sand Island, 1997 - 2004.

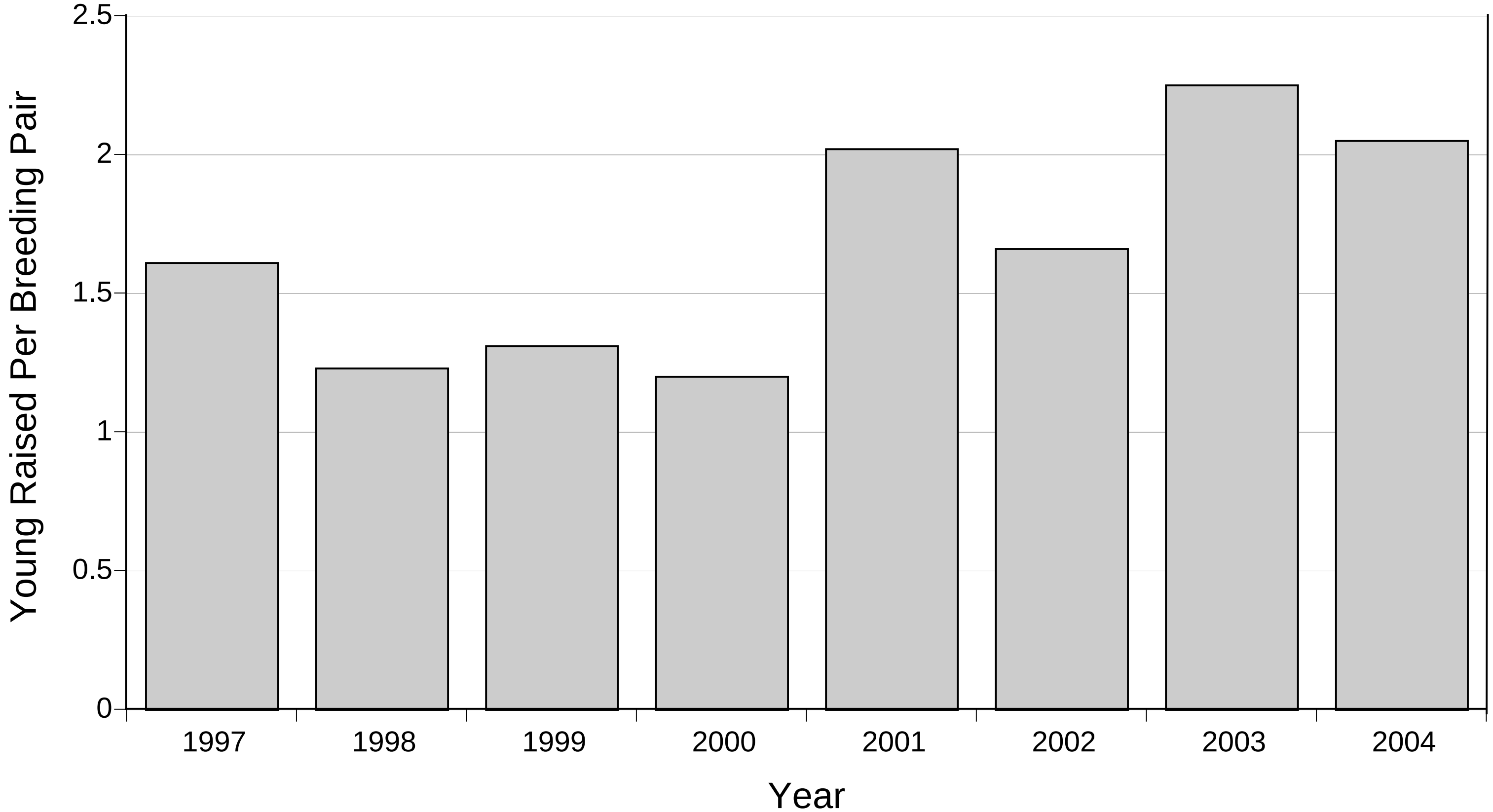


Figure 21. Double-crested cormorant nesting success at East Sand Island, 1997 - 2004.

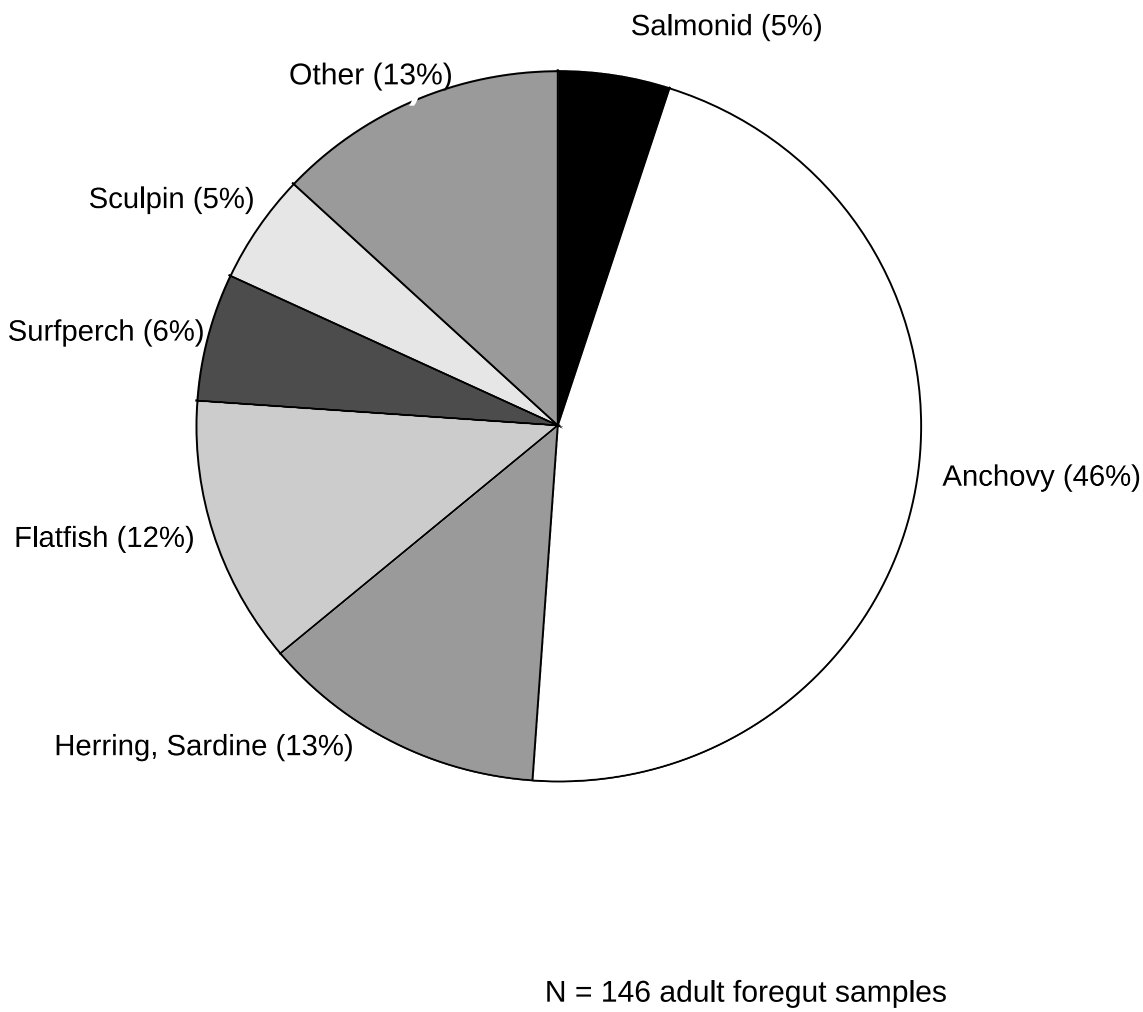


Figure 22. Preliminary diet composition (based on analysis of soft tissue only) of double-crested cormorants nesting on East Sand Island in 2004 (see text for methods of calculation).

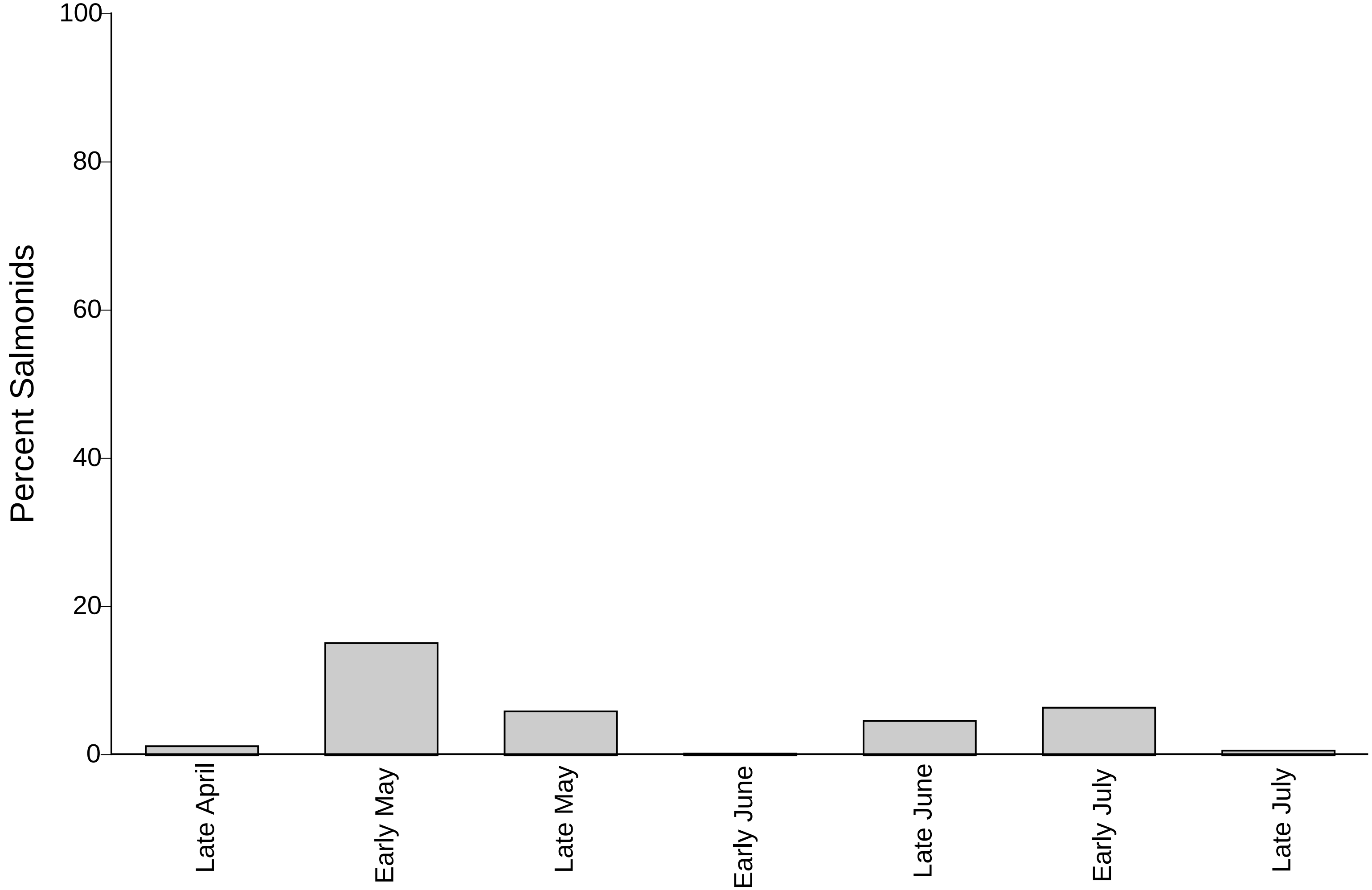


Figure 23. Proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in 2004.

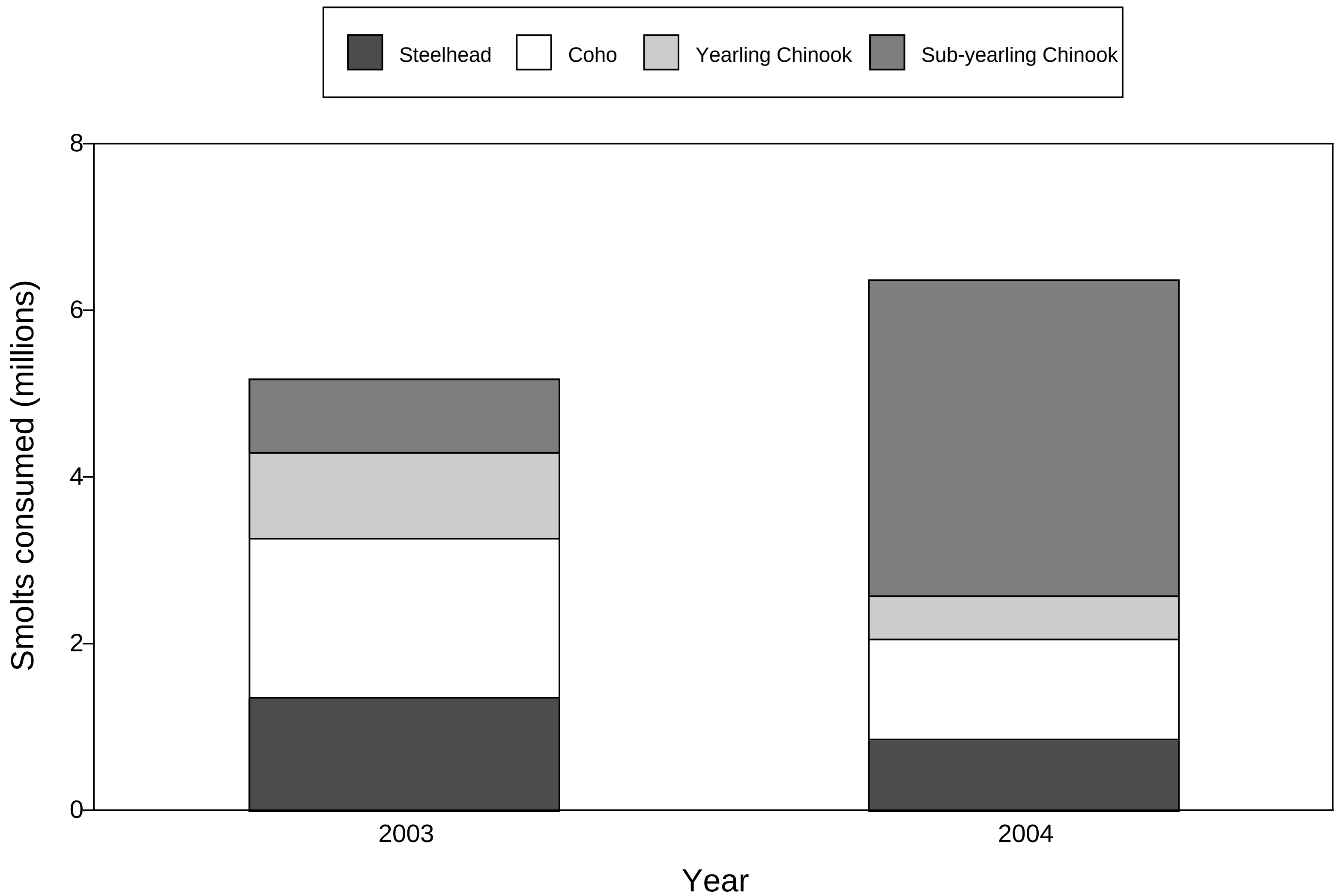


Figure 24. Total estimated consumption of three species of juvenile salmonids by double-crested cormorants nesting in the Columbia River Estuary, 2003-2004.

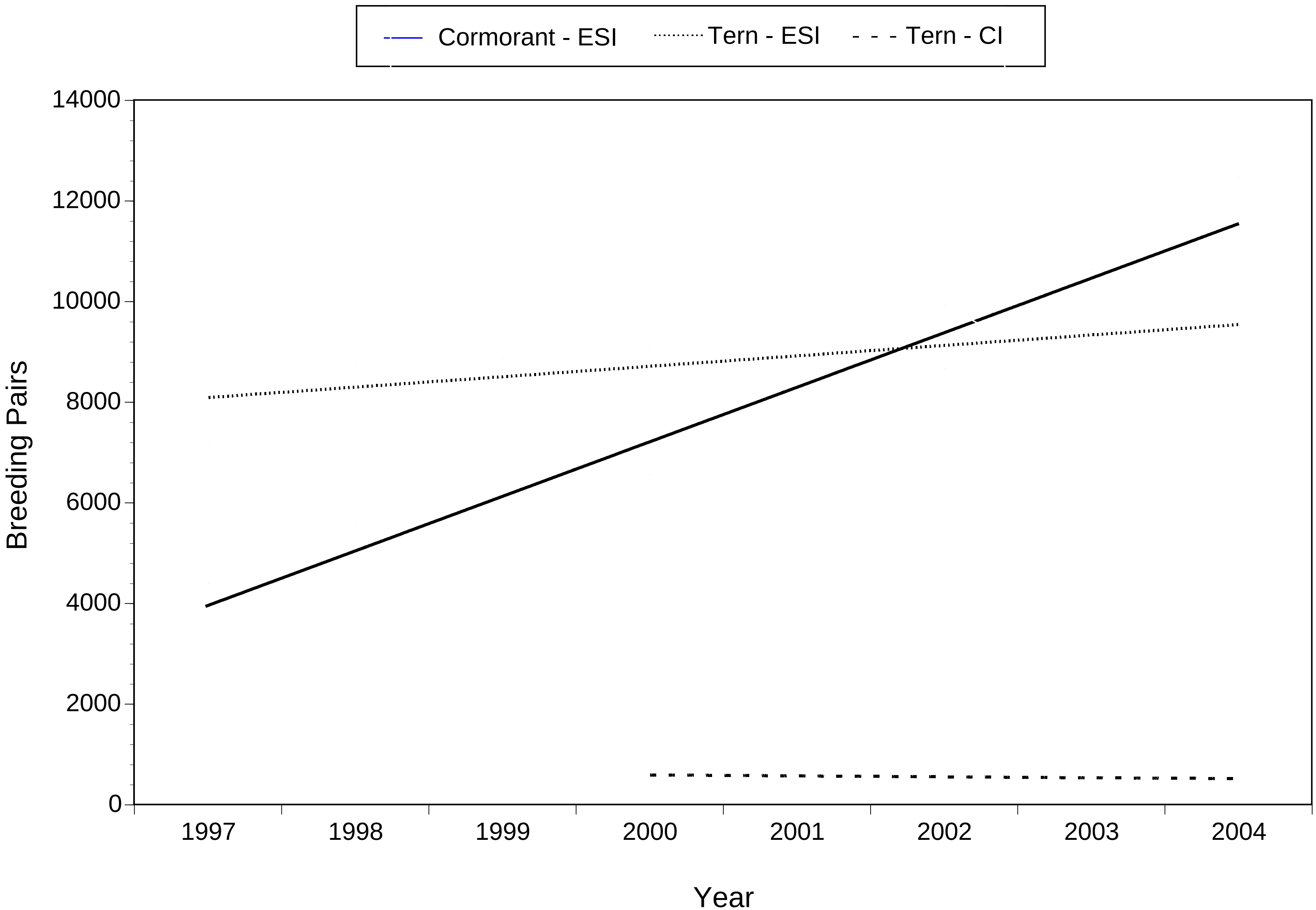


Figure 25. Population trends for double-crested cormorants and Caspian terns nesting on East Sand Island (ESI) and Caspian terns nesting on Crescent Island (CI), 1997 - 2004.

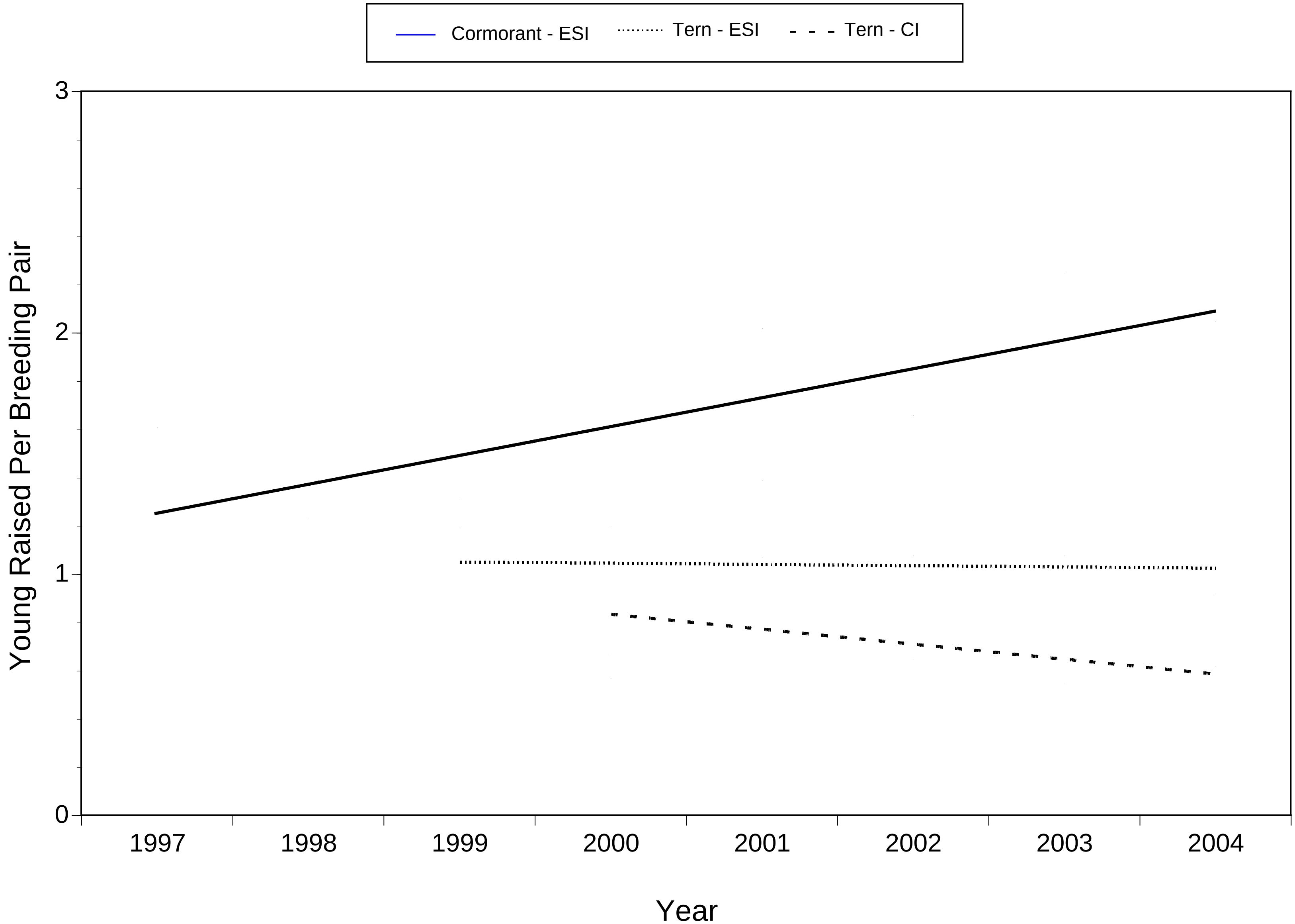


Figure 26. Productivity for double-crested cormorants and Caspian terns nesting on East Sand Island (ESI) and Caspian terns nesting on Crescent Island (CI), 1997 - 2004.

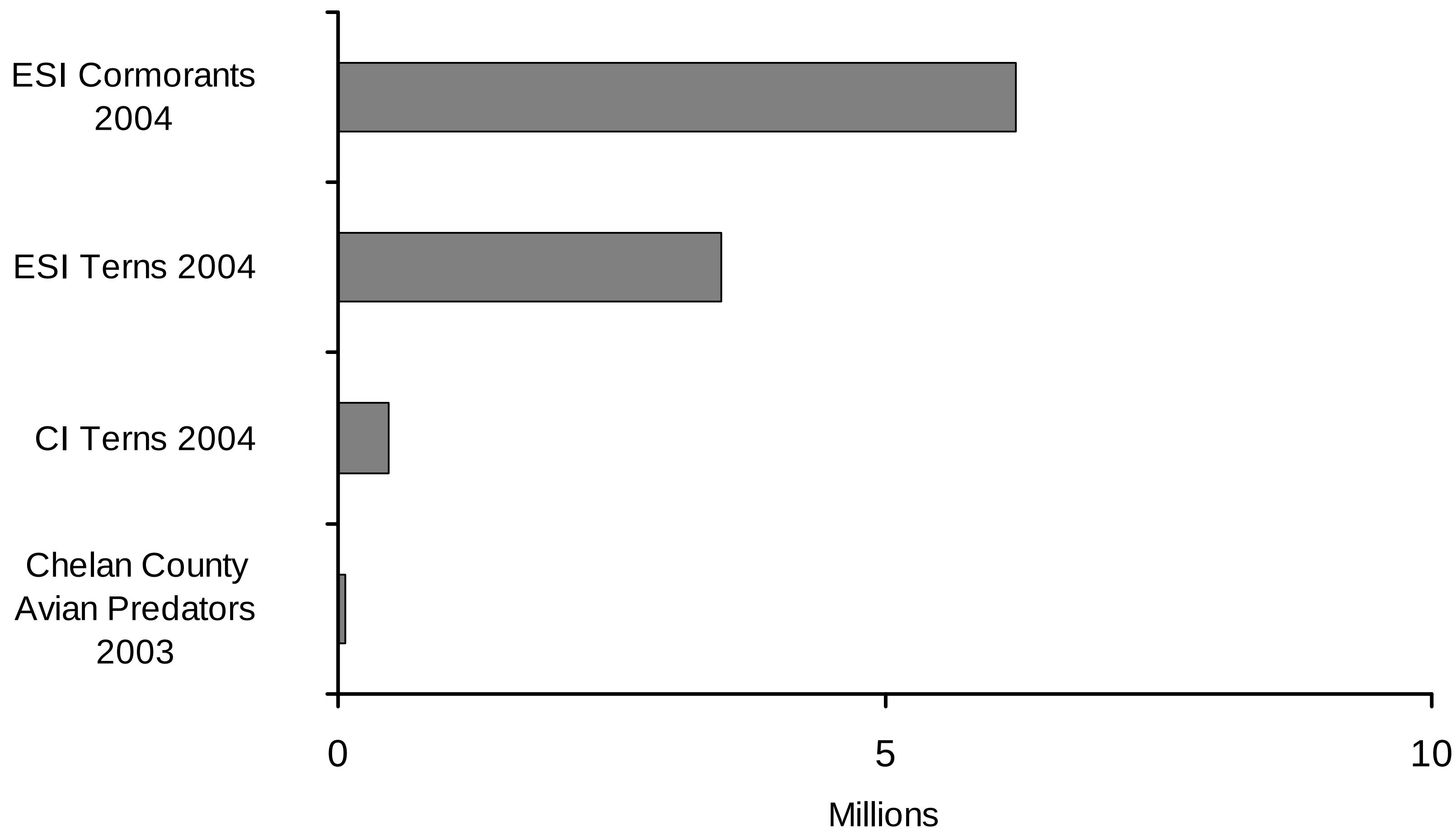


Figure 27. Juvenile salmonids consumed by selected avian predators in the Columbia River basin (ESI = East Sand Island, CI = Crescent Island). A variety of avian predators at Rock Island and Rocky Reach Dams and the associated reservoirs in Chelan County, Washington consumed 45,000 – 65,000 smolts in 2003 (Parrish et al. 2004).

Table 1. Diet composition (% identifiable prey items) of Caspian terns nesting on Rice Island and East Sand Island, 1997-2004.

	1997-1998	1999		2000		2001	2002	2003	2004
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.
Herring, sardine, shad	10.7	1.8	8.2	1.7	10.1	20.3	18.4	18.5	29.3
Anchovy	0.0	6.5	15.9	0.5	11.6	22.4	14.1	23.7	25.2
Peamouth, pike minnow	2.0	1.0	0.5	0.9	0.8	0.6	0.5	0.1	0.7
Smelt	6.2	0.9	3.8	0.7	5.6	5.1	7.3	17.6	9.3
Salmonid	**72.7**	**76.5**	**45.6**	**89.6**	**46.5**	**32.5**	**31.1**	**24.1**	**16.8**
Cod	0.0	0.0	0.0	0.0	0.0	2.2	0.1	0.3	2.4
Sculpin	1.2	1.3	3.3	1.9	5.1	3.6	2.4	3.0	3.1
Surfperch	5.5	2.8	10.7	1.2	10.0	5.9	11.6	6.7	11.5
Pacific sand lance	0.1	0.1	5.9	0.1	5.6	3.1	2.5	4.5	0.2
Flounder	0.2	0.3	0.2	1.8	0.6	0.2	0.1	0.0	0.2
Other	1.4	8.7	5.8	1.6	3.9	3.9	11.9	1.5	1.4
Total no. of prey	1,448	5,305	5,486	5,023	5,387	6,007	5,661	5,476	5,854

Table 2. Number of Passive Integrated Transponder **(**PIT) tags removed by hand from the Crescent Island tern colony, 2004. Unique or newly discovered tags represent the number of PIT tags not previously detected by NOAA Fisheries using electronics.

Removal Date	No. PIT tags Removed	No. Functional (% of total)	No. Unique
24-26 March	10,278	5,854 (60.0%)	688
17-19 August	21,625	19,077 (88.2%)	7,921
TOTAL	31,903	24,931 (78.1%)	8,609

Table 3. Detection efficiency (DE) of test PIT tags intentionally released (R) on the Crescent Island tern colony during four discrete time periods in 2004. Test tags were distributed evenly among four study plots.

	Plot 1		Plot 2		Plot 3		Plot 4		
Date	R	DE	R	DE	R	DE	R	DE	TOTAL
26 March	71	70.4%	70	42.9%	70	61.4%	70	58.6%	58.3%
10 May	70	81.4%	70	71.4%	70	88.6%	70	81.8%	81.8%
3 July	50	84.0%	50	86.0%	50	92.0%	50	90.0%	90.0%
29 July	50	100%	50	98.0%	50	100%	50	99.0%	99.0%
TOTAL	241	82.6%	240	71.7%	240	83.3%	240	83.3%	80.2%

Table 4. Predation rates by Crescent Island terns on all PIT-tagged salmonid smolts released in-river, 2004. PIT-tagged smolts are from seven different listed Evolutionarily Significant Units (ESU's). 95% confidence intervals (±) based on the normal approximation and were derived from release groups of PIT-tagged smolts within the corresponding ESU. Predation rate estimates were adjusted for bias due to tag collision and detection efficiency.

	Released In-river		Average Predation Rate		
ESU	Hatchery	Wild	Hatchery	Wild	Over-all
SR steelhead	41,784	32,150	10.8% (±5.5)	4.8% (±4.5)	7.6% (±4.0)
UCR steelhead	385,810	-	2.1% (±1.0)	-	2.1% (±1.0)
MCR steelhead	12,261	3,544	1.3% (±0.7)	2.0% (±0.6)	1.5% (±1.0)
SR F chinook	36,455	1,995	0.8%	0.0%	0.7%
UCR S chinook	331,574	2,389	0.3% (±0.2)	0.0%	0.3% (±0.2)
SR S/S chinook	205,210	82,967	0.3% (±0.2)	0.2% (±0.2)	0.3% (±0.2)
SR sockeye	4,714	616	0.0%	0.0%	0.0%

Table 5. Stock-specific predation rates by Crescent Island terns on all PIT-tagged salmonid smolts released (R) in-river, 2004. Stock identification within each Evolutionarily Significant Unit (ESU) is based on genetic and geographic criteria developed by NOAA Fisheries. Sample sizes and predation rates are listed separately for hatchery (H) and wild (W) fish. Predation rate estimates were adjusted for bias due to tag collision and detection efficiency.

Species	ESU	Stock	Released H	Released W	Predation Rate H	Predation Rate W	Predation Rate Overall
Steelhead	SR						
		Imnaha River	4,876	3,717	16.31%	8.62%	12.99%
		Grande Ronde River	5,757	5,685	7.47%	3.53%	5.51%
		Clearwater River	12,419	9,618	12.80%	2.22%	8.18%
		Salmon River	8,254	11,146	12.12%	0.82%	5.62%
		Lower Snake	10,478	1,984	5.34%	8.61%	5.86%
		Average			**10.81%**	**4.76%**	**7.63%**
	UCR						
		Okanogan River	45,026	-	2.28%	-	2.28%
		Methow River	247,471	-	1.59%	-	1.59%
		Entiat River	-	-	-	-	-
		Wenatchee River	93,313	-	2.28%	-	2.28%
		Average			**2.05%**	**-**	**2.05%**
	MCR						
		Walla Walla & Touchet	9,921	2,259	1.22%	2.26%	1.41%
		Yakima	-	976	-	2.17%	2.17%
		Umatilla	2,340	309	1.71%	0.00%	1.51%
		Average			**1.46%**	**1.48%**	**1.70%**
Chinook	SR Fall						
		Mainstem Snake River	36,455	1,995	0.80%	0.00%	0.76%
	SR S/S						
		Salmon River	98,918	56,008	0.35%	0.15%	0.28%
		Grande Ronde/Imnaha	54,752	9,663	0.26%	0.28%	0.27%
		Lower Snake River	2,041	-	0.06%	-	0.06%
		Clearwater River	49,499	17,296	0.50%	0.25%	0.43%
		Average			**0.29%**	**0.19%**	**0.24%**
	UCR S						
		Methow River	55,731	-	0.26%	-	0.26%
		Entiat River	59,052	719	0.54%	0.00%	0.53%
		Wenatchee River	216,791	1,670	0.23%	0.00%	0.23%
		Average			**0.34%**	**0.00%**	**0.34%**
Sockeye	SR						
		Redfish Lake	4,714	616	0.00%	0.00%	0.00%
TOTAL		ALL STOCKS	1,017,808	123,621	1.34%	0.99%	1.30%

Table 6. Estimated predation rates by Crescent Island terns on PIT-tagged salmonid smolts that were interrogated/tagged at Lower Monumental Dam (Snake River; SR), Rock Island Dam (Upper Columbia River; UCR), and the Middle Columbia River (from fish released below the confluence of the Snake and Upper Columbia rivers but upstream of McNary dam; MCR). Predation rates on wild or naturally produced smolts are listed separately (% wild) for each species and river location. Predation rate estimates were adjusted for bias due to tag collision and detection efficiency.

		Estimated Predation Rate		
Species	Sample	SR (% wild)	UCR (% wild)	MCR (% wild)
Steelhead	32,809	22.5% (18.9)	3.9% (3.5)	4.1% (6.9)
Yearling Chinook	118,460	1.5% (1.5)	0.8% (-)	0.4% (1.1)
Sub-yearling Chinook	28,801	1.2% (-)	-	0.3% (0.3)
Coho	13,098	9.3% (-)	-	0.4% (-)
Sockeye	1,151	0.0%	0.8% (0.8)	N.A.

Table 7. Transportation-corrected predation rates by Crescent Island terns for PIT-tagged juvenile steelhead, yearling chinook, and sub-yearling chinook, 2004. Tags were from smolts interrogated at Lower Monumental Dam (Snake River) and Rock Island Dam (Upper Columbia River). Predation rates for Snake River smolts were adjusted by accounting for the proportion of fish that were transported in fish barges or trucks around Crescent Island (i.e., fish not available to terns). Smolts from the Upper Columbia River were not transported. Predation rate estimates were adjusted for bias due to tag collision and detection efficiency.

	Snake River		Upper Columbia River
	In-River Predation Rate	Adjusted Predation Rate[a]	In-River Predation Rate
Steelhead	22.5%	0.8%	3.9%
Yearling Chinook	1.5%	0.2%	0.8%
Sub-yearling Chinook	1.2%	< 0.1%	0.3%

[a] Calculated by multiplying the PIT tag predation rate by the proportion of the run that migrated in-river based on transportation data from Lower Granite Dam (i.e., transportation rate of 96.4% for steelhead, 87.2% for yearling chinook, and 95.2% for sub-yearling chinook; FPC 2004).

Table 8. Diet composition (% identifiable biomass) of double-crested cormorants nesting on Rice Island and East Sand Island, 1997-2004.

	1997-1998		1999	2000	2001	2002	2003	2004
Prey Type	Rice Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.
Herring, sardine, shad	0.6	27.8	4.7	11.4	17.1	30.7	11.7	13.3
Peamouth, pike minnow	24.0	10.7	8.6	5.5	2.9	5.1	4.3	5.1
Sucker	5.8	4.7	4.3	1.2	0.0	0.0	2.8	1.9
Smelt	0.3	7.6	0.8	0.6	0.9	8.7	2.0	1.2
Salmonid	**45.7**	**15.9**	**24.7**	**18.3**	**9.3**	**5.2**	**9.3**	**4.9**
Stickleback	5.0	2.1	1.6	5.0	0.1	0.8	1.7	3.4
Sculpin	8.0	9.2	4.6	12.6	12.4	8.8	8.9	4.7
Surfperch	0.3	7.3	7.8	6.3	5.8	6.2	13.9	5.5
Pacific sand lance	0.0	1.8	0.0	5.1	2.1	1.4	6.1	0.2
Flounder	8.5	9.8	8.6	18.0	14.3	11.1	6.6	11.8
Anchovy	0.0	0.0	30.1	11.4	22.4	20.2	22.9	45.9
Cod	0.0	0.0	0.3	2.9	12.1	1.3	5.6	1.6
Lamprey	0.0	0.0	1.4	1.3	0.6	0.2	0.7	0.2
Gunnel	0.0	0.0	0.0	0.2	0.1	0.1	1.4	0.1
Other	1.8	3.1	2.6	0.0	0.0	0.1	1.4	0.3
Total mass (g)	20,370	13,016	11,205	16,260	17,730	17,947	19,953	28,252